1 Problems of current school chemistry

In this thesis I will address two main problems of current school chemistry. The first problem I will address is the *problem of the structure*: what is the structure of the chemical concepts and chemical relationships present in school chemistry textbooks? The second problem I will address is *the problem of escape*: why do reforms of the current school chemistry curriculum lead only to marginal changes? This in turn raises the question whether the structure of the current school chemistry curriculum is an asset or an obstacle for reforming school chemistry. Thus the solution of the problem of escape bears on the solution of the problem of structure.

In this Chapter, I will first describe the origin and relevance of these problems (1.1). Second, I will discuss the research design and methods I use to address the problems of structure and escape (1.2). Third, I outline the theoretical curriculum framework used in this thesis – based on the work of Schwab, Goodlad, Kuhn, and Roberts – which I use to analyze and explain the curriculum data I gathered in my research into the structure of current school chemistry (1.3).

Finally, I will give an overview of the contents of my thesis in terms of the general argument which is based on the research I have undertaken to formulate and test a hypothesis on the current structure of school chemistry, and to analyze and evaluate an attempt to escape from the currently dominant school chemistry curriculum by an innovative chemistry course, called Salters' Chemistry (1.4).

1.1 Relevance of problems of structure and escape

The problems of structure and escape arose, initially, in the context of a citizen-oriented reform of school chemistry (1.1.1). Besides this practical root, the problem of structure also had a theoretical root in the fundamental research as performed by the Department of Chemical Education of Utrecht University in the 1980s on the topic of explanation in chemical education (1.1.2). In line with the practical and theoretical relevance of the problem, I will further describe how the structure and escape problems were of personal relevance to my own learning, teaching and researching of school chemistry (1.1.3).

1.1.1 Societal relevance

In a curriculum study on the development and implementation of a new society and citizen oriented chemistry curriculum for lower secondary education, the researchers (Joling et al.,1988) reported a crucial finding relevant for my research on the current structure of school chemistry:

> The transition to "Chemistry for the Citizen" resulted in a *tension between aim and structure* of chemical education (Joling et al., 1988, p. 82; all translations from Dutch original quotes are mine).[1]

The general *aim* of this two-year course, titled "Chemie-mavo", was interpreted by the developers of the course as providing future citizens with knowledge of relevant chemical aspects in their personal and social lives. The developmental project, of which the "Chemie-mavo" course was to be the outcome, started in 1975 and aimed from the outset to develop a course different from the customary "paper chemistry of just formulas and reaction equations" (ibid., p. 324). Instead, as the developers put it:

> We wanted to show the role of substances and reactions in processes of daily life in society and in other natural sciences (p. 325).[2]

Accordingly, the developers felt that the teaching materials had to be context-oriented, developed on the basis of practical experiments, and related to daily life experiences of pupils. In this way pupils who did not choose chemistry as an exam subject were provided, at least in the first year, with a self-contained course (Joling et al.,1988, p. 2).

By choosing a research design which consisted of document analysis of the teaching materials, of interviews with developers, and of extensive classroom based research of the teaching-learning process, the researchers wanted to ascertain the extent to which the general aim of the "Chemie-mavo" course had been realized, both in the textbook produced by the developers and in the teaching-learning process as enacted by teachers and students.

The chemical content selected by the developers to realize the newly set societal aim of the course was, according to the researchers, *structured* in the first year of the course around a "backbone" of the three related chemical concepts: pure substance, chemical reaction, and chemical element. The second and last year of the course dealt with the corpuscular view of matter, that is, with concepts such as atom, molecule, and ion (ibid., pp. 82, 87). This structure, they noted, was largely similar to the conceptual structure of upper secondary chemical courses, albeit in a diluted form.[3] It is a conceptual structure which has a strong scientific orientation and is, therefore, traditionally used to teach future chemists. Two conclusions of the curriculum study of "Chemie-mavo" are relevant here. First, contrary to the intentions of the developers:

> Chemical education emerges for many pupils as a closed system, both with regard to space, the classroom, and time (a couple of hours per week) with no visible relationships with the rest of the observable world.[4]

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1 Dutch original: Bij de overstap naar "Chemistry for the Citizen" ontstond een spanning tussen doel en structuur van het scheikunde-onderwijs" (ibid., p. 82).

2 Dutch original: We wilden laten zien dat stoffen en reacties een rol spelen bij processen in het dagelijks leven, in de samenleving en in de andere natuurwetenschappen (p. 325).

3 Developers had to work under the external constraint, set by the overseeing committee, that most of the traditional chemical concepts had to be addressed in the course.

4 Dutch original: Scheikunde-onderwijs ontwikkelt zich voor veel leerlingen tot een in ruimte (het leslokaal) en in tijd (enkele uren per week) gesloten systeem zonder zichtbare relaties met de rest van de waarneembare wereld (p. 313).

The second conclusion of the researchers is that:

> The research shows that is not easy for pupils to make a context switch [between a daily-life context and a chemical context], and that teachers are often not able to provide a solution which is consistent with the intentions of the authors of the course (ibid., p. 312, 313).[5]

In brief, the overall aim of the "Chemistry for the Citizen" course as embodied in "Chemie-mavo" was not met by either teachers or the developers, and consequently was not realized with the pupils. Despite the context-and-experiment led approach to the chemical content selected, developed, and taught in the course, the outcome seemed to be that many pupils still learned a kind of "paper chemistry", or chemistry in a "closed system". Thus, contrary to the intentions of the developers, the reform resulted in only marginal changes.

This led the researchers to ask the penetrating question: "Why was this aim not met more successfully in the development and teaching of the new course?" The answer, they thought, had to do with the crucial finding mentioned at the start of this subsection, namely, that there is a serious *tension* between the newly set aim of the "Chemistry for the Citizen" course and the traditional conceptual structure of school chemistry used in chemistry courses for both lower secondary and upper secondary education. I will come back to this crucial finding in Chapters 4 and 5 of this thesis, where I report on my curriculum research on the society-oriented Salters' Chemistry course as executed in the 1980s in England.

This example of an unsuccessful attempt to reform school chemistry in the Netherlands, to change the quality of chemical education especially for those pupils who most likely would *not* go on to study chemistry, raised a vexing question. Was this finding to be seen as a curriculum phenomenon of a merely local nature, or did it perhaps have a global character as suggested by one of the researchers, Wobbe de Vos? Were there not similar curriculum experiences and findings in other countries? If so, what was the general *mechanism* preventing these society- and citizen-oriented school chemistry reforms from becoming successful?

First, however, an important preliminary question had to be answered, namely, what was exactly the structure of the current school chemistry curriculum, that is, the structure of the chemical concepts and chemical relationships present in school chemistry textbooks? What was needed, was a valid description of the content and structure of chemistry as a school subject in order to analyze, and possibly overcome, via reforms of school chemistry, the *tension between aim and structure* of chemical education.

Recruitment or citizenship

It is not difficult to see that most pupils of lower secondary chemical education, from whatever stream or school type, will not choose to go on with further study in chemistry. More surprisingly, perhaps, is that this is also the case for upper secondary education, as various researchers have argued. Hondebrink & Eykelkamp (1988) concluded for The Netherlands that at most 10% of the pupils of upper secondary education would go on to study chemistry or subjects requiring basic chemical knowledge. Fensham (1984)

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5 Dutch original: Uit het onderzoek blijkt dat deze wisseling van context [tussen een leefwereld context en een chemische context] niet gemakkelijk door de leerlingen wordt uitgevoerd en dat docenten dikwijls geen oplossing in de geest van de bedoelingen van the auteurs kunnen bieden (p. 312).

in a study surveying the international situation concluded that at most 20% of the pupils in secondary education would choose to continue studies requiring chemistry as taught in secondary schools. Roald Hoffmann, a Nobel laureate with a great interest in chemical education, made the point that:

> Education is a conservative enterprise, and it does not change very quickly. I think the shift in chemistry education has to come from the recognition of the fact that 99.9% of the population are not going to be chemists (Hargittai, 2000, p. 208).

So, the majority of pupils are not provided with an appropriate chemical education in accordance with their needs. Fensham (1984) formulated the accompanying challenge:

> Can chemistry, as a subject field, contribute to the schooling of the 80+% of learners in each age group who are most unlikely to study chemistry again after leaving school?

Since the start of the "Science for All" movement in the early 1980s (Fensham, 2000), there have been several attempts to develop and implement science and/or chemistry curricula "aimed primarily at the non science student, at the informed citizen, not toward the professional" (Hoffmann, 1995, p. 228). Hoffmann gave two arguments for the urgent development of chemistry courses for the general public:

> First, if we do not know the basic workings of the world around us, especially those components that human beings have added to the world, then we become alienated. My second point of concern about chemical illiteracy returns me to democracy. Ignorance of chemistry poses a barrier to the democratic process.

Hoffmann in (Hargittai 2000, p. 208) then concluded that "[t]here is a role for experts, but the public has to decide by themselves. For this, they need to know a little chemistry."

In Chapters 4 and 5, I will report in detail on my research of a society-oriented curriculum for school chemistry, called Salters' Chemistry, which is part of the Salters' Science Project based at York University, England. Fensham (2000, p. 52) said of this 'first generation' of "Science for All" curricula:

> However, their acceptance has been difficult for many science teachers who have been strongly socialized into believing the content of the sciences consists of definitional abstract concepts, with the use of associated algorithms for application to standard, closed problems.

On the other hand, Fensham (1984) and Hoffmann (1995) argued – after analyzing the rich content of chemistry in relation to science, society, technology, culture, and history – that chemistry taken in this broad sense has to offer the general student and the general public much more than the customary one-dimensional concept-based problem solving. Both authors have themselves developed or contributed to rich 'chemistry for all' courses, Hoffmann for college students and Fensham and co-workers (1988) for students of secondary education. Fensham (2000) gave a review of some recent attempts to develop and implement "Science for All" courses, which attempted to overcome some of the problems of the first generation courses as well as to address the necessary curriculum reform on a greater, sometimes even on a national scale. An example of such a large scale attempt is the Dutch project, "New School Chemistry", the preparations of which started in 1999, and whose aim is to reform upper secondary chemical education (Bulte et al. 1999; Westbroek et al. 2000; Westbroek et al. 2001; Van Koten 2002).

Several practitioners in chemical education – researchers, developers, teachers – have been working hard to show that chemistry can contribute, and to some extent is already contributing, to these new chemistry courses, that is, to the schooling in relevant and meaningful chemistry of the general student or the general public. However, most of the work still remains to be done.

1.1.2 Scientific relevance

The problem of the structure of current school chemistry arose initially, together with the problem of escape, from a social root, that is, an unsuccessful attempt at reform of school chemistry. The problem of structure also had two important scientific roots.

