2 Normal Science Education and its dangers: The case of school chemistry

The following chapter appeared in 2000 as an article published in a special issue of "Science & Education" on: "Thomas Kuhn and Science Education".[1] With the kind permission of the publisher it has been reproduced here with some minor changes. The chapter can therefore be read as a self-contained whole. In this chapter, I argue that the currently dominant school chemistry curriculum can be interpreted as a form of Normal Science Education. Some of the topics, more fully discussed in Chapter 1 such as my research design (section 1.2) and my curriculum framework (section 1.3), are briefly summarized here. Other topics such as Kuhn's and Popper's views on science education have been elaborated upon here.

The article in "Science & Education" started with an *abstract* which follows immediately below. In the text of abstract and the main body of the article I have made some small changes such as the numbering of sections and figures. If and when necessary, I have added explanatory notes in order to relate the argument developed in Chapter 2 with the methods and framework introduced in Chapter 1.

We started the Conceptual Structure of School Chemistry research project, a part of which is reported on here, with an attempt to solve the problem of the hidden structure in school chemistry. In order to solve that problem, and informed by previous research, we performed a content analysis of school chemistry textbooks and syllabi. This led us to the hypothesis that school chemistry curricula are based on an underlying, coherent structure of chemical concepts that students are supposed to learn for the purpose of explaining and predicting chemical phenomena (2.1). The elicited comments and criticisms of an International Forum of twenty-eight researchers of chemical education, though, refuted the central claims of this hypothesis (2.2). This led to a descriptive theory of the currently dominant school chemistry curriculum in terms of a rigid combination of a specific substantive structure, based on corpuscular theory, a specific philosophical structure, educational positivism, and a specific pedagogical structure, involving initiatory and preparatory training of future chemists (2.2). Secondly, it led to an explanatory theory of the structure of school chemistry, based on Kuhn's theory of normal science and scientific training, in which Dominant School Chemistry is interpreted as a form of Normal Science Education. Since the former has almost all characteristics in common with the latter, Dominant School Chemistry must be regarded as Normal Chemistry Education (2.3). Forum members also formulated a number of normative

[1] Van Berkel, B., De Vos, W., Verdonk, A.H. and Pilot, A. (2000). "Normal Science Education and its Dangers: The Case of School Chemistry". Science & Education, Vol. 9, Nos. 1-2, 123-159.
Adri Verdonk and the late Wobbe the Vos were my former supervisors who gave many valuable comments and constructive criticisms on earlier versions of this paper. They also contributed to other parts of the research into the current structure of school chemistry as I have indicated in Chapter 1.

criticisms on dominant school chemistry, which we interpret as specific dangers of Normal Chemistry Education, complementing Popper's discussion of the general dangers of normal science and its teaching (2.4). On the basis of these criticisms, it is argued that Normal Chemistry Education is isolated from common sense, everyday life and society, history and philosophy of science, technology, school physics, and from chemical research (2.5).

2.1 Introduction

In this introductory section I will briefly describe the rationale of the research reported on in this thesis (2.1.1), the chosen research design (2.1.2), and the curriculum theoretical framework used (2.1.3). In subsection 2.1.4, I will give an overview of what will be discussed in the sequel of this chapter. See also the relevant sections in Chapter 1: sections 1.1.2, 1.2 and 1.3.

2.1.1 Rationale

Most of the studies performed, from 1985 onwards, by members of the Department of Chemical Education, Center for Science and Mathematics Education, Utrecht University, concerned the *parts* of the current school chemistry curriculum in the Netherlands which addressed topics such as chemical reactions (De Vos and Verdonk, 1985/86/87), chemical equilibrium (Van Driel, 1990), chemical bonding (Van Hoeve-Brouwer, 1996) and electrochemistry (Acampo, 1997).

After a conceptual analysis of these topics in representative Dutch textbooks, new teaching material was designed and trialled in the classroom. The feedback from students and teachers was used to redesign each teaching unit in order to match the proposed educational structure of activities to the aims set by the respective researcher, such as how and why a particular topic of school chemistry must be taught and learned.

The completion of a number of these small-scale research projects led to the problem of the *hidden structure* of school chemistry, as we initially called it (De Vos, 1992). We began to wonder why school chemistry textbooks from different countries look so remarkably similar. What does the school chemistry curriculum *as a whole* look like? How can we arrive at a valid description of it? Further, why is school chemistry so *resistant* to reforms? Is the structure of the school chemistry curriculum a support or a hindrance to the quality of chemical education?

In 1991 the Department of Chemical Education started the Conceptual Structure of School Chemistry (CSSC) research project in order to find out whether it would be possible to arrive at a curriculum theory or framework (see 1.3) in terms which we could: (1) describe, analyze, and criticize the structure of school chemistry curricula, traditional as well as innovative ones; (2) answer relevant curriculum questions such as the ones raised above, and (3) contribute to the ongoing reforms in secondary education in chemistry. In brief, the project set out to develop a chemistry-specific curriculum framework (Van Berkel and De Vos, 1993; Van Berkel, 1996).

2.1.2 Research design

The phases of our research design are formulated in general categories which stem from Popper.[2] These phases are specified for the International Forum (IF) part of the CSSC project, and correspond to sections of this chapter (Figure 2.1).

Figure 2.1 Research design for the IF part of the CSSC project

Popper's categories	Research phases of CSSC project	Sections in this chapter
Initial problem (P1)	Problem of hidden structure	Introduction (2.1)
Tentative theory (TT1)	Coherent CSSC, summarized in *Ten Statements*	Introduction (2.1)
Error Elimination (EE1)	Probing International Forum	IF response to core statements (2.2)
New problem (P2)	Many IF responses are inconsistent with statements of coherent CSSC	Analysis of IF response to core statements (2.2)
Revised Theory (TT2)	Dominant school chemistry: *descriptive* theory of school chemistry	Analysis of IF response to core statements (2.2)
	Normal chemistry education: *explanatory* theory of school chemistry	Normal science education (2.3)
Critical Discussion	Specific and General Dangers	Normal chemistry education and its dangers (2.4)

In order to solve the first problem (P1), the problem of the hidden structure of school chemistry, and informed by our previous research, we performed a content analysis of textbooks and syllabi. The analysis contained chemical, philosophical, and educational dimensions and was applied to current and post-war textbooks and syllabi representative of secondary chemical education in mostly Western countries (see 1.2.2). This led to our initial *hypothesis* that school chemistry curricula are based on an *underlying*, *coherent* structure of chemical concepts that students are supposed to learn for the purposes of explaining and predicting chemical phenomena (De Vos, Van Berkel and Verdonk, 1994).

In the next phase of the IF part of the CSSC research project, we tried to test or validate the *hypothesis* on the *coherent* conceptual structure of the school chemistry curriculum (TT1). For that purpose the hypothesis was summarized in *Ten Statements* of a *general* nature (See Chapter 1, Figure 1.4), which were used as a probe with an International Forum (IF) of twenty-eight experts in chemical education: researchers, developers and teachers. About half of them were enrolled in the IF during the 11th International Conference on Chemical Education in York (Kempa and Waddington,

[2] Popper (1972, 1994) describes science, as well as life, as a *revisionary* spiral of problem posing and problem solving, using terms as mentioned in the left column of Figure 2.1.

1992), while others were approached through other conferences or during work visits of the first author.[3] If people showed interest in the research project (self-selection), we asked them to formulate the extent to which they agreed or disagreed with each of the *Ten Statements*, and to give written comments on some of our papers containing necessary background and detail. As anonymity of *responses* was guaranteed to respondents, we assigned randomly-generated numbers to individual respondents for the purpose of publication.

The IF responses were analyzed by the three authors of that paper, at first individually and then jointly, to arrive at the findings reported in section 2.2. The following procedure was used:

(i) For each respondent, analyze the response to *one* particular statement in connection with relevant comments made by the same respondent to *all* ten statements.
(ii) Analyze the response to a particular statement by *one* respondent in the light of *all* IF responses to this statement (including relevant comments to other statements).
(iii) Consider the IF response to a statement in the light of relevant research evidence, either taken from the research literature or from our own research.
(iv) Decide on the basis of (i – iii) how many respondents agree or disagree with a particular statement and how many respondents do not respond or address the statement in question.[4]

2.1.3 Curriculum framework of analysis

After the exploratory phase, posing the problem and formulating the initial hypothesis, we have adopted, and *adapted* to our research purposes, a curriculum theoretical framework introduced by Schwab (1964a/b/c, 1978) in the context of the 'structure of the disciplines' movement. Schwab (biologist, philosopher, and educationalist) distinguished in science curricula the following structures, which we take as specifications of the dimensions (chemical, philosophical, and educational) that we used before (see Figure 1.1 in Chapter 1, and Figure 2.2. below).

- *Substantive* structure: scientific concepts, relationships and techniques;
- *Syntactical* structure: changed into *philosophical* structure, containing the methodology as well as the foundations of science and chemistry;
- *Pedagogical* structure: aims of and approaches to learning and teaching.

3 See Appendix 3 for a list of International Forum respondents. In another cycle of the CSSC project we tested the hypothesis on coherent school chemistry with a Dutch Forum (DF) of twenty-two experts in chemical education (see section 1.2.3 and Appendix 4)

4 As a final step should be added: (v) Decide on the basis of (i – iv) how to reformulate the original statement by weighing the evidence in the light of the principle mentioned by Schwab (1964a, p. 35): "The scientist takes account of a vast variety of data which must be accounted for. He treats each datum as a limitation on what may be conceived as accounting for the whole range of data, and within the boundaries of these complex limitations he conceives a solution to the problem." (see also section 1.2.3).