Tradition of research in chemical education

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 *parts* of the current school chemistry curriculum in The Netherlands. These studies 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, an educational structure of activities was designed which described how and why a particular topic of school chemistry must be taught, and learned, and was trialled in the classroom. The audio-taped data of the teaching and learning process from teachers and students was used to redesign each teaching unit in order to match its structure to the new aims set by the respective researchers.[6]

The completion of a number of these small-scale, in-depth research projects led to the concept of the *hidden structure* of school chemistry, as it was initially called by De Vos (1992). He began to wonder what the current school chemistry curriculum *as a whole* looks like, why school chemistry textbooks from different periods as well as from different countries look so remarkably similar? How can we arrive at a valid description of this structure of school chemistry? Further, why is school chemistry so *resistant* to reforms? Is the structure of the current school chemistry curriculum a support or a hindrance to the quality of chemical education? The problem of structure seemed to be of international scientific relevance.

Conference on explanation

In 1986, the Department of Chemical Education organized a one-day Conference on the subject of "Explaining in Chemical Education" ("Verklaren in chemie-onderwijs") for teachers, developers, and researchers in secondary education. As a result of the activities and discussions of that "Explanation Day", two of the organizers, De Vos and Verdonk, tentatively formulated a set of three important structural relationships that exist between concepts of school chemistry. As we shall describe in more detail below (section 1.2.2), this concerns the three conditions a chemical reaction must obey in order for the reaction to occur: (i) conservation of chemical elements; (ii) decrease of chemical (Gibbs) energy;

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6 For a detailed description of this research methodology, called "Developmental research", developed, used, and refined by researchers at the Centre for Science and Mathematics Education, see Lijnse (1995).

(iii) kinetic instability. Only these three conditions *together* explain the occurrence of a chemical reaction. In line with this finding, they formulated as the general aim of school chemistry: the explanation and prediction of chemical phenomena in terms of the chemical-reaction conditions (stated above).

Hidden structure

The need to arrive at a valid description of the structure of chemistry as a school subject was felt all the more, because De Vos and Verdonk could not find a "generally accepted description of a conceptual structure underlying school chemistry" in official documents (De Vos et al., 1991), although various authors did mention or seem to refer to such a structure in papers and documents. For example, the exam program for the vocational-oriented stream in secondary education in The Netherlands (HAVO) stated:

> Although it is true that a syllabus presents the topics in an order, that is, as logical as possible, this does not mean that the topics of a course in a certain year have to be taught in that order. The teacher is free to choose an order, though often *the structure of the subject* makes it necessary to teach certain topics before others." (Min O&W, 1984; translation and italics mine)

An initial solution of the problem of the structure of current school chemistry, stemming from the social and scientific roots mentioned above and given by De Vos and Verdonk (1990), laid the groundwork for my research. In the 1990 paper they arrived at the hypothesis of a *coherent* conceptual structure in school chemistry. The concept of the chemical reaction and the three reaction conditions mentioned above occupied therein a central place; (for an elaboration of this hypothesis, see also De Vos et al., (1994). Subsequently, it was decided to test the hypothesis on the *coherent* structure in current school chemistry against the curriculum experiences and views of both an International Forum and a Dutch Forum of chemical educators, developers, and researchers (see also1.2.3). To explore the international relevance of the problem of structure:

- We wanted to test our hypothesis against the curriculum experiences and knowledge of chemical educators in both our own country and other western countries in order to see whether it was grounded or valid at both national and international levels.
- We felt that if we could establish and describe the structure of current school chemistry as an international curriculum phenomenon, it would greatly enhance the urgency to change the current state of school chemistry, either locally or globally.
- We needed a valid description and analysis of the structure of school chemistry, but only as detailed as required for this chemical educational purpose since our ultimate goal was to contribute to reforms of school chemistry. Therefore, we refrained from embarking on an extensive and detailed historical study of school chemistry curricula.
- We also hoped to learn more about the mechanism that prevented reforms of school chemistry, at a national or international level, from realizing their newly set educational aims.

1.1.3 Personal relevance

What follows in this subsection is a personal case study, and as such is less objective than a case study performed on another subject. Its function is to introduce the problems, that will be discussed in this thesis in an abstract or empirical way, in a more personal way, and thereby hopefully make these problems more accessible. By sharing my curriculum experiences, the reader might recognize and be able to identify more readily with the problems discussed. These experiences can also serve as further illustrations of some of the general claims backed by empirical research I will arrive at in this thesis and discuss at the end of this study (Chapter 6).

Although I have followed chemistry at secondary school and studied chemistry as an undergraduate student at university and later in the context of a teacher-trainer course, these learning experiences did not give me a clear idea of the *conceptual structure* of school chemistry or, for that matter, the conceptual structure of university chemistry. I will now describe some current reflections on a few of these experiences that are relevant to the study at hand.

Secondary school

In 1963, I was introduced at age 15 to chemistry as a school subject in grade 9 of a secondary school, the so-called "Hogere Burger School" (HBS), a Dutch school-type at the time. Pupils who passed the HBS exam were admitted to any university in the country they wished to attend, provided they met certain requirements, like sufficient training, for the subject they chose to study. I received chemistry lessons from three teachers. The first teacher, who was quite an old teacher in my perception, often failed to get the 'right' results in the experiments he demonstrated to us. One time, though, he succeeded to engulf the classroom as well as the whole school in hydrogendisulfide (H_2S) smoke and smell. This event might have been one of the reasons why he left. His place was taken halfway through the school year by a much younger teacher who tried to relate to us more and to motivate us for his school subject, but without much success. He left at the end of the school year. After grade 9, we had to choose either HBS-A, a humanities-oriented exam course, or HBS-B, a science-oriented exam course. Having chosen the latter, I was fortunate to get as my third chemistry teacher, in both grades 10 and 11, an inspiring person who was able to motivate many of us, including me, for his subject. This resulted in better achievements in the classroom, in better marks on tests and final exams.

Textbooks

The textbook we used in grades 9 and 10 was written by Meurs and Baudet (1959), and entitled *Beginselen der Scheikunde, part I*. The first edition of this textbook appeared in 1921; it could be called a 'systematic' introduction to chemistry. The table of contents shows that it is organized around elements and groups of elements, that is, it consists largely of chapters of descriptive chemistry interjected with a few chapters on theoretical topics, such as combustion or valence. In my day as a student we used the nineteenth edition which did contain more theoretical chapters (about 10), although the descriptive, systematic chemical chapters still dominated (about 25). In their foreword to this edition the authors remarked on the addition of chemical theory:

> We think we have achieved in this way that students do not have to learn outdated concepts which otherwise have to be replaced with great difficulty by modern concepts (my translation).

This textbook did, however, include demonstration experiments for teachers to perform, but no practicals to be done by pupils. In any case, we did none that year. In my last year (grade 11) at the HBS, my chemistry teacher decided to use a new textbook written by Feis et al. (1962), and titled simply "Scheikunde" (Chemistry). This text presented a different, a more theoretical view on chemistry. The subject matter was organized around corpuscular theories, such as the atomic theory of Rutherford and Bohr. As the authors explained in their foreword:

> By putting theory first we have been able to strongly limit the space given to the systematic discussion of elements and compounds, and which is needed for the written final exam of the HBS (my translation).

As for experiments, most were again demonstrated by the teacher. In this last year, though, we ourselves performed some practical experiments, or rather exercises as they were called, in a room specially equipped for that purpose. I recently learned from an interview with my former chemistry teacher that his aim for letting us do these practical exercises in grade 11 was to give us some experience of those *chemical reactions we would probably come across in final exam questions* such as precipitation reactions and titration reactions. Looking back I found this rather revealing. The goals proposed in the 1970s for using 'pupil' experiments – to motivate pupils for school science, to introduce and/or verify chemical laws and theories presented in school chemistry textbooks, and to illustrate scientific method – were fully absent in this case. Instead, practical exercises were used as an additional asset to the textbook, lectures and demonstrations to help us to solve exam problems in order to prepare us for the final exam.

In sum, I got a rather 'textbookish' introduction to school chemistry, largely along 'systematic' chemistry lines, and only in grade 11 along theoretical, corpuscular lines. What we did, mostly, was to solve problems chapter-by-chapter from both textbooks, which prepared us for our exams. The few practicals we did were selected for that same purpose. Although I did pass my final exams for the subject chemistry, the relations between chemical theory and observation and experiments did not at that point become clear to me at all. I suppose this accounts for my ignorance at the time of the existence of a *conceptual structure* of school chemistry, a theoretical structure (as I learned much later) which could be used for describing, explaining and predicting chemical phenomena, and thereby give pupils an understanding of the nature and structure of chemistry as a science.

Undergraduate chemistry

This state of affairs did not improve much at university, I must say. I still had to study textbooks, but now more and bigger ones, introduced to us by several lecturers. By studying the lecture notes and textbooks it was fairly easy, however, to pass the required test to go on to the next course, and the next test. Admittedly, we had to attend much more practical courses as well, such as practical courses on organic chemistry, inorganic chemistry, physical chemistry, physics, and botany, but without seeing much relations between what was presented theoretically in lectures and textbooks and the topics offered in the practical courses.

Practical courses were organized as separate blocks as well, and were not really connected to, or in preparation for, each other; nor did they relate clearly to the theory or lectures we followed. As a rule the practicals had a certain format. First, we studied some 'relevant' theory, then we discussed this with a teaching assistant and performed the (related) experiment. The experiment was followed by a discussion of the results with the same assistant. Again, this process did not lead to any real theoretical understanding of what we had done in our practical work. After all, what we had to do, we could realize by following the given prescriptions, the recipes (De Jager, 1985). Following a number of these prescriptions as a rule led to the required experimental results and on to the next practical course. In brief, besides chemical formulas given in textbooks, we now had learned, or rather reproduced, chemical recipes as they were given in what could be called chemical 'cookbooks' (Van Keulen, 1995).

Thus, in the undergraduate chemistry courses I got a rather fragmentary view of chemistry as a discipline, as portrayed by several textbooks and 'cookbooks'. This did not give me a coherent picture of chemistry as a science. Something that could have provided an overview, such as a course in the history or philosophy of science or chemistry, was, not available, or at least not known to me, and it was certainly not mandatory.

An episode

Sometimes I could not take it all in. So, I twice had to do the subject 'organic chemistry' that was focused on organic name reactions. Since I failed both times, I could not pass the ensuing 'kandidaats' (bachelor) exam. As a last resort an oral examination could be taken. I prepared myself thoroughly for this with the help of a tutor, a member of the chemical faculty who seemed pleased with my progress in his hands. However, I did not pass the oral exam. The examiners, one of whom was a newly appointed professor in organic chemistry, did not examine me on the required subject matter of organic name reactions, the reproduction of which I had rehearsed for some months to the satisfaction of my tutor. Instead they decided to ask me some penetrating questions about the reaction mechanism of some organic reactions. They also wanted me to explain – concerning whatever I managed to suggest – a possible path of the reaction. I must say that I was not prepared for that type of organic chemistry thinking at all. Since I did not pass the oral exam, I could as a result not pass the bachelor exam either. However, by law students were allowed to take written tests again. At the next opportunity, I took the written test and finally passed, this time, though, on the usual topic of organic name reactions. As you can imagine, it was much later that I began to appreciate the mechanisms of organic reactions.

The structure of the undergraduate course in chemistry, consisting of a row of separate theoretical and practical courses, also meant that students were only dimly aware of such a thing as chemical research. Some of our practical assistants were as PhD's involved in chemical research, but I had no idea what this entailed. Chemical education and chemical research were at that time almost fully separated from the undergraduate level. Nevertheless, I decided to choose as my first minor biochemical research inspired by the reading of "The Double Helix", a popular book on the discovery of the structure of DNA by James Watson (1968).

Philosophy of science

It was at this point in my life, that I became interested, through discussions with friends, in the philosophy of science. And I decided, after a half-hearted and aborted attempt to do some biochemical research, to continue my studies with a course in the philosophy of the 'exact' sciences. Subsequently I studied history of science and history of chemistry.

It was in these courses that I began to understand that chemistry as a science aims at explaining and predicting chemical phenomena, and how that involves the generation and testing of knowledge (Popper, 1968). I learned about the structure of science and the structure of theories, for example, about the atomic-molecular theory, its relation to chemical and physical phenomena, and the empirical laws that it explained and predicted (Nagel, 1968).

I found out how hard it had been for scientists to arrive at an interesting hypothesis, how difficult it was to develop this into a valid theory, a theory which could explain and predict the known facts and also predict novel facts. Seen in this light, the purpose of experiments was not so much to introduce or illustrate a theory, as is usual in school science; rather, experiments were viewed as tests of a proposed hypothesis. When hypotheses withstood the tests, they could lead to theories, thereby furthering the growth of knowledge (Popper, 1965).

As sketched above, none of this transpired from my school chemistry or university chemistry. I felt rather alone in this, but later I found out that it was not an uncommon experience. Other students, at school or university, have experienced similar things, even including those who have gone on to do chemical research and become professors (Verdonk, 1995).

Teacher training

Some time after I graduated in philosophy of science, I decided to take a teacher-training course. This course consisted of a major in chemistry and a minor in chemical education. The latter consisted of period of teaching chemistry as a teacher-trainee at a secondary school and of a small research project in chemical education. At the end of the teacher training course, I came across a paper written by Wobbe de Vos and Adri Verdonk on the "Vakstructuur van het Schoolvak Scheikunde" (1990). This paper was a major eye-opener for me (see further the summary in section 1.2.2, section 1.2.3 and the reference given there). It gave me a first idea of the structure of chemistry as it pertained to *school chemistry*. Suddenly I saw that at the level of school chemistry a serious attempt can be made to teach students the explanation and prediction of chemical phenomena with regard to both chemical substances and chemical reactions.

De Vos and Verdonk (1990) pointed out that in essence there were two comprehensive theoretical structures involved in chemistry as a school subject. The first one was organized around chemical *substances* and the *corpuscular* theories which explained the structure and bonding of these chemical substances. The second theoretical structure was organized around chemical *reactions* and included the principle of the conservation of chemical elements, thermodynamic theory, and kinetics, which together offered a surprisingly coherent chemical reaction view on chemistry. From my studies in the history and philosophy of science, I was well aware of the existence and theoretical coherency of the first, the *corpuscular* point of view. The second theoretical structure, though, which De Vos and Verdonk described in some detail in their paper was quite new to me. I was receptive to this second theoretical structure because of the major I did in heterogeneous catalysis in my teacher-training course.

In sum, after my studies in the philosophy and history of science, I studied some chemistry in the context of a teacher-training course, and unexpectedly found out what the structure school chemistry was all about by reading the pathbreaking paper mentioned above by Wobbe de Vos and Adri Verdonk. I now had an idea of the conceptual structure of school chemistry.

Research in chemical education

My own struggle to arrive at this point made me conscious of a second issue involved, which we later called the *isolation* of the current school chemistry curriculum. Why had I not seen at least an outline of *a conceptual structure of school chemistry*? Maybe not at school, but at least at the university, or at the latest as I followed the teacher training course? I had not even grasped it when I was doing my chemical education research project on chemical equilibrium.

When I started in the 90s to teach chemistry at a secondary school, I experienced as a teacher that there existed more or less the same school chemistry curriculum that I had experienced when I was a pupil in the 1960s. This was despite the fact that, as I knew, there had been a major reform of school chemistry in the 1970s. Just as my teachers had done, I began to lecture and demonstrate experiments to my students at school, following the new textbook (Pieren, 1983). Admittedly, in line with the intent of the (then) recent curriculum reform, the pupils did more practical work, but again they performed the experiments as given by recipes. Besides lecturing, I spend most of the time on problem-solving which prepared pupils for the written tests I gave them. Full circle! Here I was giving pupils almost the same kind of chemistry teaching I had received, and to boot, had not liked. This kind of school chemistry was codified in textbook, tests, and exam. It apparently did not matter that I knew there was more to chemistry, such as its history or philosophy, which I had studied, and the chemical education research I had done. In that first year of teaching, I hardly had motive or opportunity to integrate such other content into my lessons, operating as I was under the demanding constraints of keeping 'order' and covering the required subject matter.

Not much later, I was fortunate to have an opportunity to do research in chemical education, this time on the problem of the *conceptual structure of school chemistry*, that is, on the same "Vakstructuur van het Schoolvak Scheikunde", De Vos and Verdonk had recently written about. This way, I had a chance to learn more about this structure and its relation to textbooks and to the practice of teaching in this country and/or in other countries. Are there any differences across time or place? Why is the structure of school chemistry so invisible? How is it possible that despite major reforms, in this and other countries, the structure remains more or less the same? Why is it so rigid? This led to the two major problems mentioned before. First, what is the structure of school chemistry, that is, what are its elements, relationships and structure? Second, why is this structure so resistant to reforms in chemical education, or, as we later called it, why is school chemistry so rigid? Knowing what the structure is and how it blocks change might put us in a position to reform, or as we later called it, to *escape* from school chemistry.

1.2 Research design

First, I will explain the terms De Vos and Verdonk (1990) used to describe the problem of the structure of current school chemistry (1.2.1). Second, I will give an outline of their hypothesis on the structure of chemistry as a school subject, by focusing on the structural features of the school chemistry curriculum (1.2.2). Third, I will discuss the research methods used in my research: the method I used to test the initial hypothesis on the structure of current school chemistry, and the method I used to evaluate and analyze the attempt to escape from the prevailing school chemistry curriculum by an innovative school chemistry course called Salters' Chemistry (1.2.3).

1.2.1 Analysis of the problem situation

In their attempt to describe the specifics of the structure of school chemistry, De Vos and Verdonk (1990, pp.19 -21), realized they had to be clear about the following points.

In their initial publication in The Netherlands on the structure of the current school chemistry curriculum, De Vos and Verdonk noted that the locution *the structure of the subject chemistry* does *not* refer to chemistry *as a scientific discipline*, but must be taken as a structure of chemistry *as a school subject*. The structure of chemistry as a school subject does not coincide with the structure of chemistry as a discipline (De Vos et al., 1991a, p.1), nor does the structure of chemistry as a university subject coincide with the structure of chemistry as a discipline (see 1.1.3). Secondly, they defined their general idea of structure by three features (1990, p. 20):

– a structure consists of a number of building blocks, i.e., chemical concepts;
– between these chemical concepts exist chemical relationships;
– a structure exhibits a certain demarcation from its surroundings.

De Vos et al. (1991a, p.1) added a fourth feature to this general idea of structure: structure is a "continuity in the way key concepts are mutually related", that is, the property of a structure to repeat itself in place and/or time (Van Hiele, 1986).

In a later paper, De Vos et al. (1994, p. 743) summed up these features of the idea of structure by stating that "structure in this article refers to a more or less limited entity that consists of interrelated elements". In view of the fourth feature mentioned above, this general idea of structure refers to an *enduring* entity, largely stable over time and place.

Thirdly, in their papers De Vos and Verdonk (1990, 1991) focused on the *chemical content* contained in the structure of chemistry as a school subject and on the relationships between chemical concepts. Furthermore, De Vos et al. (1994, p. 743) stressed that:

> In designing our structure we decided to limit it to the *chemical content* of the curriculum, leaving teaching strategies and theories of learning, important as they may be for actual implementation of a curriculum, aside. This allows the structure to be combined with various teaching strategies and learning theories.

As for the view on science underlying school chemistry, De Vos et al. (1994, p. 743) remarked that school chemistry:

> (…) is associated with a specific view of science and science education that seems to stem from the 19th century, that is, chemistry is taught in a strictly scientific context, one that sees science as providing descriptions, explanations and predictions of natural phenomena.

As for the general objective of the current school chemistry curriculum De Vos et al., (1994. p. 743) stated that:

> (…) students learn to explain and to predict chemical phenomena by studying the facts, theories and methods produced by predecessors.

This implies, that the intent of current school chemistry is to prepare pupils for further study in chemistry and eventually for university chemistry.

Analysis and discussion

Whereas De Vos and Verdonk were trying to describe the *specifics* of the current structure of school chemistry, my research problem became more and more at this stage one of trying to find *general* curriculum categories in terms of which I could analyze different specifications of the school chemistry curriculum including their version as a special case thereof (see Figure 1.1 below).

In the initial stages of my research, called at that time the Conceptual Structure of School Chemistry Research Project, I used the terms chemical, philosophical, and educational dimensions (Van Berkel, 1993, Van Berkel 1996). At a later stage of my research (Van Berkel etal., 2000), I decided to describe and analyze the structure of chemistry as a school subject in terms of three substructures: the substantive, philosophical and pedagogical structures, curriculum categories I derived from Schwab (1978). This reformulation of the problem of the structure of school chemistry brings in both the curriculum as a field of study and the possible relevance of curriculum theories for the domain of science (chemistry) education. In studying the science education literature I had often come across the term *structure-of-the-discipline* approach to science education (Bruner, Schwab). In particular Schwab's syntactical and substantive structures of a discipline were referred to frequently. About the same time a colleague, Fred Janssen, in his search for the fundamental principles of (school) biology, had come across a little booklet (Ford and Pugno, 1964) which contained two articles by Schwab on the structure of the natural disciplines. While studying these articles the relevance of Schwab's curriculum ideas for my research became clear. This led to my adoption of Schwab's theoretical curriculum framework in which the coordination of a substantive, syntactical, and pedagogical structure of a science curriculum holds a central place (see 1.3.2).