Figure 2.2 Categories and codes for analyzing school chemistry curricula

Substantive structure	[Sub]	Philosophical structure[a]	[Phil]	Pedagogical structure	[Ped]
Chemical concepts	[CC]	Foundations of science	[FS]	Aims	[A]
Chemical relations	[CR]	Methodology of science	[MS]	Teaching approach	[TA]
Chemical techniques	[CT]	Foundations of chemistry	[FC]	Learning approach	[LA]
		Methodology of chemistry	[MC]		

[a] Reason for subdivision is given in subsection 2.2.2 below.

The categories and subcategories of Figure 2.2 proved to be fruitful for the authors of this article in the analysis of school chemistry curricula. Where appropriate in this article, in the text and in quotations, the codes corresponding to these categories are provided in brackets in order to allow readers to make their own judgment as to their usefulness.

The main problem which the CSSC project tried to resolve can now be reformulated in terms of Schwab's categories as follows: to describe, analyze, and critique the *relationships* between the specific substantive, philosophical, and pedagogical structures that together were found to comprise current school chemistry curricula.

Following Goodlad (1979, 1994) many researchers performing curriculum studies (e.g. Van den Akker, 1998, p. 422) see curricula as composed of several curriculum levels. In this study we use the following curriculum levels and terms:

- intended curriculum: formulation of a number of aims by textbook writers and developers;
- formal curriculum: operationalization of aims in textbook, teaching units, and syllabus;
- taught curriculum: execution of formal curriculum by teachers in the classroom;
- learned curriculum: learning of taught curriculum by students in the classroom (exams).

It is to be noted that the curriculum categories mentioned above – the substantive, philosophical, and pedagogical structures – can be assigned to *each* level of school chemistry curricula. IF responses to our *Ten Statements* probe were analyzed and interpreted as referring mainly to the *intended* and *formal* curriculum, and also, as we will see, in connection with the *taught* and *learned*, or the realized curriculum of school chemistry.

2.1.4 Preview

The elicited IF response refuted the central claims of our hypothesis on the structure of *coherent* school chemistry. This led to a new problem situation (P2) which we have resolved as follows. Firstly, we acknowledge that the coherency of structure and aim *ascribed* by us to the intended / formal school chemistry curriculum does not validly *describe,* according to IF respondents, the *realized* school chemistry curriculum, that is, the taught and learned curriculum. Secondly, the refutation of coherent school chemistry leads to the characterization of the currently *dominant* form of the school chemistry curriculum as a *rigid* combination of *specific* substantive, philosophical, and pedagogical structures (section 2.2).

Subsequently, using Kuhn's (1970a) theory of normal science and scientific training, we *interpreted* dominant school chemistry as a form of *normal science education* (NSE). The latter has the following characteristics: (i) NSE prepares future scientists for normal science; (ii) NSE is the dominant or normal form of science education in the natural sciences at the tertiary *as well as* at the secondary level; (iii) NSE contains implicit norms with respect to science and its philosophy and pedagogy (section 2.3).

As we will show, dominant school chemistry shares almost all of its characteristics with NSE. More specifically, it must be regarded as *normal chemistry education*. Thus, on the basis of our empirical findings, we will argue that Kuhn's view on normal science education is *confirmed*, in particular for *chemistry* as taught in schools. Figures 2.3, 2.4 and 2.5 give a summary of the structure of dominant school chemistry (left side) and a summary of the structure of normal science education (right side).

IF respondents also formulated a number of *normative* criticisms on dominant school chemistry, that is, criticizing what is realized de facto in the school chemistry curriculum. These criticisms point to specific *dangers* of normal chemistry education and complement Popper's (1970) discussion of the general dangers of normal science and its teaching. On the basis of these criticisms, it is argued that *normal chemistry education* is isolated from common sense, everyday life and society, history and philosophy of science, technology, school physics, and from chemical research (section 2.4).

2.2 Analysis of response International Forum

In section 2.2.1, I will describe how I categorized the *Ten Statements*, as given in Figure1.4, in terms of my curriculum theoretical framework in order to analyze the responses given by IF members. In section 2.2.2, I will analyze what I have called the *core* statements (statements 1, 2, 3, 8 and 9) taken as representing the *core* of our hypothesis on coherent school chemistry. This analysis is followed by a concluding discussion in section 2.2.3.

2.2.1 Methodological introduction

Initially, we ordered the *Ten Statements* using the following dimensions: chemical (Statements 2 – 8), philosophical (Statements 9 and 10), and educational (Statements 1 and 10). During the analysis of the IF response to the *Ten Statements* we thought it fruitful to replace these dimensions with Schwab's categories (Figure 2.2).

Statement 1 is taken as addressing the *pedagogical* structure [Ped], the aim and the teaching approach of school chemistry. IF respondents responded accordingly, while some also pointed to components of the philosophical structure (see below).

Statements 2 – 8 address the *substantive* structure [Sub], which is further ordered as follows: Statements 2 and 3 address the three basic, *phenomenological* concepts of school chemistry: pure substance, chemical reaction, and chemical element. Statements 4 and 5 are elaboration's of Statement 3, while Statements 6 and 7 are elaboration's of Statement 2. Several IF respondents responded to these same combinations of statements.

Statement 8 focuses on corpuscular explanations of phenomenological concepts mentioned in Statements 2 – 7. Many IF respondents commented that corpuscular explanations prevail in *current* school chemistry.

Statement 9 addresses the *philosophical* structure [Phil], as well as part of the pedagogical structure, especially the teaching approach [TA] of school chemistry. IF respondents responded by pointing to relationships between the substantive, philosophical, and pedagogical structures. Finally, Statement 10 adds an historical dimension to Statement 9 as well as to Statement 1.

Thus, while probing the IF, it became clear that Statements 1, 2, 3, 8 and 9 could be considered as the *core* of our hypothesis on coherent school chemistry, therefore, this section is restricted to these five *core* statements. (Illustrations of these general core statements, taken from school chemistry textbooks, are given in Appendix 1).

2.2.2 Analysis of core statements

We begin our analysis by presenting the original formulations of each of the core statements. Second, we briefly summarize the IF response to each core statement and quote respondents who agree or disagree with its *central* claim, that is, the substatement containing an italicized keyword. Third, we reformulate the central claims as *universal statements* in order to emphasize their theoretical character and their refutation by IF responses. Fourth, we give a revised formulation of the central claims, which taken together constitute the core of the currently *dominant* structure of the school chemistry curriculum (Figures 2.3, 2.4 and 2.5).

Statement 1 Our original formulation was:

> From the moment chemistry was introduced as a subject in secondary education in the nineteenth century, it has always been taught *as a science*. It is made clear, often on the first page of the book or even in the first sentence, that chemistry is one of the natural sciences. Concepts to be taught are selected on the basis of their scientific relevance. The student is seen as a future scientist, who wants to specialize in chemical research [Ped/A] and therefore has to become familiar with research methods and research results obtained by applying these methods. The use of chemical products and processes in society is presented as something that follows from scientific theory, not the other way around.

Almost all IF respondents disagree with the claim that school chemistry is taught *as a science* [Ped/A], an activity equated here with prediction and explanation of chemical phenomena (cf. Statement 3). The next quote epitomizes the IF view that in fact *current* school chemistry gives an incorrect picture of chemistry as a science:

> We tend to teach chemistry by using certain well established *standard items of dogma … theoretical propositional* knowledge often *dominates* school chemistry and *symbolic notation* becomes a *reified* account of many facts which have never been observed (R4).

Ten respondents address the claim of Statement 1 directly, using in their responses terms such as *algorithms*, *rules, techniques,* and *rote learning* [Ped/LA] to characterize current school chemistry. Several other respondents (5) can be taken to disagree since they deny that the aim of prediction and explanation of chemical phenomena refers de facto to school chemistry. Another ten IF respondents disagree implicitly, by pointing to *relevant* chemistry courses which instead try to teach chemistry as an *applied* science. A few respondents do not address the central claim of Statement 1, and only one respondent (R12) appears to agree with it.

Besides relevant society-oriented curricula, such as Salters' Chemistry and ChemCom, IF respondents mention process-oriented curricula such as Nuffield Chemistry, but these curricula are mentioned as actual or desirable *alternatives*, not as part of the mainstream development. Some respondents (R1, R8) point out that different forms of science education, emphasizing societal relevance or scientific processes, have been viable *before* 1900.

In sum, IF respondents appear to say that the currently dominant school chemistry curriculum is mainly oriented towards the imparting and recall of results [Ped/A], that is, to the propositions and algorithms of chemistry. Thus, the IF response leads to a revision of the central claim of Statement 1:

CENTRAL CLAIM STATEMENT 1	All school chemistry curricula are being taught *as a science* to students seen as future chemists.
REVISION STATEMENT 1	All school chemistry curricula belonging to the dominant version are being taught and learned as *propositions and algorithms* to students seen as future chemists.

One should bear in mind here that the original statement1 refers mainly to the formal and taught curriculum of school chemistry, while the revised statement refers to the dominant curriculum *as realized*, according to IF respondents, in the taught *and* learned curriculum. The same applies to Statements 2, 3 and 8. We return to the *pedagogical* structure and its relation to the philosophical and substantive structure of school chemistry when we analyze the IF response to Statement 9 below (Figure 2.5).