Briefly, the reformulation of the problem of the structure of school chemistry in Schwab's terms led to the following. The conceptual structure or chemical content to which De Vos and Verdonk had largely limited their study was treated by me as their specification of the substantive substructure of the school chemistry curriculum. The strictly scientific nineteenth century context of school chemistry, mentioned by De Vos and Verdonk (above), I interpreted as their specification of the syntactical substructure of the current school chemistry curriculum. And theories of teaching and learning, although left aside by De Vos and Verdonk (1990), I took to be a part of the pedagogical structure of the school chemistry curriculum, together with the aim of school chemistry which they *did* specify as *learning to explain and predict chemical phenomena*.

In section 1.3.2, I will elaborate on Schwab's curriculum framework which I adopted making some slight adaptations for my research purposes. It will be shown (Chapter 2), if and to what extent the *specific combination* of a substantive, philosophical, and pedagogical structure, posited initially by De Vos and Verdonk, had to be changed as a result of confronting this initial hypothesis on the current structure of school chemistry with the experiences and knowledge of chemical educators in The Netherlands and other western countries.

Figure 1.1 Sources and terms used at different stages of the research project

De Vos and Verdonk (1990, 1991)	**Van Berkel** (1993, 1996)	**Schwab** (1978)	**Van Berkel** (2000)
Specified chemical content around the concept of chemical reaction	Chemical dimension	Substantive structure	Substantive structure
19th century, positivistic view of science	Philosophical dimension	Syntactical structure	Philosophical structure
Specified aim; Teaching and learning strategies unspecified	Educational dimension	Pedagogical structure	Pedagogical structure

1.2.2 Initial hypothesis: Coherent School Chemistry

The introduction of De Vos et al. (1991) contains the following set of queries:

> Is there a hidden structure in secondary school chemistry curricula? An underlying structure that explains why chemistry school books from different countries and different periods look so remarkably similar? Most school books are based on exam/course syllabi or similar documents stating which concepts are to be taught and in which order. Do the chemical concepts and the order in which they are *normally* mentioned in these documents represent a widely accepted structure behind chemistry teaching that determines not only the contents of school books but also the teaching activities of chemistry teachers? And if such a structure exists, is it inherent to chemistry itself or is it a result of *choices* that have been made in the past for teaching purposes and that have for a long time remained unchallenged? (italics mine).

De Vos and Verdonk (1990, 1991) attempted to explicate a conceptual structure of school chemistry *as a whole* by focusing on chemical content or concepts in the tradition of the method of *content analysis* as performed by the Department of Chemical Education before on *parts or chapters* of the school chemistry curriculum (see 1.1.2). Textbooks and syllabi from various countries and periods were analyzed to yield a number of essential chemical concepts and relationships between them which add up to *fragments* of a conceptual structure. See References, the section on school chemistry textbooks and syllabi.[7]

Our aim was to formulate, by explication *and* construction, from these available fragments a *coherent* conceptual structure of school chemistry. De Vos et al. (1994, p. 743) defined “a curriculum structure as coherent if it is, in its entirety, in agreement with a specified objective.” In the process of *constructing additional relationships* between chemical concepts De Vos et al. (1994) adhered to the following design criteria:

- It must include all essential chemical concepts that appear in a standard secondary school syllabus.

[7] De Vos and Verdonk were led to their hypothesis on Coherent School Chemistry by their research of the most representative Dutch (and English) textbooks. Their perusal of a book-case full of schoolbooks from different countries such as Sweden, Poland or China did not gave them grounds to change their claims.

- It must include essential relationships already described in standard textbooks and syllabi.
- It must present secondary school chemistry as a coherent and complete unity.

List, sequence or structure

In order for a conceptual structure to be coherent it should at least be more than a mere *list* of concepts, and also more than just *a sequence* of concepts.

Mere lists of topics, sometimes even alphabetical lists, can be found in exam syllabi for school chemistry and other educational documents (Figure 1.2). For example, a Dutch exam syllabus for upper secondary chemical education (Min. O & W, 1984) begins with the topic of analysis, continuing with the concepts of atomic structure, chemical bonding, and so forth.

Figure 1.2 Alphabetical listing of chemical concepts

Dutch list[a] (Min. O & W, 1984)	**IUPAC-CTC list** (Bradley & Sane, 1993)
analytical chemical methods	acid
atomic structure	atom
chemical bonding	chemical bond, compound
energy, entropy & equilibrium	element
industrial chemistry	mixture
organic chemistry	molecule
reaction rate	oxidation
reaction mechanism	physical change
reduction/oxidation	pure substance
stereoisomerism	reaction

[a] My translation did not change the alphabetical order in the original document

The list of chemical concepts on the right side of Figure 1.2 is taken from a publication of the IUPAC-CTC project, and also follows an alphabetical order. The latter list is actually a small selection taken out of a longer "alphabetical listing of concepts" (Bradley & Sane, 1993).

Of course, such an alphabetical order is often chosen because it is convenient for purposes of presentation. However, for purposes of teaching chemistry a different kind of ordering of chemical concepts is usually given. For example, in the Dutch course syllabus (Min. O&W, 1984), an educational document in which topics and concepts are described in more detail, a *sequence of concepts* is suggested for each grade (list somewhat shortened by me):

– substance, substance property, pure substance, reaction, atom (grade 9);
– periodic system, ions, chemical equilibrium, acids and bases (grade 10);
– energy, entropy and chemical bonding (grade 11/12).

Thus, for teaching purposes a different order, that is, a particular sequence, is recommended. The authors of the same document add, however, an important qualification (see section 1.1.2):

> Although it is true that a syllabus presents the topics in an order which is as *logical* as possible, this does not mean that the topics of a course in a certain year have to be taught in that *order*. The teacher is free to

> choose an order, though often *the structure of the subject* makes it necessary to teach certain topics before others. (Min. O&W, 1984b; translation mine)

It seems to be clear, at least to the authors of this document, that the criterion of logical presentation does not prevail over teaching criteria, while the criterion of "the structure of the subject" does. It is as if the structure of the subject acts as *a kind of internal constraint* on any chosen order of teaching.

What is not clear from this or any other known official educational document (national or international), is what exactly is meant by the structure of the subject. What does this structure look like? As De Vos et al. (1994, p. 743) remarked:

> We found no textbook or other document offering a coherent description of the essential concepts of the secondary school curriculum as well as their mutual relations.

Structural features of school chemistry

Based on De Vos et al. (1994), I will give here an outline of the hypothesis on the coherent school chemistry curriculum focusing on the following structural features (Figure 1.3):

- Demarcation;
- Relationships between concepts at the macroscopic level;
- Conditions for reactions;
- Theories of structure and bonding.

Figure 1.3: A Coherent Conceptual Structure of School Chemistry

Categories	Codes	Specifications from De Vos, Van Berkel, and Verdonk (1994)
Substantive structure	[Sub]	Reaction Chemical Approach (RCA)
Chemical concepts	[CC]	chemical reaction/classes of reactions (inorg./org.) chemical/pure substance/classes of substances (inorg./org.) substance properties: chemical and physical chemical element: as material principle/indecomposable substance periodic classification of elements; taxonomy of functional groups equilibria, energy and entropy; stoichiometrie, composition, structure, valency and bonds corpuscula: molecule/atom/ion/electron/quantum
Chemical relationships	[CR]	(i) demarcation from: common sense, physics, technology, society. (ii) interconnectedness of chemical concept, e.g. chemical reaction and pure substance concept presuppose each other (iii) three coherent reaction conditions: element conservation, decrease Gibbs energy and kinetic instability (iv) restrictions for substances, e.g. limited number of elements; limited combinations, periodicity, octet rule (all based on valency) (v) theory of reaction mechanisms/theory of absolute reaction rates (macro-micro explanation) (vi) theories of structure and bonding, e.g. Dalton, Kekulé, Lewis, Bohr, Hoffmann (structural explanation/structural formulae)
Chemical techniques	[CT]	separation techniques qualitative/quantitative analysis

Figure 1.3: A Coherent Conceptual Structure of School Chemistry (continued)

		Philosophical structure [Phil]
foundations of science	[FS]	basic science tentative, fallible nature of knowledge pragmatic view on explanation/reduction cohesive explanatory framework
methodology of science	[MS]	generation and testing of tentative, revisionary hypotheses/ models description, explanation, prediction, experimentation
foundations of chemistry	[FC]	relative autonomy vis-a- vis. physics/biology; descriptive chemistry and stoichiometry physical chemistry (thermodynamics, kinetics) corpuscular theory as (a) explanatory framework and (b) background theory of representation/symbolic notation
methodology of chemistry hypotheses/ models	[MC]	generation and testing of tentative, revisionary description, explanation, prediction, Baconian (explorative) experimentation and control; making substances/synthesis of products
		Pedagogical structure [Ped]
aims	[A]	develop an understanding for the mystery of chemical change gradually learn to argue and experiment: observe, describe, relate, explain, predict, model, interpret, experiment, measure, control, make
teaching approach	[TA]	guided discovery/simulation of research using empirically, iteratively researched chemical educational structures
theory of learning	[TT]	learn via direct experience to explain surprising phenomena interactive and reflective discourse

Demarcation of school chemistry

School chemistry is usually, and more or less explicitly, demarcated by three areas: (i) everyday life; (ii) school physics; and (iii) chemical technology.

Demarcation from everyday life

The common sense ideas students use in everyday life, such as their idea of ‘stuff’ when talking about chemical materials or their ideas about the way ‘stuff’ changes, are often regarded as *preconceptions* (or even misconceptions) in comparison with the correct chemical concepts, pure chemical substance and chemical reaction, as taught in school chemistry courses.

However, extensive research in science education on preconceptions and conceptual change emphasizes that it is very hard for students to overcome, or even to see the point of changing (Klaassen, 1995), their common sense ideas, preconceptions, or intuitions (Pfundt and Duit, 1987; Fensham, 1994). The scientific concepts of the natural sciences (biology, chemistry, physics) are often experienced as *counter-intuitive* concepts, as *unnatural* concepts or as *uncommon* sense (Wolpert, 1992; Cromer, 1993; Van Berkel, 1999).

Demarcation from school physics

The authors of a British school chemistry book (Clynes and Williams, 1960) stated that:

> A chemical change is accompanied by the formation of new substances, while a physical change is not. This is the really important point.

As soon as "this really important point" is made, students subsequently learn the 'proper' or correct names for the concepts of chemical change and chemical substance, that is,

> A chemical change is often called a chemical reaction, and substances taking part in it are called reagents or reactants (Mee, 1960).

As a consequence pupils tend to see chemistry and physics as completely separate subjects even when the same terms are used such as atoms, molecules, and/or electrons.

Demarcation from technology

The concept of chemical or pure substance is a scientific one, defined at the macro level in terms of fixed properties and reproducible procedures, and at the micro level in terms of identical molecules. But in a *technological* context a pure substance can mean something quite different, namely, a particular mixture. Although purified to a certain degree, tap water or purified water does, even must, contain essential additional ingredients which comply with specific societal and technological demands associated with health and taste. Hence, students visiting a water purification plant are likely to become confused. This example illustrates that 'pure' school chemistry as a rule does not deal with chemical activities in technological or industrial contexts.

This brief discussion on the threefold demarcation of coherent school chemistry raises the question of its function in relation to the general objective of the curriculum, that is, learning how to explain and predict chemical phenomena. In Chapter 2, I will come back to the question of why school chemistry has been demarcated the way that it has.

Relationships between macroscopic concepts

Whether a change should be classified as physical or chemical depends on understanding other chemical concepts, namely, on understanding the difference between the concepts of pure substances and mixtures. This understanding, in turn, depends upon the concepts of separation and isolation of pure substances from homogeneous mixtures using methods like distillation or chromatography. That is, it depends on ascertaining a difference in properties of the substances present in reaction mixtures before and after a chemical reaction.

This brief *conceptual analysis* shows that the meaning of the concepts of chemical reaction, pure substance, separation, and their counterparts (physical change, mixture, combination) are all connected to each other. This points to a first *structural feature* of school chemistry, which I will call the *interconnectedness* of chemical concepts.

The relationships among these macroscopic concepts can be elaborated upon. The definition of the concept of chemical reaction quoted above implies or presupposes a specific chemical concept of pure substance. The reverse also holds since a pure substance is defined in terms of its chemical properties, that is, properties or dispositions to react with other substances. For example, hydrogen is identified, and therefore also often defined, in school chemistry by its property, or rather its disposition, to react explosively with oxygen (under certain conditions).

The introduction of the concept of a chemical element in the conceptual structure of school chemistry follows that of the concept of a chemical reaction and the concept of a 'chemical' or pure substance, and is defined in terms of both (De Vos et al., 1991a).

The concept of element is defined in two ways. First, it is a substance which cannot be further decomposed by chemical or (ordinary) physical means. The reference to chemical substance is given explicitly; whereas, the expression 'chemical means' implies the concept of a chemical reaction. Second, the concept of chemical element can also be defined as a 'principle', that is, as the material principle which is conserved, both qualitatively and quantitatively, during a chemical reaction. In this case there is an explicit reference to the reaction concept. However, this definition of a chemical element also presupposes the chemical substance concept. Thus, in a cycle of copper reactions starting with copper, the element copper, taken as a chemical substance, disappears to reappear at the end of the cycle. In between, the element copper, taken as a 'material principle', has not disappeared but, rather, appears to have been conserved.

Thus the demarcation of school chemistry from school physics as described in the two quotes immediately above, that is, the distinction between physical changes and chemical reactions, can thus be elaborated in a set of connected chemical concepts. The concepts of chemical reaction, chemical substance, and chemical element form the heart of this set, while the concepts of substance property, separation, and their counterparts fulfill supporting functions.

Three coherent conditions for chemical reactions

In their hypothesis on the structure of the coherent school chemistry curriculum De Vos et al. (1991a, 1994) built their conceptual structure around the concept of a chemical reaction. The outcome of their conceptual analysis is that there are three conditions which must be fulfilled before a chemical reaction will take place, namely:

- Conservation of chemical elements
- Decrease of chemical or Gibbs energy
- Kinetic instability or perceptual reaction rate

This can be illustrated by the following example, based on De Vos et al. (1994). It is not possible, apart from being rather unwise, to change diamond (C) into sand (SiO_2). This is so because the first reaction condition, conservation of chemical elements, has not been fulfilled. It has not been observed that diamond (C), for example a diamond ring, reacts with water (H_2O) by changing into sugar ($C_{12}H_{22}O_{11}$), although in this case the first reaction condition has been fulfilled. In other words, it is possible to write a balanced equation for this reaction, namely: $12\ C + 11\ H_2O \longrightarrow C_{12}H_{22}O_{11}$.

The problem with this reaction is that the second reaction condition has not been fulfilled; that is, for this reaction a net *increase* of Gibbs energy for ambient circumstances can be calculated from thermodynamic data. But from the same thermodynamic knowledge follows a surprising, and if true, possibly, lucrative result. The *reverse* reaction, the chemical synthesis of diamond (and water), starting from sugar, must show a *decrease* in Gibbs energy: $C_{12}H_{22}O_{11} \longrightarrow 12\ C + 11\ H_2O$. However, since we know that diamond does not form spontaneously, and therefore cannot be made this way, a third reaction condition must be involved, one which has not been fulfilled. This points to the kinetics of a reaction, the reaction rate, which for all practical intents and purposes should have at least a detectable value.

As De Vos and Verdonk put it, for a chemical reaction to occur, the three reaction conditions mentioned above must be fulfilled simultaneously. They noted, however, that these three reaction conditions are not treated as a *coherent whole* in the traditional school chemistry curriculum, and therefore are not understood as such. That is, the conservation of chemical elements is usually treated in a chapter early on in the textbook, the decrease of chemical or Gibbs energy later on in another chapter (and separately, if at all), and the kinetics of chemical reactions, again separately, in still another chapter of the school chemistry textbook.

In brief, *if* we want students to understand the occurrence of chemical reactions fully, *then* we need to offer them a complete and coherent picture of these three reaction conditions in the school chemistry curriculum, or at least as complete a picture as possible given the current state of chemical knowledge with regard to these conditions.

As noted above, the aim of De Vos et al. (1994) was to formulate, by explication *and* construction, from the available fragments in textbooks a *coherent* conceptual structure of school chemistry. The first two structural features of school chemistry, demarcation and interconnectedness of concepts, could be formulated by making *explicit* and/or *consistent* certain relationships *of* current school chemistry and certain relations *within* current school chemistry. The third structural feature of school chemistry, though, the coherency of the three reaction conditions described above, could only be formulated by De Vos and Verdonk by *constructing* additional chemical relationships on top of available fragments in school chemistry textbooks. De Vos et al. (1994) arrived at the conclusion that:

> (…) We were only able to design a coherent conceptual structure after accepting two conditions that appeared to be unavoidable. The first condition was that (…) the structure had to cover not only secondary school chemistry *but also general chemistry at the level of tertiary education* in order to become a coherent whole. This suggests that [current] secondary school chemistry is not a complete subject in its own right but that it is inseparably linked to further education in chemistry (…). The second condition we had to accept was that school chemistry must be taught within a strictly scientific context, in which students are being treated as if they were future chemical researchers receiving the necessary education.

As we will see in Chapter 2, this quotation can be regarded as a first expression of the idea that a *specific conceptual structure* of a school chemistry curriculum, a structure built here around the coherence of chemical reaction conditions, is *coordinated* with a *specific philosophical structure* having a strictly scientific orientation towards general chemistry at the tertiary level, and with a *specific pedagogical structure* in which students are being treated as if they were future chemical researchers receiving the necessary education.

Theories of structure and bonding

This summary of the hypothesis on the structure of the coherent school chemistry curriculum has up to now treated only macroscopic or phenomenological chemical concepts. That is, no, or only occasional, reference has been made to a corpuscular view of chemical substances and chemical reactions, though the corpuscular view has received much emphasis in many current textbooks in tertiary as well as in secondary chemical education. All the concepts dealt with so far can be interpreted or even introduced in corpuscular terms. For example:

- A chemical reaction can be seen as a rearrangement of atoms and electrons.
- The concept of chemical element can be seen as an agglomerate of one kind of atom.
- The pure substance concept can be redefined in terms of identical molecules (or lattices).

Initially, Dalton's atomic-molecular theory of matter was used for such a purpose and became fruitful in the nineteenth century, for example, for organic chemists in developing the so-called structural theory (Franklin, Kékulé, Van 't Hoff). Structural theory was succeeded in turn by Lewis's electronic view of the structure and bonding of substances and by Bohr's theory of the structure of the atom. The latter theory was the first to use quantum mechanical ideas and was the beginning of a still evolving quantum-chemical interpretation of matter (Nye, 1993).

Chemistry as a discipline appears to consist of a hierarchical structure of successive layers of micro-theories in terms of which chemical phenomena and macro-theories are explained. Macro-theories include, on the one hand, empirical generalizations such as stoichiometric relations, trends in behavior of substances, and chemical classifications up to and including the periodic system; and on the other hand, they include sophisticated mathematically formulated theories such as chemical thermodynamics.

As for school chemistry, an attempt was made by De Vos et al. (1994), again starting from fragments in school chemistry textbooks, to formulate a set of conditions that substances must fulfill in order to exist, that is to be stable; just as an attempt was made by them to formulate the conditions necessary for reactions to occur.

In the context of school chemistry most of these *substance* conditions appear to be related to the concept of valence, a concept which was defined originally in terms of combining proportions of elements and later in terms of valence electrons. An example of such a condition is Lewis's octet rule. A *complete* set of conditions which includes Pauli's exclusion principle and classical and quantum mechanical constraints on stereochemistry and stability (e.g. Woodward-Hoffmann rules), has not been found in school or university chemistry textbooks, nor for that matter in chemistry as a discipline (Atkins, 1985; Hoffmann, 1995).

This means that, *if* we want students to understand the occurrence and stability of chemical substances, *then* we need to offer them a picture as complete as possible while at the same time teaching them the present incompleteness of chemistry in this area.

Again, as in the area of reaction conditions pertaining to chemical reactions, a complete and coherent treatment of *substance* conditions – at least as complete as is scientifically possible – would only have a point for a chemistry course in which students were being treated as if they were future chemical researchers (Fensham, 1984; De Vos et al., 1994).

1.2.3 Research methods

I will now discuss the research methods used. First, I discuss the method used to test the initial hypothesis on the coherent structure of school chemistry (1.2.2) involving the probing of a selected International Forum and Dutch forum of chemical educational experts. Second, I will discuss the method used to analyze and evaluate the attempt to escape from the current school chemistry curriculum by an innovative school chemistry course called Salters' Chemistry.

Testing the hypothesis on coherent school chemistry

In order to test the hypothesis on the coherent school chemistry curriculum, we did recast the hypothesis in the form of "Ten Statements" (Figure 1.4). Statements 2-8 were formulated in terms of "the chemical concepts which we consider as important elements of the structure of the discipline [and] are given boldface in the text" (De Vos & Verdonk, 1990, p. 21).[8] Statements 1, 9, and 10, also based on De Vos & Verdonk, were formulated to address the educational dimension of the structure of school chemistry, that is, the structure of the discipline as it pertains to school chemistry (see Figure 1.1). Statement 9 was reformulated at a later stage by the researcher to address the philosophical dimension of the structure of school chemistry, too (see also section 2.2.1).