Statement 2 Our original formulation was:

> Chemistry is immediately distinguished from other natural sciences by its object of research, which is chemical 'phenomena' or *chemical reactions*. The reaction concept is introduced very early in the curriculum and it is defined in a very general sense: it refers to a process in which one or more substances are converted into one or more other substances. Each substance is characterized by a set of substance properties. Besides, chemical phenomena are often said to be irreversible and more fundamental than physical phenomena (such as phase transitions). The definition of chemical reaction requires a specific chemical substance concept (see Figure 1.4, Statement 6).

Together with Statements 3 and 8, Statement 2 forms the core of the substantive structure of school chemistry (Figure 2.3).

Many respondents (15) agree *prima facie* with our claim that *chemical reactions* play a fundamental role in school chemistry. The agreement of other respondents seems more implicit, but when we consider the response to Statement 6, we see that most at least acknowledge, and some stress, the point that the 'fundamental' concept of chemical reaction is 'closely linked to a specific chemical *pure substance* concept', as we stated. For example, R21 emphasizes that 'the notions of reaction and substance are closely interrelated'.

However, R1 remarks, 'nor is it clear that *greater* weight should be placed on reactions than on substances'. Some respondents (8) specify their disagreement by pointing to other foci of school chemistry, such as properties of substances (4), the products of synthesis (2), or the existence of *plural* foci (2). The following quote elaborates the latter point:

> ... *three approaches* to the beginning of chemistry teaching have been advocated, and, indeed, have been the basis of published curricula. The focus of each is I believe different, namely, *substances* and their properties, *atomic structure* as the basis of chemical substances and their properties, and *chemical reactions* (R8).

As we will see below (Statements 3 and 8), of the many foci existing or possible, the corpuscular one, in which school chemistry is based on atomic structure, applies to dominant school chemistry. The IF response thus leads to revision of the central claim of Statement 2:

CENTRAL CLAIM STATEMENT 2	All school chemistry curricula are focused on *chemical reactions,* the reaction concept being closely linked to a specific chemical substance concept.
REVISION 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 Our original formulation was:

> The reaction concept is illustrated by a series of examples (and usually also non-examples) of chemical reactions. These examples emphasize the fact that chemical reactions are spectacular, manifold and, as yet, unpredictable. From that moment on, the curriculum can be seen as an attempt to answer the question of *predictability of reactions*.[5]

Some respondents (4) agree with us, but their comments seem to concern more the *intended* curriculum than the realized curriculum of school chemistry. That is, they agree but only in the sense that school chemistry *can be seen* as an attempt to answer the question of predictability of reactions.

Most respondents (16), though, disagree with our position, that is, they deny, to a greater or lesser extent, that current school chemistry *is*, de facto, devoted to this aim. For example, R8 remarks that 'very few school chemistry courses set out explicitly to predict reactions or to provide explanatory theory as you claim', and R27 comments that 'this is definitely not the declared framework'. Some respondents (4) say that it applies partly to the upper secondary level; others (3) are of the opinion that we overstate the emphasis on predictability, certainly with regard to reactions. The explanatory theory needed for this purpose, several respondents (5) point out, is not really addressed in school chemistry,

[5] I add here also the original formulation of the first part of Statement 4:
One way to predict chemical reactions is by developing an *explanatory theory*. The curriculum implicitly offers such a theory by demanding that a reaction must fulfill three conditions (4a, 4b, and 4c in Fig.1.3). Failure to meet one of these conditions is sufficient explanation for the non-occurrence of a reaction. A reaction therefore takes place only if it fulfills all three conditions.

i.e., the three reaction conditions are *not coherently* treated, but only addressed in an isolated, implicit, and often incomplete way.

In line with the corpuscular theoretical focus referred to above, the IF sees school chemistry as dealing largely with *corpuscular* explanations and predictions of properties of chemical *substances*: 'prediction of formulae of substances is I think more common in schools than is prediction of reactions' (R27). In this context, R4 emphasizes *systematization* rather than explanation:

> Valence and the more refined concept of oxidation number provide one of the most useful *systematization* schemes in the whole of chemistry. The link between oxidation number, elements, the periodic table, atomic structure and stoichiometry, I believe, is *absolutely essential to achieve a rational base* (emphasis R4) for the reaction concept. This is intimately connected to what you refer to as *corpuscular theory*.

Similarly, R16 questions whether the theme of prediction and explanation pertains at all to current school chemistry:

> I think that the emphasis on 'predictability' is overstated here. Instead, I would argue that much effort focuses on *patterns of behavior* of chemical substances. Although such patterns, once recognized, may be used for predictive purposes (by extrapolative processes based on, e.g., the Periodic Table), they frequently serve as ways of rationalizing and *systematizing large amounts of chemical information*.

Thus, the school chemistry curriculum deals, according to IF members, not so much with prediction and explanation of aspects of chemical reactions, but rather with the explanation and systematization of patterns and trends in properties of chemical substances. For instance, it is customary to explain properties of substances, such as acidity and boiling points, and to use chemical formulae in the representation of substances, in terms of corpuscular theories about composition, atomic structure, and bonding.

The IF response thus leads to revision of the central claim of Statement 3. (The original formulation shows that it refers to the *intended* curriculum of school chemistry.)

CENTRAL CLAIM STATEMENT 3	All school chemistry curricula *can be seen as* aiming at *predictability* of chemical reactions using explanatory theory.
REVISION 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 Our original formulation was:

> A distinction is made between a level of phenomena and a level of *corpuscula* or particles such as atoms, molecules or electrons. Once corpuscular theory is introduced, it provides explanations, e.g. of reactivities, of equilibrium (kinetic explanation) etc., as well as conventions, e.g. the nomenclature of substances such as 1,2-dichloroethane.

All respondents agree that the corpuscular explanation of chemical phenomena is an important part of the *intended* school chemistry curriculum, with some (4) strongly in favor of the dominant focus on corpuscularity while a few others (3) are critical.[6] For example, R5 remarks, ‘The consequence of concentration on the molecular is that it diverts attention away from the macro [level].’ At the same time, many respondents emphasize that the distinction mentioned above between corpuscula and phenomena is only partially realized in teaching. They give examples of the problems with the translation of this distinction from the intended curriculum to the formal curriculum level, i.e. textbooks, and to the levels of the taught and learned curricula, respectively:

> The distinction between the macroscopical and microscopical levels of description certainly exists. However, it is not adequately stressed in school chemistry books. Indeed, the descriptive language used in these books does not maintain that distinction. Phrases such as ‘nitrogen has a triple bond’ illustrate the point: nitrogen is a colorless, odorless unreactive gas; the nitrogen *molecule* has a triple bond. The triple bond provides the explanation of the unreactive nature of the substance. (R27)
>
> Often language is used inaccurately, e.g., you speak of iron when you have to speak of iron-ions. (R2)
>
> I agree that the corpuscular theory provides explanations for phenomena but am unsure how far these are internalized by students. Many continue to reason in macroscopic terms about events, even after being taught corpuscular theory. (R13)
>
> ... students ascribe properties of substance to particles: They melt, they grow etc. (R2)

Again, the IF response leads to a revision of the central claim of Statement 8.

CENTRAL CLAIM STATEMENT 8	All school chemistry curricula make a distinction between a level of *phenomena* and a level of *corpuscula*. Once corpuscular theory is introduced it provides explanations of macroscopic phenomena and relationships.
REVISION 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.

Finally, it is to be noted that the choice for a substantive structure of school chemistry in terms of corpuscularity has implications, as pointed out by R8 above, for the scope and sequence of concepts developed in the curriculum, choices which reflect views on philosophy and pedagogy of chemistry. With Statement 8 we conclude our analysis of the IF view on the substantive structure of school chemistry as such (Figure 2.3).

[6] According to the Dutch Forum (DF), the currently dominant school chemistry curriculum in the Netherlands introduces corpuscular theory after a phenomenological introduction of one or two semesters. Apart from this, the DF gives a similar characterization of dominant school chemistry as does the IF.

Figure 2.3 Substantive structure of dominant school chemistry and normal science education

Category	Dominant School Chemistry (based on International Forum response)[a]	Normal Science Education (based on Kuhn's work)[b]
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	- concepts (pencil and paper), facts
Chemical relations	- demarcation, mostly implicit, from: common sense, everyday life and society, technology, history/philosophy of science, physics, and research	- insulation, mostly implicit, from: common sense, everyday life and society, technology, history/ philosophy of science, related sciences, and research front
	- implicit (partly incomplete) relations between chemical reaction, chemical substance, and chemical element - reaction conditions often implicit, incoherent, and partly incomplete[c] - conditions for substances are presented only as fragments[c]	- definitions, laws, theories are presented briefly, precisely, and systematically
	- 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)	- as separately and seriatim as possible
Chemical techniques	- school laboratory, using simple reactions; separation techniques	- laboratory experiments, techniques, measurement

[a] The points in this column are taken from IF responses; the same applies to Figures 2.4 and 2.5.

[b] Most of this column is quoted directly from Kuhn (substantive structure follows latest paradigm, that is, for school chemistry corpuscular theory); the same applies to Figures 2.4 and 2.5

[c] We refer here, of course, to reaction conditions and conditions for substances as far as they are known. After all, chemistry, as a science, is still incomplete in some of these respects (De Vos, Van Berkel, and Verdonk, 1994).