These "Ten Statements" were used as a probe to elicit comments and criticisms from the members of an International Forum (IF), and also, using a Dutch translation ("Tien Stellingen"), as a probe to elicit comments and criticisms from the members of a Dutch Forum (DF). The IF members received as background material a paper entitled "A Structure in School Chemistry" (De Vos et al., 1991), an (unpublished) English version of the original Dutch paper called "Een vakstructuur van het schoolvak scheikunde" (1990), the paper which the DF members received (see also Chapter 2).

Formation of IF and DF

In August 1991 Adri Verdonk, Wobbe de Vos, and myself attended the Eleventh International Conference of Chemical Education (ICCE), held in York (UK). As it turned out, this added considerable momentum to the establishment of the IF which I had started by way of a literature search around the work of some colleagues of De Vos and Verdonk.

Firstly, the search for colleagues who might be interested in our project was greatly facilitated by the Book of Abstracts issued by the organizers of the conference. In particular, it became much easier to locate and approach any interested colleagues present and to engage with them in personal dialogue, which usually turned out to be very informative and inspiring. I concluded this by extending each one an invitation to participate in some way in my research project.

Secondly, one of us, Wobbe de Vos, had been given a chance to present the research project in a plenary lecture entitled, "The Hidden Structure in School Chemistry and How to Escape from It". At the end of the lecture he also extended an invitation to our colleagues in chemical education present, stating that the aim of our research project was:

> to get into contact with colleagues from abroad who are interested in the concept of a structure underlying the curriculum and who are willing to read our papers, comment on our work, answer our questions, and criticize our ideas. What we need is "*an international scientific forum*" (De Vos, 1992).

[8] De chemische begripen die we als belangrijke elementen van de vakstructuur beschouwen zijn in de tekst vet gedrukt (De Vos & Verdonk, 1990, p. 21; my translation above).

Figure 1.4 Summary in Ten Statements of Coherent School Chemistry

1. 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 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.

2. 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.

3. 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*.

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 (see 4a, 4b, and 4c). 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.

   a. The first condition is element conservation. Conversion of substances A and B into C and D is impossible if C and D do not consist of the same elements as A and B, qualitatively as well as quantitatively. This explains why, for instance, mercury and sulfur cannot react to form sugar. The first condition implies that any reaction that does take place can be represented by a balanced equation.

   b. The second condition is a decrease in free energy of the reaction system (or an increase in entropy of the system and its environment) accompanying the reaction. Usually this thermodynamic condition is not formulated in these general terms in secondary school chemistry. It is, however, introduced implicitly in chapters on acids and bases, redox reactions and electrochemistry in terms of rules-of-thumb involving the equilibrium constant K or the standard reduction potential E^{o}, both of which are directly related to the change in free energy ΔG.

   c. The third condition is that a reaction is said to take place only if it occurs at a minimum reaction rate. A reaction that fulfills the first and the second conditions may still fail to occur because of its high activation energy. Explanations of why the activation energy is low or high are not given in general terms in secondary school chemistry, but in some specific cases differences or changes in reaction rate are explained.

Figure 1.4 Summary in ten statements of coherent school chemistry (continued)

5. Predictability of chemical reactions is achieved not only by means of theories but also through descriptive chemistry. Whereas theoretical chemistry sets the boundaries of the reaction phenomenon, descriptive chemistry gradually fills in the available space within these boundaries with concrete examples. Students learn individual reactions as well as groups of reactions and the circumstances under which they occur. The groups of reactions include, e.g. solubility rules of salts in inorganic chemistry and reactions of functional groups in organic chemistry.

6. Although the reaction concept is the most fundamental concept in school chemistry, it is closely linked to a specific chemical pure substance concept. This concept helps to distinguish between chemical and physical phenomena. Students have to understand that a phase transition and the formation of a mixture are not chemical reactions, even though a mixture does not have the properties of its components. As a pure substance is characterized by a set of substance properties, it is important to learn how to isolate and purify substances in order to be able to recognize them. This explains the chapter on separation techniques early in the curriculum.

7. The predictability question also applies to substances and, as in the case of reactions, it is answered along two lines: a theoretical line introducing valence as an important concept for predicting formulas, and a descriptive line dealing with substances individually and in groups. (We have not yet been able to identify a specific set of conditions that substances must fulfill in order to exist.)

8. 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.

9. 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, nor 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.

10. In its historical development the traditional structure has shown a gradual shift of emphasis from descriptive to theoretical chemistry. This is a result of the enormous growth of chemical knowledge: the theoretical approach offers a more efficient way of organizing and presenting knowledge. However, at the same time it makes chemistry more difficult to understand for many students.

It became clear from these 'piloting' meetings that our colleagues not only recognized the problems discussed by us, but also acknowledged them as important problems. The discussion then revolved on possible ways to solve these problems, especially the problem of escape.

When I left the eleventh ICCE in York the IF had about thirty potential members, mostly from Western countries, who were researchers and developers of chemical education. About half had agreed to take part in the search for, as we called it, the hidden structure in school chemistry. Since then, the number of potential IF members increased (snowballed) to about sixty members: (i) through personal contacts made at conferences on science education (NARST, Atlanta, 1993; Summer School, Driebergen, 1993); (ii) because colleagues wrote or visited us; and (iii) by references from colleagues or the literature to other potentially interested researchers and/or developers of chemical education.

Starting in June 1992 I sent letters to IF members inviting them to comment on the “Ten Statements” and to indicate whether they agreed or disagreed with each of the ten statements presented to them (Figure 1.4). Twenty-six IF members (researchers **20**, developers **5**, and teachers **1**) responded by writing comments on the statements, of about 1-5 pages length. A few were also interviewed and recorded on tape (Appendix 3: List of international respondents).

The establishment of the IF was followed by the formation of a similar group in the Netherlands called the Dutch Forum on Structures in School Chemistry (DF). In this case, educators were approached who were familiar with the different sectors of the Dutch system of provision of chemical education, such as research, development, assessment, teaching, teacher training, implementation, and administration. Also approached were persons from the fields of history and philosophy of chemistry and research chemistry who were interested in secondary chemical education.

As noted above, DF members’ understanding of our hypothesis on coherent school chemistry was probed in the same way as with IF members. Thus, starting in June 1993 letters were sent to DF members inviting them to comment on the “Tien Stellingen” (“Ten Statements”) and to indicate whether they agreed or disagreed with each of the ten statements (Figure 1.4). Twenty-two (out of thirty) DF members actually responded by writing comments of 1-5 pages length (researchers **4**, developers **5**, teachers **6**, philosophers and historians of chemistry **4**, and persons from other sectors of chemical education **3**). (See Appendix 4: List of Dutch respondents.)

Analysis

The analysis of the IF and DF responses was first performed individually by the three researchers involved at this stage: Adri Verdonk, Wobbe de Vos, and myself. We arrived largely at similar results in our analysis, and in the ensuing discussions we resolved any remaining differences or unclear points in our analysis (see further Chapter 2).

As I will explain in greater detail in Chapter 2, the “Ten Statements” are not all of the same kind. Whereas statements 2-8 address the chemical conceptual dimension or structure, statements 1, 9, and 10 make claims about the relationship between the conceptual structure of school chemistry here posited, and the philosophical or educational dimension of school chemistry, using the terms *philosophy of science* and *teaching approach*.

In the course of the analysis of the IF data on the structure of the coherent school chemistry curriculum, it proved fruitful to categorize the curriculum data in terms of:

– the substantive, philosophical, and pedagogical structures, three substructures of the curriculum based on Schwab (1964c, 1978), replacing the three dimensions of school chemistry (chemical, philosophical, educational) that were initially used (see Figure 1.1 in subsection 1.2.1);

– the curriculum levels: the intended and formal curriculum levels, and the taught and learned curriculum levels based on Goodlad (1979), further explained in subsection 1.3.1.

The method of testing a hypothesis by trying to confirm its consequences is a well-known method used in the natural and social sciences, usually called the hypothetical-deductive method (Schwab, 1964b, p. 34; Popper, 1968). A special form of this method has been described as "structural explanation" (McMullin, 1978), since it is often used in research where it is necessary to construct a model of a possible structure, say of an atom or a gene. In this case we are dealing with an hypothesis on the *structure* of the school chemistry curriculum as formulated by De Vos and Verdonk (1990,1991). Schwab (1964b, p. 35) has remarked on the character of this kind of hypothesis:

> Further, each such hypothesis represents a major act of constructive imagination. 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.

Wobbe de Vos and Adri Verdonk did just that with regard to their original solution of the problem of the structure of school chemistry. The next step was then to ascertain whether their solution to the problem of the structure of school chemistry would stand the test.

The revision of the hypothesis on the structure of the coherent school chemistry curriculum (De Vos et al., 1994), in light of the scrutiny of the collected IF data, led to the formulation of the *currently dominant* structure of the school chemistry curriculum, in brief *Dominant School Chemistry* as described in Chapter 2.

The IF response to our probe "Ten Statements" was about 50% (28 out of 60 IF members reacted); the non-response having about the same representativeness as the response.[9] After a preliminary analysis of the IF responses we stated our preliminary position in an intermittent report, called "Position Paper" (Van Berkel & De Vos, 1994). This was sent, together with an article giving our latest views on the conceptual structure of the chemistry curriculum (De Vos et al., 1994) to the IF respondents prior to the 13Th ICCE in Puerto Rico. The workshop, which Wobbe de Vos and myself held there, was attended by a few IF members who made some interesting comments. Answering the question of one IF member about the validity of our structure of school chemistry, it became clearer that we preferred to find a description of the structure of school chemistry which was valid and not so much a description based on a consensus (which would have resulted from a Delphi-type of research). As we put it there:

> The structure is valid in so far as: (i) it is confirmed by data gathered from different sources such as content analysis of current curricula/textbooks, responses of forum members and teachers, historical analysis of school chemistry; (ii) it is considered by members of the chemical education community as an relevant and effective instrument for the analysis and design of new curricula.

Initially, we set out to perform two or three (what we called at the time) Delphi-rounds, but which are now better described as a *survey*, followed by two or more rounds of

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[9] The written response from the developers in York was low, probably because the focus of the interviews with them, as well as the focus of the developers themselves, was more on the problem of escape than on the problem of structure. A couple of developers, such as Garforth and Lazonby, were interested in the problem, though.

communication with IF members "who are willing to read our papers, comment on our work, answer our questions, and criticize our ideas." (De Vos, 1992).