Relationship between substantive, philosophical and pedagogical structure

We will now review the IF response to statement 9, and analyze and discuss the relationships between the substantive and the philosophical structures of school chemistry on the one hand, and the pedagogical structure of school chemistry on the other. Where appropriate we review the IF response to Statement 10 and Statement 1.

Statement 9 Our original formulation was:

> The conceptual structure in the curriculum does not imply a *specific* philosophy of science, e.g. inductivism or hypothetico-deductivism; or a *specific* philosophy of chemistry. Neither does it in itself prescribe a *specific* teaching approach. While some teachers (and books) aim at a direct transfer of knowledge, others prefer students to discover as much as possible by themselves. Both traditional and modern teaching methods may be based on the same curriculum structure.

A number of respondents (11) agree in general, though some add that 'the content of a traditional syllabus' (R13) is *retained*, or that 'similar content' (R23) is used, which is 'OK for able, motivated students' (R28). Those who agree mostly refer in their responses to the *content* of school chemistry [Sub], that is, to the conceptual or substantive structure, as we specified it later, taken as a *part* of the school chemistry curriculum. About an equal number of respondents (12) disagree, most of them quite explicitly:

> Contrary to what you imply I believe that the *conceptual structure of the curriculum* [Sub] does prescribe a specific teaching approach [Ped/TA]. Until the 1960s, *descriptive chemistry* [Sub] ... students learned much of this *by rote* [Ped/LA] ... then replaced in the late 60's by the *physical chemists' approach* [Sub] in which explanatory theory [Phil] was given paramount importance. Practical work was aimed at students to *discover*, via the experimental method, theoretical relations between facts for themselves [Ped/TA]. (R4)

> I do not see any evidence for the first sentence, indeed I believe the reverse. I would argue that the *conceptual structure of the curriculum* [Sub] is as value-laden as science itself and *implies* a philosophy of science [Phil], the philosophical roots go back to F. Bacon and the beginning of European Science. (R5)

> While the *structure of the text* does not prescribe a specific teaching style [Ped/TA], *it has traditionally implied one*. First of all, in the ordering of the content [Sub], secondly, in the emphasis it places on laboratory work versus book work [Ped/TA], some texts only describe experimental procedures; others insist the students perform certain techniques. (R1)

It is to be noted that most respondents who *disagree,* refer, as does R1, to the *curriculum structure as a whole* or to the *current* school chemistry curriculum by using terms such as 'book' (R26), 'text' (R11) or 'chemistry taught' (R8). Remaining IF respondents do not, or say they cannot respond, because of our unclear or ambiguous terms. Some rightly point out that the claim of Statement 9 is to be taken as 'an empirical matter' (R21).

Looking at the further IF response, especially to Statements 1 and 10, we come to the conclusion that most respondents disagree, at least implicitly, with Statement 9 taken as a claim pertaining to *current* school chemistry. Thus, the IF contends that the currently dominant school chemistry curriculum comprises a specific substantive structure, a *physical chemists' approach* to school chemistry, which is combined with a *particular* philosophical structure and a *particular* pedagogical structure (see Figures 2.4 and 2.5).

Discussion

Some respondents (4) disagree with Statement 9, both in the sense of referring to the curriculum structure *as a whole* and to the substantive structure *in or of* the curriculum. The latter response lays bare the fact that school chemistry has used more than one substantive structure. This confirms the point made by R8, in connection with Statement 2, about the existence of three different approaches to school chemistry.

Furthermore, the first quotation of R4 (given above) makes clear that the choice for a particular substantive structure – descriptive chemistry or physical chemistry – is at least *intended* to have consequences for the choice of pedagogical structure – rote learning or discovery learning – as well as for the choice of philosophical structure – inductivism or hypothetico-deductivism. Whether these last two choices have left much traces in the *realized* curriculum is another matter, and doubted by many IF respondents. Recent research confirms that little has persisted of the reforms of the 60s and 70s (Fensham, 1992; Duschl, 1993; Matthews, 1998).

On the basis of IF comments to Statement 9, we thought it useful to replace Schwab's syntactical structure with an extended and specified philosophical structure consisting of four coded subcategories: foundations of science [FS], methodology of science [MS], foundations of chemistry [FC], methodology of chemistry [MC]. See Figure 2.2. The most important reason for the substitution is that the IF response to these statements reveals, besides methodological assumptions, several implicit philosophical foundations in school chemistry.

In order to determine the *specific* components of the philosophical structure and the pedagogical structure of current school chemistry, we treat the IF responses towards Statement 9 as directed to three substatements expressing the following central claims:

- the substantive structure does *not* imply a *specific* philosophy of science (9a1);
- the substantive structure does *not* imply a *specific* philosophy of chemistry (9a2);
- the substantive structure does *not* imply a *specific* teaching approach (9b).

Substatement 9a1

There are relatively few IF respondents (4) who explicitly address specific components of the philosophical structure, though some respondents implicitly address the philosophical structure in responding to other relevant statements (Statements 1 and 10).

The comments and criticisms on substatement 9a1 fall under four points. The first is exemplified by respondent R26, who says that in school chemistry, 'Science appears like the key to solve *all* our problems: it is neutral, pure, aseptic.' But while R26 gives an apt description of *scientism* [FS], R5 points to a different aspect of scientism, namely, 'Humankind's considerable power over matter ... hides from discussion our lack of knowledge.' As for the other three points, R26 feels that 'the philosophy of science in the vast majority of the books is *positivism*' [FS], R5 points to 'reduction to the atomistic level' [FS], and to 'predictability, nature being brought under control' [FS].

Thus, contrary to what we claimed in Statement 9a1, and without explicitly addressing the *foundational* issue, these respondents claim that the substantive structure of current school chemistry entails a *specific* choice for a philosophy of science, which consists of the following assumptions: (1) scientism, (2) positivism[7], (3) reductionism, and (4) predictability as control (Figure 2.4).

A few IF respondents (3) also address the issue of the methodology of science as

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[7] Chalmers (1980, p.1, 2) describes the common-sense view of science briefly as follows: "Scientific knowledge is *proven* knowledge. Scientific theories are *derived* in some rigorous way from the facts of experience acquired by observation and experiment". He argues in his book that this "naive inductivist" methodology and positivistic account of science "is quite mistaken and even dangerously misleading".
Van Aalsvoort (2000) explicates in detail the positivistic assumptions in current Dutch school chemistry textbooks.

portrayed de facto in school chemistry textbooks. R26 feels that 'the scientific method of the first page is the old positivist physics method' [MS]. R11 elaborates on this:

> The opening chapter of most texts gives a brief and inaccurate description of the scientific method [MS], but the student is not asked to apply this approach in later pages. Moreover, the historic experiments described later are all successful, and their *interpretation is always correct*, using the hindsight of many decades. There is *no uncertainty of conclusions* [MS].

The relative scarcity of explicit IF responses testifies to the partially *hidden* nature of the philosophical structure of school chemistry. In the last decade there has been a renewed and systematic interest in the philosophical assumptions underlying school science, as is evident from many articles, books and studies, and from substantial sections on history and philosophy of science (HPS) in encyclopedias of science education (Duschl, 1993; Matthews, 1998).

Substatement 9a2

Again, there are few explicit comments and criticisms of IF respondents on substatement 9a2. They fall under three points. First, some respondents, for example R18, point to a theory-driven orientation of school chemistry: 'We teach the chemical theories first and then we collect some examples illustrating theories.' Second, as noted above, in the 1960s the substantive structure of school chemistry changed to a 'physical chemists' approach' (R4). Third, this led to a corpuscular oriented curriculum for school chemistry, where 'atomic structure is the main subject, sometimes the only one and [where] chemistry appears like something less than physics' (R26).

Thus, contrary to what we claimed in substatement 9a2, and without explicitly addressing the *foundational* issue, these respondents claim that a *specific* philosophy of chemistry is implied in the substantive structure of school chemistry. This philosophy consists of the following assumptions: (i) primacy of chemical theories/concepts, (ii) dominance of physics, and (iii) a corpuscular curriculum emphasis (Figure 2.4). Few respondents comment explicitly on the issue of a methodology of chemistry as portrayed de facto in school chemistry.

If we take the criticisms of IF respondents to substatements 9a1 and 9a2 together, we must conclude that the content of current school chemistry is largely presented in textbooks, and taught and learned in classrooms, as consisting of established and definitive facts with little regard either to their generation or testing. Dominant school chemistry appears to entail a positivist philosophy and methodology of science (Duschl, 1993, p. 446) which we will call from now on *educational positivism*. The influence of educational positivism [Phil] explains to a large extent why the content of school chemistry has been *persistently* presented, taught, and learned as *propositions and algorithms* (see analysis Statement 1), or using Schwab's terms, as a *rhetoric of conclusions* (Schwab, 1962).[8]

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8 Schwab (1962, p. 24), in a section called "The Teaching of Science as Dogma", argues that science has for a long time been taught as a "*rhetoric of conclusions* (...), a structure of discourse which persuades men to accept the tentative as certain, the doubtful as the undoubted, by making no mention of reasons or evidence for what it asserts, as if to say, "*This*, everyone of importance knows to be true." "(italics Schwab). As we show in this paper, the teaching of school chemistry has, alas, not changed much from this picture. See also Duschl (1993, p. 450), who characterizes this curriculum phenomenon "final form science".

Figure 2.4 Philosophical Structure of Dominant School Chemistry and Normal Science Education

Code[a]	**Dominant School Chemistry** (based on International Forum responses)	**Normal Science Education** (based on Kuhn's work)
FS	- scientism (pure, certain, neutral) - positivism - reductionism - predictability and control	- pure or basic science - outcomes/accepted knowledge - development-by-accumulation - solvable normal science problems
MS	- no uncertainty of conclusions: interpretation always correct, reified account, models as facts - positivism of physics	- paradigmatic puzzle-solving: obtain/articulate/concretize the known - not to uncover/explore the unknown, either by discovery or confirmation
FC	- primacy of chemical theories/concepts - emphasis on physical chemistry and physics - corpuscular orientation: atoms/molecules/atomic structure as basis for stoichiometry, formulae, and equations	- foundations implicit in latest paradigm - chemistry as one of the physical sciences
MC	- systematization of substances and reactions - description of patterns of properties of substances and reactions (periodic table)	- criteria implicit in latest paradigm - methodology of the physical sciences

[a] See Figure 2.2

Substatement 9b

The IF contention that dominant school chemistry combines a specific substantive structure, based on *corpuscular theory*, with a *specific* pedagogical structure raises the question regarding the properties of that pedagogical structure. A number of respondents, especially those disagreeing with *Statement 9b,* mention *specific* components of the pedagogical structure of school chemistry. Two characteristics have already been addressed in the discussion of Statement 1: (i) teaching and learning science as propositions and algorithms, and (ii) initiation and preparation of future chemists. The IF responses following elaborate on and add to these characteristics (Figure 2.5). With regard to the first characteristic, there is a tendency in school chemistry to encourage *rote learning* by presenting 'well established standard items of dogma mainly because this can be conveniently reproduced within the confines and limitations of school' (R4). And, there is also a tendency to teach models as facts since 'it is *not uncommon* to find that students have learned to regard a *conceptual model* such as the ionic bond *as an established fact*' (R4). As for the training of future chemists, some respondents (4) point to the crucial role of teachers in the initiatory and preparatory training of future chemists, that is, 'the desire of chemistry teachers to *role play* what *professional* chemists do' (R5).

Figure 2.5 Pedagogical Structure of Dominant School Chemistry and Normal Science Education

Code[a]	**Dominant School Chemistry** (based on International Forum responses)	**Normal Science Education** (based on Kuhn's work)
A	- initiation and preparation for university chemistry/future chemist - learn systematization of chemical information: learn explanation/ prediction of properties, formulae, valence, and bonding by applying simplified corpuscular rules	- pre-professional curriculum; dogmatic initiation into pre-established problem-solving tradition - increasing understanding of known and/or similar puzzles in terms of latest scientific paradigm/language
TA	- established standard items of dogma: theoretical propositions and algorithms are conveniently reproduced within the limitations of school - role play what professional chemists do	- textbook and exemplar conducted: students solve puzzles, paper/ pencil or laboratory, closely modeled in method and substance on a given exemplar or text
LA	- rote learning of propositions and algorithms (distinctions, facts, definitions, theories, techniques)	- providing students, in the most economical and easily assimilable form, the outcomes of research

[a] See Figure 2.2

IF respondents seem divided in their views on the persistence, or as we call it, the *rigidity* of the current combination of the substantive, philosophical, and pedagogical structures of school chemistry. For example, has the *substantive* structure of school chemistry been largely *retained*, as one group of respondents (10) say, or has it been modified as a result of its combination with the new pedagogical and philosophical structures introduced in the 60s and 70s? Another, second group IF respondents (11) seem to be more optimistic on this point , that is, they feel that different forms of *pedagogical* structure are, or at least *should be*, compatible with approximately the same conceptual structure.

The changes in the curriculum structure of school chemistry that IF respondents perceive extend on the one hand from 'a major paradigm shift', as instigated by the 'applications first approach: relevance and student motivation to learn is now the guiding force' (R4); and on the other hand to the 'ideologically controlled' (R5) curriculum entailing a traditional didactic or transmissive pedagogy. Between these extremes respondents point to various variables such as (i) ordering and organization (linear vs. spiral) of content; (ii) curriculum emphasis on e.g. experimental work, theory, or problem solving; (iii) a new teaching approach, e.g. the context-led approach of Salters' Chemistry or ChemCom; and (iv) a new learning approach such as constructivism.

Thus, the second group of IF respondents perceive a greater variation in pedagogical structure, compatible with largely the same substantive structure, at least greater than the variation in philosophical structure which, as we have seen above, reduces de facto to educational positivism. The first group thinks, however, that at least for the variations in pedagogical structure tried in the past, it can be said that they reduce as a rule de facto to the *initiatory and preparatory training* of future chemists. Relevant research reviewed by Fensham (1992), Duschl (1993), and Matthews (1998) amply confirms the latter claim.

Therefore, we conclude that, contrary to what we have claimed in substatement 9b, the substantive structure of school chemistry does imply, as a rule, a specific pedagogical structure.[9] The IF response to substatements 9a1, 9a2, and 9b taken together leads to the following revision of the central claim of Statement 9:

CENTRAL CLAIM STATEMENT 9	All school chemistry curricula have a conceptual structure which does not imply a specific philosophical or a specific pedagogical structure.
REVISED 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, *educational positivism*, and a specific pedagogical structure, *initiatory and preparatory training* of future chemists.

2.2.3 Discussion

We did not foresee, nor did we intend, that there would be so many IF responses which strongly refuted our hypothesis. Apparently our IF probe, a summary of our hypothesis on *coherent* school chemistry, triggered respondents to be candid in expressing their views on the *currently dominant* school chemistry curriculum. We had expected criticisms on the *degree* of explicitness and coherency of our hypothetical curriculum structure of school chemistry. What we found, though, was an explicit *refutation* of the *central* claims of coherent school chemistry, which led to a specification of the substantive, philosophical, and pedagogical structures of *dominant* school chemistry (Figure 2.3, 2.4 and 2.5).

Further, probing the IF revealed that the *coherent* school chemistry curriculum does not refer to the *realized*, taught and learned, school chemistry curriculum but rather it must be taken as our *interpretation* of the *intended and formal* school chemistry curriculum. In other words, coherent school chemistry is to be regarded as an *idealization* of school chemistry *constructed* on the basis of a content analysis of a number of representative textbooks and syllabi *in the light of* our views on chemistry, science, and pedagogy, and their coherency. The resulting description of the structure of dominant school chemistry receives empirical support in the majority of IF responses, which in turn are likely to be informed by relevant research on the school chemistry curriculum, including research performed by the IF respondents themselves.

The *choice* for a *corpuscular* substantive structure in dominant school chemistry entails a preference for a particular kind of chemical content and for the scope and order in which this content must be taught. This substantive structure is, as a rule, combined with a specific philosophical structure, called educational positivism, and a specific pedagogical structure involving initiatory and preparatory training of future chemists.

9 In forming this conclusion, I have used the principle mentioned by Schwab in note 4, as I did at other places in section 2.2 in the process of revising the original central claims of statements 1, 2, 3, 8 and 9.

Thus, we arrive at an important characteristic of the currently *dominant* school chemistry curriculum, namely, that there exists a *rigid* relationship among specific substantive, philosophical, and pedagogical structures.

Finally, many respondents strongly disagree, *de jure,* with the actual situation of school chemistry, as described above. Although dominant school chemistry *is* the case, it *should* not be so. That is why several respondents endorse existing alternative process-oriented or society-oriented curricula, and why some other respondents welcome our proposal for a more coherent school chemistry.

2.3 Normal Science Education

In this section we will first discuss Kuhn's views on scientific training (2.3.1), which I have dubbed Normal Science Education. In subsection 2.3.2, I will show that the currently dominant school chemistry curriculum must be seen as a form of Normal Science Education, which is followed by a brief discussion (2.3.3).

2.3.1 Kuhn's views on scientific training

Kuhn underpinned his famous theory of the dynamics of *normal science* with a less well-known theory on the structure and function of tertiary and secondary science education (Siegel 1990). Reading Kuhn (1963, 1970a/b/c, 1977a/b) from the perspective of a researcher in science education, one obtains a specific view of science education which we have called, in Kuhn's vein, *normal science education* (NSE). Subsequently, we interpret *dominant* school chemistry as a form of NSE, since the former has almost all characteristics in common with the latter.

In a symposium on 'The Structure of Scientific Change', Kuhn presented a paper with the provocative title, 'The Function of Dogma in Scientific Research', which also contains a clear statement of his views on 'scientific pedagogy' (Kuhn, 1963, pp. 350, 351):

> The single most striking feature of scientific education is that, to an extent quite unknown in other creative fields, it is conducted through *textbooks* [TA], works written especially for students. Even books that compete for adoption in a single course *differ mainly in level and in pedagogic detail* [Ped]*, not in substance or conceptual structure* [Sub].
>
> ...apparently scientists agree, about what it is that every student of the field *must* know. That is why, in the design of a *pre-professional curriculum*, they can use textbooks instead of eclectic samples of research (italics Kuhn, 1963, p. 351).

Kuhn is best known for his analysis of the structure and role of *paradigms* as (i) disciplinary matrices and (ii) *exemplars*. In his later work Kuhn (1970a, pp. 182, 187) gives the greatest emphasis to paradigms as exemplars, which he describes as standard examples shared by a community of (future) scientists, on which other (end-of-chapter) problems are modeled. Through a textbook's exemplars the student is initiated into the disciplinary matrix: current theory, methods, and criteria of a normal science. Kuhn's analysis of the structure of science textbooks, especially of the *techniques of textbook presentation* [Ped/TA], leads him to the following conclusions:

> Except in the occasional introductions that students seldom read, science texts make little attempt to describe the *sorts* of problems that the professional may be asked to solve or to discuss the *variety* of techniques that experience has made available for their solution. Instead, these books exhibit, from the very start, concrete problem-solutions that the profession has come to accept as paradigms [as exemplars], and they then ask the student either with a pencil and paper or in the laboratory, to solve for himself problems very closely modeled in method and substance upon those through which the text has led him (italics Kuhn, 1963, p. 351).