In the period 2000-2002, I sent my paper on *Normal Science Education and its Dangers: The Case of School Chemistry* and five reports (Van Berkel 2000a,b,c, 2001a,b, 2002) which together comprised the first draft of my thesis, to the 28 IF members. About 50% acknowledged receipt and said they looked forward with interest to read the reports and the paper. Some members said they found the paper and reports "very valuable", "useful and stimulating", or commented favorably on my argument for a "non-normal science" approach to science education. No one raised objections to the claims made in the paper or in the reports, except for a number of the developers of the Salters' Chemistry course (see further Chapters 4 and 5). The thesis which I am presenting here will be sent to the IF members (and DF members) to inform them of the results of my research into the structure of the school chemistry curriculum.

Method of curriculum evaluation

The second problem I address in this thesis, the problem of escape, can now be reformulated as follows. Is it possible when designing a new school chemistry curriculum to escape from Dominant School Chemistry, and if so, to what extent?

As will be explained in Chapter 4, in 1991 I selected the society-oriented school chemistry course, Salters' Chemistry, as a good candidate to probe for answers to this question. At the time, the Salters' Chemistry course was viewed by many researchers and developers of chemical education, including the developers of the course itself, as a *radical* departure from traditional school chemistry. Later, it was classified by Fensham (1992) and Aikenhead (1994) as a "chemistry through technology and society" course. The radical nature of the Salters' Chemistry course was formulated by the developers in a set of design criteria used in the development of their new school chemistry course (see Chapter 4).

In Chapter 5, I will systematically *analyze* one of the units of this course, called Metals, to demonstrate the extent to which the design criteria of the unit are adhered to *consistently* by developers designing the lessons of the unit Metals, and by a teacher teaching the unit Metals.

On the basis of extensive data collected on the design and teaching of the unit Metals, I will analyze the extent to which the developers and the teacher involved escaped from *Dominant School Chemistry* in relation to the design criteria they set for themselves.
The data on the development of the unit were collected via in-depth interviews with a number of developers and by a thorough content analysis of the unit Metals, performed by Wobbe de Vos and myself, in the light of the design criteria laid down by the developers. The data on the teaching and learning of the unit Metals were collected by classroom observation and audio taping the lessons of the unit, by interviewing the teacher involved, and by administering a questionnaire to the students in the class. For this method of *consistency analysis* see further section 4.1.3 and section 5.1.4.

Thus, I gathered data on the visionary, designed, interpreted, taught, and learned curricula of Salters' Chemistry (Goodlad; see 1.3.1). Drawing also on the relevant research literature, I will conclude my domain-specific evaluation of the Salters' Chemistry course with a discussion of the degree of escape of Salters' Chemistry from *Dominant School Chemistry* (see 5.5). This will be followed by an explanation of the curriculum data, including the degree of escape, in terms of my curriculum framework (for Schwab, see 1.3.2; for Goodlad, see 1.3.1).

1.3 Curriculum framework

Science curricula are a very complex field of study (Jackson, 1992). In the course of my research into the structure of school chemistry, the curriculum frameworks of Goodlad (1979), Schwab (1962), Roberts (1982), and Kuhn (1970) helped me to understand the structure of school chemistry curricula, that is, these frameworks appeared to be fruitful for describing, ordering, analyzing and explaining the curriculum data I gathered in this research.

First, following Goodlad (1979), I will distinguish, depending on the practice and study at hand, several curriculum *levels* in school chemistry curricula (1.3.1). Second, following Schwab (1962), I will subdivide the curriculum structure of school chemistry curricula in three related *substructures* (substantive, philosophical, and pedagogical) that can pertain to *each* level of school chemistry curricula (1.3.2). Thirdly, I use Roberts' (1982) concept of curriculum *emphasis* to characterize, in terms of seven different emphases for science curricula, the school chemistry curricula I am dealing with in this thesis (1.3.3). Finally, Kuhn's view on scientific training makes it possible to single out, characterize, and explain the *dominant* emphasis and structure of the current school chemistry curriculum (1.3.4).

1.3.1 Goodlad's framework of curriculum levels

Following Goodlad's "*Curriculum Inquiry, The Study of Curriculum Practice*" (1979), many researchers, performing curriculum studies, analysis, and/or evaluation, consider a curriculum as being composed of several curriculum levels. Goodlad (1979, p. 50), describes the final aim of his studies into the practice of the curriculum as follows:

> … our intent is to draw attention to the *study* of curriculum planning, processes and products, to the ongoing nature of praxis in all domains, and to the delineation, and ultimately, understanding of the phenomena.

In his article on the science curriculum in the *International Handbook of Science Education*, Van den Akker (1998, pp. 421, 422) distinguishes the following curriculum levels:

- the *ideal* curriculum: the original vision underlying a curriculum (basic philosophy, rationale or mission);
- the *formal* curriculum: the vision elaborated in a curriculum document (with either a prescribed/ obligatory or exemplary/voluntary status);
- the *perceived* curriculum; the curriculum as perceived by its users (especially teachers);
- the *operational* curriculum: the actual instructional process in the classroom, as guided by previous curriculum representations (also often referred to as the curriculum-in-action or the enacted curriculum;
- the *experiential* curriculum: the actual learning experiences of the students;
- the *attained* curriculum: the resulting learning outcomes of the students.

More or less differentiation in curriculum levels is possible (Goodlad, 1979; Van den Akker, 1998). It depends on the particular practice and study which curriculum levels are distinguished, how they are described, and which are focused on. On the other hand as we will see below, sometimes slightly different words or terms are used for essentially the same level. For example, the well-known TIMMS study (Rosier and Keeves, 1991) focuses on the intended (cp. the term *ideal* above), the implemented (cp. the term *operational* above), and attained curriculum (same as above; Van den Akker (1998).

Application of framework of curriculum levels
Applying the framework of curriculum levels makes it possible to:

– collect with the appropriate methods the relevant data at each curriculum level;
– find out the discrepancies between two curriculum levels (Goodlad, 1979, p. 64);
– determine the relationships between various curriculum levels;
– explain the curriculum data, discrepancies and relationships between curriculum levels

As we will see in this study in Chapter 2, the IF responses to the "*Ten Statements*", a summary of Coherent School Chemistry, are taken as referring to the following curriculum levels of school chemistry:

- *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)

The IF responses to our *Ten Statements* probe were analyzed and interpreted as referring mainly to the *intended* and *formal* curriculum, but sometimes also, as we will see, in relation to the *taught* and *learned*, or the realized curriculum of school chemistry.

In Chapters 4 and 5 on the evaluation of the innovative school chemistry curriculum, Salters' Chemistry, I have used the following curriculum levels and terms:

- *visionary* or *intended* curriculum: the formulation by the developers of a number of design criteria (cp. the term ideal curriculum above; Van den Akker, 1998);
- *designed* curriculum: the first operationalization of the design criteria by the developers in prototypical teaching materials;
- the *written* curriculum: the follow-up of the designed curriculum which is realized by elaborating or revising prototypical teaching materials after trials or testing in the classroom;
- *formal* curriculum: the official codification of the designed curriculum product in a syllabus by the developers in collaboration with the staff of an exam board;
- *interpreted* curriculum: the curriculum (units) as perceived by teachers (cp. the term perceived curriculum above);
- *taught* curriculum: teachers in the classroom executing the curriculum units;
- *experienced* curriculum: students in the classroom experiencing the teaching of the curriculum units (cp. the term experiential curriculum above).

The slightly different terms I have used for the curriculum levels above refer, I take it, to essentially the same curriculum levels as those described by Van den Akker. In the context of the evaluation of the *process* of the development of units in the Salters' Chemistry course, however, I was led to distinguish another curriculum level, namely, the *designed* curriculum, that is, the operationalization of the design criteria by the developers in the prototypical teaching materials during the trials of these teaching materials. This is as a rule followed up by the written curriculum, the next phase (or phases) of the designed curriculum (see Chapters 4 and 5).

An important relationship that may hold between several curriculum levels, and which, as I will show, pertains to the curriculum development process of the Salters' Chemistry course, is:

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

Curriculum levels and corresponding methods of data collection

As I will describe in detail in Chapters 4 and 5, the following methods were used for collecting data, and for analysis of these data, appropriate for the curriculum levels investigated.

For the visionary and designed curriculum were used: content analysis of relevant documents produced and interviews with the developers who envisioned and started the project. For the written curriculum were used: content analysis at the level of the lessons of a particular teaching unit produced. For the interpreted and taught curriculum were used: observation, audio-taping, and interviewing, thus collecting data on both the behavior and opinions of the teacher. For the experienced curriculum were used: observation, audio-taping, and a questionnaire, thus collecting data on both the behavior and opinions of the students.

In sum, by performing a curriculum study of the currently dominant school chemistry curriculum and a curriculum evaluation of the innovative school chemistry curriculum, Salters' Chemistry, in terms of Goodlad's framework of curriculum levels, I have collected data on the curriculum *products* as well as on the *behavior* and *opinions* of teachers and students. Also, the process of curriculum development was gauged by interviews with developers.

In Chapter 6, I will come back to the relationship between curriculum levels and the methods appropriate to study them – methods which address the realized curriculum products or the behavior (such as activities performed in the classroom) or the opinions of the actors involved.

1.3.2 Schwab's curriculum framework for the natural sciences

In my research into the structure of school chemistry I have adopted, a*nd adapted to the purposes of my research*, Schwab's framework on science curricula (1962, 1964a,b,c; Westbury and Wilkof, 1978). This means that, throughout this thesis, I will describe and analyze the school chemistry curricula I am dealing with in terms of three curriculum substructures composing a curriculum structure, namely, the *substantive* structure, the *philosophical* structure, and the *pedagogical* structure of the curriculum.

Before I describe and explain the adaptations I made in the context of my research to

Schwab's curriculum framework, I will first give a brief summary of Schwab's curriculum framework for the natural sciences, and of the concepts and terms he used.

Schwab's view on the organization of the disciplines

Schwab's *general* curriculum views originated from his work on the "problems of the *organization* of the disciplines" (Schwab, 1964b, p. 7) in the 1940s in the practical context of the development of the so-called "Three-Year Program in the Natural Sciences" (Westbury and Wilkof, 1978), a college curriculum which embodied a liberal form of science education at the University of Chicago in that period. Later on during the 1960s Schwab contributed from this background to the structure-of-the-disciplines movement (Westbury and Wilkof, 1978, p. 25) at the high school level. Schwab's view of the structure of the curriculum of the natural sciences (Schwab, 1964a) is therefore part of his overarching view of the structure and organization of the disciplines which include natural, social, and humanitarian sciences.

According to Schwab the structures of a discipline consists of two *related* components, namely the s*ubstantive structure of the discipline* and *the syntactical structure of the discipline*. These two central concepts of Schwab's curriculum framework for the natural sciences (discussed below) turned out to be relevant for my research into the structure of the school chemistry curriculum. It is important to note that Schwab discussed these two concepts in the context of science education, that is, "for purposes of instruction" (1964a, p. 47).