The pedagogic function of the textbook presentation is to accomplish:

> ... a relatively *dogmatic initiation* into a *pre-established* problem-solving tradition that the student is neither invited nor equipped to evaluate (ibid p. 351).

It is equally revealing to see what, according to Kuhn, is *not* included, in science textbooks:

> The objective of a textbook is to provide the reader, in the most economical and easily assimilable form [Ped/TA], with a statement of what the contemporary community believes it knows and of the principal uses to which that knowledge is put [Sub]. Information about *how that knowledge was acquired (discovery)* and about *why it was accepted by the profession (confirmation)* would at best be *excess baggage* [Phil]. Though including that information would almost certainly increase the 'humanistic' values of the text and might conceivably breed more flexible and creative scientists, it would inevitably detract from the ease of learning the contemporary scientific language. To date only the last objective [Ped] has been taken seriously by most writers of textbooks in the natural sciences (Kuhn, 1977b, p. 186).

Kuhn emphasizes in various places that the 'misdirection supplied by science texts is both systematic and *functional*' (1977b, p. 187). The dogmatic *initiation* into a normal science tradition by creating among students a misleading picture of the nature of science, a *textbook image of science* as Kuhn calls it, enhances 'the research *efficiency* of physical scientists' (p. 187). The systematic textbook presentation described by Kuhn will therefore *initiate and prepare* students for the handling of normal science problems, that is, for the activity of *puzzle-solving* as set within the current paradigm or disciplinary matrix, which is all that future normal scientists need in order to *function* successfully.[10]

Thus, Kuhn's view on science education, *normal science education*, stands for a specific view on science [Phil], i.e. normal science, in combination with a specific view on education [Ped], i.e. the teaching of normal science through textbooks-cum-exemplars to future scientists while using the current paradigm as a substantive structure.

2.3.2 Dominant School Chemistry as a form of Normal Science education

The characterization of the currently dominant school chemistry curriculum in terms of a *rigid* relationship among specific substantive, philosophical, and pedagogical structures (section 2), has led us to interpret the structure of *dominant* school chemistry curricula as a form of normal science education, that is, as *normal chemistry education* (NCE).

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10 See Kuhn (1970b, p. 237) for the logic of the functional argument which he uses to explain 'how and why science works', that is, why *normal* science and *normal* science education work. See also section 6.1.2.

Conversely, Kuhn's theory of the nature and function of science teaching, although referring predominantly to tertiary education, has been confirmed for the secondary level by the IF response, in particular for school chemistry.[11] A comparison of our findings in terms of the substantive, philosophical, and pedagogical structures of dominant school chemistry and normal science education reveals a number of interesting commonalities (Figures 2.3, 2.4, 2.5).

Concerning the substantive structure, Kuhn (1970a, p. 140) remarks that scientific knowledge is presented in textbooks as an *accumulation* of 'experiments, concepts, laws, and theories of the *current* normal science (...) as *separately* and as nearly *seriatim* as possible'. In other words, the structure of a science, as portrayed in a textbook, resembles 'the addition of bricks to a building' (p. 140). Furthermore, textbooks tend to make scientific revolutions *invisible*, transforming them into a development-by-accumulation pattern which disguises any changes in the development of paradigm components, such as theories, concepts, methods, techniques, criteria, and aims. As we have seen above, some IF respondents also comment upon the anti-historical character of the substantive structure of school chemistry, but (*pace* Kuhn) without endorsing the latter.

Other conspicuous similarities are to be found in the philosophical and pedagogical structure of school chemistry. With regard to the philosophy of science, *within* a paradigm of normal science *and* in the textbook based on it, positivism still appears to reign uncontested, despite the successful critiques of Popper and of Kuhn himself.[12] As shown above, the positivistic philosophy and methodology of science is still present in school chemistry. Following Kuhn's functional argument (1970b, p. 237), we have called this phenomenon *educational positivism*.

With respect to the pedagogical structure, there are strong similarities between a 'pre-professional curriculum' (Kuhn) and the initiation and preparation for university (IF), and between 'easily assimilable *outcomes* of research' (Kuhn) and rote learning of propositions and algorithms (IF). Finally, conveniently reproduced standard items of dogma (IF) are perfectly amenable to puzzle-solving (Kuhn).

2.3.3 Discussion

Thus, dominant school chemistry shares many of its characteristics with *normal science education*. The existence of *normal chemistry education* as a training for normal chemists helps to answer two questions mentioned in section 2.1.1. The first of these is, why do school chemistry textbooks from different countries look so remarkably similar? This is because the substantive structure of most textbooks follows the latest paradigm. The second question, regarding the resistance of the dominant school chemistry curriculum to reforms, we can now reformulate in terms of why it is so hard to *escape* from the

11 Barnes (1982, p. 6) feels that Kuhn's theory of scientific training is 'the most weakly substantiated part' of his work. However, the empirical research reported in this paper substantiates Kuhn's theory for chemical education at the secondary level.

12 Kuhn, both in his philosophical work on the dynamics of science and in his articles and books on the history of science, is at great pains to convey "a quite different concept of science" (1970a, p. 1) that goes beyond the standard positivistic philosophy of science.

rigidity of dominant school chemistry. Such an escape would involve the analysis, criticism, and *coordinated replacement* of a rigid combination of (i) a specific substantive structure, i.e. the current corpuscular paradigm; (ii) a specific philosophical structure, i.e. normal science and educational positivism; and (iii) a specific pedagogical structure involving the teaching of normal science through textbooks-cum-exemplars to future chemists.

As the history of reforms in science education shows, modifying only one of these structures in response to a set aim, for example, updating the substantive structure without a *coherent* coordination in the philosophical and pedagogical structures, will not do (DeBoer, 1991; Fensham, 1992). Furthermore, the existence of NCE can explain the resistance of school chemistry to reforms (e.g. its *rigidity*), since the pedagogical structure of NCE determines to a great extent the substantive structure and thereby also implicitly the philosophical structure of school chemistry. In brief, aim determines content and form.

Finally, the existence of NCE answers another question brought forward by our analysis, namely, why school chemistry textbooks contain such a misleading picture of the history and philosophy of chemistry. This is because it is thought educationally functional for training future chemists to provide them with such a (misleading) picture.

2.4 Normal Chemistry Education and its dangers

In the last section we concluded that school chemistry is a form of normal chemistry education. In this section we deal with the question of whether this *should be* the case. Let us return for a moment to Kuhn's views on science and science education.

According to Kuhn (1977a, p. 233), the characteristic problems a scientist is *ordinarily* confronted with in *pure* or basic science are 'almost always repetitions, with minor modifications, of problems that have been undertaken and partially resolved before'. Kuhn (1970a, p. 5) elaborates on the task of the *normal* scientist, saying that:

> ...when engaged with a *normal* research problem ... his object is to solve a *puzzle*, preferably one at which others have failed, and *current theory* is required to *define* that puzzle and to guarantee that, given sufficient brilliance, it can be solved.

In his 'Normal Science and its Dangers', Popper (1970, p. 52) admits that what Kuhn describes does exist, but he adds, 'it is a phenomenon which I dislike'.

> The normal scientist, in my view, has been taught badly. I believe, and so do many others, that all teaching on the University level (and *if possible below*) should be training and encouragement in *critical thinking*. The 'normal' scientist as described by Kuhn has been badly taught. He has been taught in a *dogmatic* spirit: he is a victim of indoctrination. *He has learned a technique which can be applied without asking for the reason why*, ... he is, as Kuhn puts it, content to solve 'puzzles' (Popper 1970, p. 53).

Hence, Popper feels that 'normal' science teaching results in an uncritical or dogmatic attitude which is 'a *danger* to science and, indeed, to our civilization' (ibid. p. 53). Thus, for Kuhn, 'it is precisely the abandonment of critical discourse' (1970a, p. 6) which characterizes mature, productive science, whereas for Popper it is critical thinking which is essential for the growth of scientific knowledge. As we will see, the marked differences between Kuhn's and Popper's philosophies of *science* entail equally different views on *science education*.[13]

2.4.1 Sevenfold isolation of Dominant School Chemistry

In this subsection the boldfaced characters (**a-g**) put in parentheses will denote, firstly, fields from which physical science is *insulated*, according to Kuhn, and, secondly, fields from which school chemistry is *isolated*, according to IF respondents.

An important factor besides puzzle solving which, according to Kuhn (1970a, p. 164), *explains* the special efficiency of normal science and its training is:

> ...the unparalleled *insulation* of mature scientific communities from the demands of the [a] *laity* and of [b] *everyday life*. (...) Even more important, the insulation of the scientific community from [b] *society* permits the individual scientist to concentrate his attention upon problems that he has good reason to believe he will be able to solve.

Although Kuhn's work does not address this point explicitly, the 'educational initiation' (Kuhn, 1970a, p. 165) into normal science implies that students give up or replace their pre-scientific conceptions with the scientific concepts accepted in normal science. In other words, students must supersede (**a**) their common sense views (Cromer, 1993). Because normal science is focused on *pure* science, the scientific community and its future practitioners are insulated not only from (**b**) everyday life and society, but also from (**c**) technology, with respect to both applied research and invention (Kuhn, 1977a, p. 238). Furthermore, as Hoyningen-Huene (1993, p. 186) states in a comprehensive study on Kuhn's philosophy of science:

> ... the *dominance* of textbooks in *training* for normal science leads, first of all, to the almost complete *insulation* of *students* from the *primary* literature, from those publications in which scientists originally communicate, or communicated their results.

This implies that during the training for normal science students are also insulated from (**d**) the research *front* as well as from (**e**) the history or foundation of a discipline. Kuhn has emphasized the latter by arguing that textbooks give, and for good functional reasons *should* give, a distorted picture of the history of a discipline. Hence 'the textbook-derived tradition in which scientists come to sense their participation is one that, in fact, *never* existed' (Kuhn, 1970a, p.138). Textbooks are rewritten after a scientific revolution. Further, normal science education is insulated from (**f**) the philosophy of science, that is, from the context of discovery *and* the context of confirmation (Kuhn 1977b). Finally, having an established paradigm insulates chemistry, per definition, from (**g**) other physical sciences, such as physics, which have their own specific paradigms.

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13 Independent of Kuhn and Popper, Schwab (1962, 1964a/b, 1978) developed his views on the dynamics of science and science education in terms of *principles of stable and fluid enquiry*. It is remarkable that he did this in the context of the study, research, and development of science (biology) curricula. Schwab's pair of concepts: stable enquiry / fluid enquiry strongly resembles Kuhn's concepts of normal science and revolutionary science (Duschl, 1993). Schwab and Popper, one could say, both regret the dominance of stable enquiry or normal science, especially the dogmatic science education based on it. Schwab, again as Popper, wanted to *teach science as enquiry*, especially as fluid enquiry (see also Siegel, 1990, p. 101).

In Kuhn's view, the practice of normal science is insulated from these seven dimensions *in order* to concentrate the attention and energy of students, the future practitioners of normal science, upon problems which the scientific community has good reasons to believe are solvable, that is, on *puzzles* of a *specific* domain defined by a particular paradigm. The question we now want to address is whether IF respondents report on the *isolation* of dominant school chemistry along the same dimensions, and how they feel about this.

(a) Common sense.

An important problem mentioned by respondents (5) in this context is the resistance of students' common sense ideas to the conceptual change that NCE tries to induce: 'many continue to reason in macroscopic terms about events, even after being taught corpuscular theory' (R13). In turn, such resistance leads to naive realism, to the unintended pedagogical result that 'students ascribe properties of substances to particles: they melt, they grow etc.' (R24). School chemistry's reputation of being inaccessible and incomprehensible may have much to do with a covert transition from common sense beliefs to textbook science. Recent research on preconceptions has unearthed many other examples of difficulties which students have in relating textbook-based scientific knowledge to their own common sense knowledge. Thus, while a normal scientist can assume that his colleagues and advanced students 'share his own values and beliefs' (Kuhn, 1970a, p. 164), the teacher in the classroom cannot do so with regard to his or her pupils. As R19 remarks, 'The language I normally used in a chemistry class often did not have the same *meaning* for many of my students.'

(b) Everyday life and society

Several respondents (14) point to the lack of societal relevance of current school chemistry, e.g. R18 notes that in school chemistry there is a 'lack of everyday life experience', but most respondents 'see significant changes in chemistry curricula' (R20). For example R15, referring to the Salters' Chemistry course, remarks that 'there has been a marked trend in the last six years to the inclusion of scientific knowledge on the basis of its relevance to society'.[14]

(c) Technology

These respondents also point to the lack of craft- and science-based, technology. For example, R26 remarks that 'there is a lot of *pragmatic* knowledge in chemistry that does not appear in books (...) our science textbooks forget the [local] chemistry tradition'. R4 mentions a number of dimensions including technology: 'School chemistry often fails to show how the reaction concept is also of fundamental importance to related sciences, *technology*, and society.'

(d) Research front

Some respondents (5) comment on the fact that school chemistry fails to give an account of recent developments in chemical research. For example R4 says, 'Biochemistry despite its *relevance* and the fact that it has been the most fruitful area of research in

[14] In the second part of the research project we investigated to what extent an innovative course in school chemistry, Salters' GCSE Chemistry Course (1987), managed to *escape* from NCE. See Chapters 4 and 5.

recent years is sadly neglected in school chemistry.' And R26 notes that in school chemistry books 'the emphasis is ... never on the non-existing compounds'. As we saw above, a number of respondents (9)
stated explicitly that current school chemistry does not prepare students for science *as enquiry*.

(e) History of science

Several respondents (8) comments concern this dimension. Thus, R18 thinks, 'It is important that students after having finished secondary school know something about the history of *chemistry* as part of history of human culture, e.g. the major periods of chemistry, the main reasons of chemistry development steps, the famous scientists, and useful inventions.' On the other hand, as R26 remarks, 'I do not know – like Aarons or Hecht in physics – a secondary textbook that shows chemistry like a historical process.' Historic experiments in school chemistry are, as R11 says 'all successful ... interpretation is always correct'.

(f) Philosophy of science

Several respondents (7) comment along this dimension. The last quotations also touch upon the way the nature of science or chemistry is, or is not, dealt with in school chemistry books. Here is a clear statement to this effect from R4, reminiscent of Schwab's view on science education:

> We often fail to teach through school chemistry *the nature of our scientific enterprise* (...) We need to show in school chemistry the relationship between scientific method, important for hypotheses *generation and testing* theories, and theoretical propositions aimed at providing a cohesive explanatory framework for observations.

And, R6 makes an important methodological point: 'Students (...) must be made aware of the fact that the currently accepted theory with which they are being *indoctrinated* is merely the successor of the previously accepted theory and also the predecessor of the next theory which will be adopted at some future date.'

(g) Related sciences: physics and biology

Some respondents (4) argue explicitly against the demarcation of school chemistry from school physics (see also Figure 2.3). For example, R19 makes the point: ' "Chemistry", "physics", and "biology" are concepts which have been historically subjected to an *artificial separation*. There is no point at which one can say that chemistry stops here and physics begins there.' Several other respondents (8) discuss, in connection with Statements 2 and 6, the difficulties in teaching and learning the distinction between chemical and physical changes.

Finally, some respondents (3) point more specifically to the irrelevance of current school chemistry to *ecological* problems. One respondent (R10) does not believe in the idea that school chemistry could 'gradually change', and favors therefore 'the abolition of school chemistry and reconstruction of a topic like perhaps *material environments and their changes*'. Eight respondents do not make any remarks along the dimensions mentioned above.

Conclusion and discussion

It thus appears, that most of the IF response on the isolation of school chemistry (De Vos et al., 1993; Van Berkel, 1996) and Kuhn's remarks on the insulation of normal science can be characterized by the same dimensions. In sum, normal chemistry education is isolated from common sense, everyday life and society, history of chemistry, philosophy of chemistry/science, school physics, and chemical technology, and from chemical research. The discipline of chemistry as a normal science, especially its 'unparalleled insulation', accounts for the isolation of school chemistry along the same dimensions. After all, the latter is regarded as an initiation and preparation for the former.

Thus, here the existence of NCE explains a second important general feature of dominant school chemistry: its isolation or its current inaccessibility to reforms. Whereas the first general feature, its *rigidity* or its resistance to reforms, characterizes the *internal* structure of dominant school chemistry, the second general feature, its *isolation*, characterizes the (lack of) external relations of dominant school chemistry (see also Figure 2.3).

But does the exclusion of these dimensions from scientific training – which according to Kuhn enhances the research efficiency of normal scientists – also enhance the puzzle-solving skills of (secondary) students aspiring to be scientists, i.e. chemists? In brief, is NCE effective? As we showed for the secondary level (section 2.2), NCE fails to realize its own set goals of initiating and preparing future chemistry students by teaching them the processes of understanding, explanation, and prediction of chemical phenomena (Figures 2.4, 2.5). The opinion of R11 reflects in a candid way the views expressed by a number of respondents (9):

> Not only does the theoretical approach make chemistry more difficult to understand, it also transforms it into a plugging of numbers into inaccurate formula for students to get answers to questions while *understanding neither the question nor the answer*.

The seven-fold isolation of dominant school chemistry has not been efficient in promoting its set goals. Instead, its isolation has led to the teaching and learning of *propositional knowledge and algorithms,* to which the 'unparalleled insulation' of normal chemistry has contributed.

2.4.2 General dangers of Normal Science Education

The latter conclusion with regard to normal chemistry education at the secondary level resembles a *parody* of what normal science education should be. To use Kuhn's terms, neither the puzzle set, nor the solution defined by the paradigm are understood by students. Instead, scientific results are simply reproduced as propositional knowledge and algorithms or as *a rhetoric of conclusions*.[15] Also contributing to this state of affairs is the pressure of the current poor forms of testing students' knowledge and skills, which seem to select the most routinized forms of puzzle solving (De Vos, et al., 1993).

It should be noted that just before the curriculum wave in the 1960s, Kuhn deplored such a 'parody of what scientific education should be' (1963, p. 390) as it pertained to, for example, the secondary level of science education in American high schools and colleges. As we have argued in this article, in the 1990s a similar parody of NSE still exists as NCE and is equally deplored by IF respondents, and many other researchers in science education (Fensham, 1992; Duschl, 1993; Aikenhead, 1997; Matthews, 1998). However, Kuhn insists in his reply to comments of B. Glass, one of the NSF curriculum reformers 'that it is a parody, i.e., that it is not irrelevant' (ibid., p. 390). The discussion between Glass and Kuhn shows clearly that Kuhn thinks his theory of scientific training *also* applies to secondary education. But Kuhn had one reservation about the discovery and process oriented reforms of the 1960s, though he welcomed them as a whole:

> In particular, I wonder to what extent the facts (whether 'authoritative' or not) can be dispensed with in favour of 'methods of investigation' (emphasis Kuhn). I suspect that students will learn *both together* as samples of *accepted* achievement, which is only to say that I suspect they will learn *paradigms* (Kuhn, 1963, p. 391).

Kuhn appears to be saying that, although there is an urgent need to improve bad forms of NSE, such as the parodies mentioned above, any reform should be in the direction of NSE. Furthermore, Kuhn points here to an important characteristic of NSE not discussed so far, namely, its *domain specific* nature which entails that methods cannot be taught separately from facts. On the contrary, science methods, and/or processes and facts, and/or conceptual content should be taught and learned together while using exemplary problem-solutions solvable within the context of the current paradigm.[16]

The same authors on whose work we have drawn for our Kuhnian interpretation of school chemistry (Popper, 1970; Barnes, 1982; Ziman, 1980; Hodson, 1988; Siegel, 1990; Duschl, 1993; Matthews, 1994) have also pointed to *general* dangers associated with NSE. In particular, they take issue with Kuhn's view on the initiation into normal science as a 'narrow and rigid education' (1977a) which requires or instills a *dogmatic* attitude. The gains of this initiation, that is, efficient puzzle-solving, befall mostly to the scientific *group*, says Kuhn, while the 'loss due to rigidity accrues *only to the individual*'

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15 Schwab (1962 pp. 24, 39) describes this state of affairs as follows: 'Our teaching laboratories invite students to discover the satisfaction of *techniques* mastered. (...) Our classrooms are imbued with the same dye of established law and *accepted* knowledge. This is obvious in the premium put on "learning the lesson". It is most poignantly seen in the well-nigh universal reference to the phrase "problem solving". This is currently a popular phrase in the schools and is supposed to mark a new and higher conception of means and ends in education. But when the problems posed are examined and the "solving" inspected, "problem solving" turns out to be little more than *meticulous application of given procedures to situations which follow strictly the model problem on which the procedures were learned*.' It is noteworthy that Schwab anticipates Kuhn's idea of puzzle-solving, while observing that the practice of school science is reduced to the most routinized form of it, that is, to 'problem solving'.

16 Schwab (1962, p. 102) equally deplored the tendency 'to divorce "content" and "method" ' and warned against the danger of treating thereby '*both* of them as orthodoxies by a rhetoric of conclusions'. Schwab, of course, wanted to teach science as enquiry, especially as fluid enquiry, which involved 'a treatment of scientific knowledge in terms of its origins in the *united* activities of the human mind and hand which produce it'.

(ibid., p. 166). But, as these critics of Kuhn say, in order to further the growth, not only of scientific knowledge but also of personhood and democracy, a *critical* attitude is called for. The following arguments have been brought forward to support this claim.

(i) The twentieth century has seen increasingly more 'fluid enquiry' (Schwab, 1962), both in terms of the extent and 'the duration of a revisionary cycle of stable enquiry' (p. 18) or, in Kuhn's terms, of normal science. In an age where 'the modal rate of revision is probably of the order of fifteen years' (p. 20), tertiary science education should largely aim for the training of more fluid enquirers, while secondary science education should be concerned mostly with teaching *about* fluid enquiry (p. 38).

(ii) Up to the 1940s, fluid enquiry or critical science (Popper, 1994, p. 76), or in Kuhn's terms, revolutionary science, has been much more important for the growth of scientific knowledge than stable enquiry or normal science. Popper (*pace* Schwab) sees increasingly more specialization and 'scientific "*routine*" ' (p. 76) since then, but in his opinion this calls all the more for the encouragement of a critical attitude; otherwise 'it will be the end of science as we know it – of great science' (p. 72).

(iii) Whereas in normal science (education) 'the loss due to rigidity accrues *only* to the individual', for the sake of the presumed effectiveness of the *collective* practice of normal science, in critical science (education) the critical abilities learned accrue to the *individual*, that is, not only for the sake of critical science, but also for the sake of personhood and democracy.

Furthermore, these scholars argue that critical abilities acquired in critical science education contribute to other important educational goals regarding future citizens and/or the public need, for example, the growth or development of democracy (Popper, 1950, 1970; Schwab, 1962); the growth or development of personhood (Koertge, 1996); autonomy, open-mindedness, pluralism, and respect for evidence (Siegel, 1990); the growth or development of culture, both the scientific and the humanistic culture (Snow, 1959; Ziman 1980; Matthews, 1994); and the maintenance and the sustainable development of the natural environment.

On the other hand, the rigidity or dogmatism inherent in normal science education seriously impedes the realization of these goals because such rigidity entails both a distortion of the history of science and a grossly misleading picture of the nature of science (Medawar, 1963; Popper, 1983, p. 50), thereby encouraging blind commitment and dogmatism in the name of professional training.

(iv) A more fluid or critical science education would motivate students by involving them actively in processes of enquiry, such as reasoning, observing, and experimenting (Verdonk, 1995). As such it would also be in line with humanistic values like autonomy and open-mindedness.

(v) Finally, many researchers in science education (Ziman 1980; Garforth 1983; Fensham 1992) point to the fact that only a minority of students continue to study chemistry and of them only a few actually become professional chemists. Nobel laureate chemist Roald Hoffmann (1995, p. 228) concurs and suggests that chemistry courses 'must be aimed primarily at the nonscience student, at the informed citizen, not toward the professional'.

2.4.3 Discussion

These arguments (i – v) lead us to the view that a critical science education is both desirable and urgently needed. The next question is whether it is feasible and effective. It is Kuhn's contention that only normal science can be the basis for an effective scientific training (NSE), and he seriously questions the possibility of a training for revolutionary or critical science. Schwab and Popper, as we have seen, disagree, as do many researchers in science education.

Ultimately this is an *empirical* matter: whether we can *escape* from NSE can only be settled by empirical research in science education. Classroom-based research, for example that performed by our group in the last decade (Van Driel, 1990, Van Hoeve-Brouwer, 1996; Acampo, 1997; Van Aalsvoort, 2000) shows that modest forms of critical chemistry education are feasible as well as effective on a *small scale* under specific, researched conditions. Also there have been some successful large scale attempts to realize forms of critical science education, e.g. Harvard Project Physics and the Biological Sciences Curriculum Study, the latter led by B. Glass and J.J. Schwab in the 1960s (Matthews, 1994, p. 6). But the question remains: why is it that critical science education, although it has been shown to be both feasible and effective at the secondary level, has not yet managed to replace normal science education except marginally and temporarily (Fensham, 1992; Duschl, 1993; Matthews, 1998). See on this topic futher Chapter 3.

We have tried to explain in this article why it is so difficult to escape from NCE, rigid and isolated as it is. Such an escape must entail the *coordinated replacement* of the currently rigid combination of specific substantive, philosophical, and pedagogical structures of school chemistry, not only at the level of the intended and formal curriculum, but also at the level of the realized curriculum. Furthermore, such an *internal* change in the structure of school chemistry can only succeed if school chemistry also overcomes its isolation, that is, if all those involved in school chemistry seek to enlist the seven dimensions it is now lacking. This will also involve a major change in pre-service and in-service teacher education aimed at increasing the competence of teachers to recognize, analyze, criticize, teach, and develop teaching materials emphasizing different combinations of substantive, philosophical, and pedagogical structures.[17]

2.5 Conclusion

The structure of the currently dominant school chemistry curriculum is accurately described 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

[17] I would now formulate the claims I make in this paragraph less absolutely. As I did in Chapters 3 and 6 of this thesis, I would reformulate them in terms of three necessary conditions, without implying that these are sufficient conditions for the escape from Normal Chemistry Education.

structure of dominant school chemistry as a whole suffers from a sevenfold *isolation*: from common sense, everyday life and society, history and philosophy of science, technology, school physics, and from chemical research.

These general features of dominant school chemistry, rigidity and isolation, are explained in terms of the concept of *normal chemistry education* (NCE). Escape from NCE is only possible through a *coordinated replacement* of the currently rigid combination of substantive, philosophical, and pedagogical structure of school chemistry.

NCE fails to realize its own set goals, that is, teaching and learning (for all pupils) the prediction and explanation of chemical phenomena; instead it teaches / learns a set of propositions and algorithms. Neither the effectiveness of NCE nor its superiority over more critical forms of secondary chemistry education has been conclusively demonstrated. It is not possible to justify, *by argument or experiment*, an NSE based chemistry course that is suitable for *all* pupils. Maybe this can be done with regard to the small minority of students who will study chemistry at a further level, some of whom might become chemists. NCE cannot be regarded as a form of chemistry education *appropriate* for *all* pupils, *exactly because* it consists of a dogmatic, domain-specific training for future chemists.

Therefore, at the secondary level, the *initiation* into normal chemistry should be largely *replaced* by an education *in or through* fluid, critical, or revolutionary chemistry (HPS-education, Matthews, 1994), together with an education *in or about* the relations between chemistry, technology, and society (STS-education, Solomon and Aikenhead, 1994).