Substantive structures of the disciplines

Schwab (1964b, p. 12) gives the following description of the function of a substantive structure of a discipline, or conceptual structure as he calls it alternatively.

> In general, then, enquiry has its origin in a conceptual structure, often mathematical, but not necessarily so. It is this conceptual structure through which we are able to formulate a telling question. It is through the telling question that we know what data to seek and what experiment to perform to get those data. Once the data are in hand, the same conceptual structure tells us how to interpret them, what to make of them by way of knowledge. Finally the knowledge is formulated in the terms provided by the same conception.

Schwab mentions three important characteristics which substantive structures of the natural science disciplines acquired more and more in the twentieth century.

First, the substantive structures of a discipline are not one, but many. Schwab, himself a biologist, gives some specific examples from the science of biology such as the taxonomic, functional, and evolutionary substantive structures. In Chapter 2 we will come across the plural character of chemistry as a discipline. An example of a substantive structure from chemistry as a discipline is thermodynamics, a research area which focuses exclusively on macroscopic magnitudes like P, V, and T to the exclusion of microscopic models while searching for the laws of thermodynamics. Another example is in the atomic-molecular theory, a theory which focuses on submicroscopic entities such as atoms and molecules and their mechanisms, in order to explain macroscopic phenomena and relations in its terms (Vollebregt, 1998; Van Berkel, 1999).

Second, substantive structures are not only elaborated on during the course of enquiry, but also tested and, eventually, revised. Third, the scientific knowledge gained in terms of a substantive structure stems from selected abstractions or idealizations of the subject matter or referent in question and is, therefore, always partial and incomplete.

Syntactical structures of the disciplines

Schwab (1964b, p. 14;1964c, p. 11) describes "the problem the *syntactical* structure of the disciplines" as follows:

> There is, then, the problem of determining for each discipline what it does in the way of discovery and proof, what criteria it uses for measuring the quality of its data, how strictly it can apply canons of evidence, and in general, of determining the route or pathway by which the discipline moves from its raw data through a longer or shorter process of interpretation to its conclusion.

Further, Schwab (1964c, p. 10,11) emphasizes that to each of the possible, many substantive structures of a discipline there corresponds a distinctive syntactical structure of the discipline.

> If different disciplines pursue knowledge of their respective subject fields by means of different substantive structures, it follows that there may be major differences between one discipline and another in the manner and the extent to which each can verify its knowledge (…). Further, the kind of evidence, and the degree to which it is evidential, required by different researches within the natural sciences differ markedly from field to field (biology against physics, for example) and even within researches within a field.

In chemistry, for example it is the case that to the different substantive structures of thermodynamics and the atomic-molecular theory there correspond different syntactical structures in terms of "the manner and the extent to which each can verify its knowledge (…) the kind of evidence, and the degree to which it is evidential" (Schwab 1964c, p. 11).

This makes the syntactical structures of a discipline also plural, as well as specific to the domain involved. As Schwab (1964c, p. 31) puts it:

> Of greatest importance perhaps, in view of the present state of education in this regard, is that syntax effectively does away with the embarrassing divorce of "method" and "content". A syntax cannot be described except through reference to the concrete subject matter involved in concrete enquiries.

Discipline structure and pedagogical structure

As noted above Schwab discusses the problems of the structures of the disciplines, and its sub-problems: the problem the *substantive* structure of the disciplines and the problem of the *syntactical* structure of the disciplines in the context of education or pedagogy, listing and emphasizing each time the educational significances of his concepts (Schwab, 1978).

> Both of these – the conceptual and the syntactical – are different in different disciplines. The significance for education of these diverse structures lies precisely in the extent to which we want to teach what it is true and have it understood.

In a long paper titled "Education and the Structure of the Disciplines" written in 1961 but published in 1978 (Westbury and Wilkof, 1978, p. 241, 242), Schwab elaborates on the relationship between the (substantive) structure of the discipline and the *pedagogical structure* – the latter a term he used only once as heading of a subsection of this paper – as follows:

> We also have the task of learning to live with a far more complex problem – that of realizing that we will no longer be free to choose teaching methods, textbook organization, and classroom structuring on the basis of psychological and social considerations alone. Rather, we will need to face the fact that methods

> are rarely if ever neutral. On the contrary, the means we use color and modify the ends we actually achieve through them. *How* we teach will determine *what* our students learn. *If a structure of teaching and learning is alien to the structure of what we propose to teach, the outcome will inevitably be a corruption of that content. And we will know that it is* (my italics).

The structure of a discipline does not have, as such, a pedagogical structure, but it does *take on* a relationship to a pedagogical structure in the context of education, that is, in relation to teaching methods, curriculum materials, and learning. Thus, in the context of education, the substantive and syntactical structures of a discipline assume a specific relationship to the pedagogical structure of a curriculum.

Adaptations of Schwab's curriculum framework

Let me discuss now the ways in which I have adapted Schwab's views to the purpose of my research (see also Chapter 2).

First, there is my *explicit* use of the pedagogical structure in my analysis of school chemistry curricula in relation to the substantive structure and the syntactical (or philosophical, see below) structure of chemistry as a discipline as embodied in the school curriculum. In the light of the discussion immediately above, this seems to be an appropriate use of the concept of pedagogical structure in the context of education. As components of the pedagogical structure of a curriculum I have taken: the aims of teaching, teaching approach, and learning approach (see further Chapter 2).

Second, I have, mostly for practical reasons as will be explained in Chapter 2, used the concept of the *philosophical structure* of a curriculum, by adding to the methodological principles contained in the syntactical structure as defined by Schwab, fundamental principles of a discipline as used in a school curriculum (taken them out of the substantive structure, as it were; see further Chapter 2).

Consequently, I have analyzed my curriculum data from the point of view of each of these three substructures and from the point of view of the interrelationship of the these three substructures, that is, the *substantive, philosophical, and pedagogical* structures of the school chemistry curriculum.

In his later essays on *The Practical*, Schwab (1978) argues strongly for the *coordination* of four topics or common places of education. These are: the subject matter, the learner, the teacher, and what he calls the milieu. The idea of coordination entails that we should strive for *coherence* in the four common places. If we do not achieve this, it will lead to ineffective teaching or alienation of learners. To repeat Schwab (1978, p. 242):

> If a structure of teaching and learning is alien to the structure of what we propose to teach, the outcome will inevitably be a corruption of that content.

Schwab seems to use here the same idea of coordination but now in connection with the substantive, syntactical, and pedagogical structure of a curriculum. I will come back to this point in section 1.3.3 and Chapter 3 in my discussion of the work of Roberts.

So, in this thesis, I will describe, analyze, and discuss school chemistry curricula also from this point of view, that is, in my case, in terms of the *coordination of the substantive, philosophical, and pedagogical structure* of a school chemistry curricula.

I use the curriculum framework, adopted and adapted from Schwab, in this thesis mainly for analyzing school chemistry curricula as products and as a process of development, and to some extent in Chapters 3 and 6 also for the purpose of contributing

to a model for the development of school chemistry curricula.
Finally, it is to be noted that the curriculum categories discussed here – the substantive, philosophical, and pedagogical structures – can be assigned to *each* level distinguished for school chemistry curricula in section 1.3.1.

1.3.3 Roberts's concept of curriculum emphasis

Doug Roberts, a Canadian science educator, and his colleague Graham Orpwood began to develop in the late 1970s a science curriculum framework centered around the concept of curriculum emphases (Roberts & Orpwood 1978, 1979, 1980). The concept of curriculum emphases is defined by Roberts (1982, p. 245) as:

> [A] coherent set of messages to the student about science (rather than within science). Such messages constitute objectives which go beyond learning the facts, principles, laws and theories of the subject matter itself - objectives which provide an answer to the student question: "Why am I learning this?"

And the framework around the concept of curriculum emphasis should be seen as:

> [A]n analytical framework for understanding what is involved for policy makers, and for science teachers, when they shape answers to the question: What counts as science education? (Roberts, 1988, p. 27).

Thus, the "conceptual lens of curriculum emphases" (Roberts (1982, 254), as it has aptly been called, has to be considered as a framework for both analysis and development. That is, to analyze, characterize and categorize (innovative) *science* curricula and to develop, sustain, and evaluate in a systematic way a *vision* on new science curricula.

Based on historical research on science curricula in North America from 1900-1980, Roberts (1982, 1988) distinguished seven curriculum emphases for science curricula (Figure 1.5).

Figure 1.5 Seven curriculum emphases

Solid Foundation:	Stresses science as cumulative knowledge
Structure of Science:	How science functions as a discipline
Science/Technology Decisions:	The role scientific knowledge plays in decisions which are socially relevant
Scientific Skill Development:	The 'science as process' approach
Correct Explanations:	Science as reliable, valid knowledge
Personal Explanation:	Understanding one's own way of explaining events in terms of personal and cultural (including scientific) influences
Everyday Applications:	Using science to understand both technology and everyday occurrences

Application of concept of curriculum emphasis

In Chapter 3, I will describe in more detail the concept of curriculum emphasis and its functions in research and development of science curricula. This will also lead into a preliminary discussion of the conditions necessary to escape from Dominant School Chemistry.

In Chapters 4 and 5, I will use the 'conceptual lens' of curriculum emphasis to characterize the innovative school chemistry curriculum, Salters' Chemistry, as well as the currently dominant school chemistry curriculum from which it tries to escape.

Finally, in Chapter 6 I will come back to the conditions necessary to escape from Dominant School Chemistry. This will lead to recommendations to escape from Dominant School Chemistry formulated in terms of the structure of current school chemistry, and of a vision and method of development, based on the curriculum theoretical framework I develop in this thesis of which the concept of curriculum emphasis forms an important part.

1.3.4 Kuhn's views on science education

In Chapter 2, I will discuss Kuhn's views on scientific training that form an important part of his well-known theory of the dynamics of the natural sciences, in which the concepts of normal science, paradigm, and puzzle-solving occupy a central place (Kuhn, 1970a).

Kuhn's views on science education will be used, firstly, to explain the resistance encountered in reforms of school chemistry, that is, to explain the two crucial characteristics of the currently dominant school chemistry, namely, rigidity and isolation.

Secondly, the analysis, in terms of Kuhn's theory, of the empirical results of my research into the structure of school chemistry leads to a recommendation for the prevention of the tacit import of, what I call, the concept of *Normal Science Education,* at all the relevant curriculum levels concerned: the visionary, designed, formal, interpreted, taught, and experienced curriculum (see Chapter 6).

Kuhn and Popper on science education

In order to set the scene for the (following) studies of the structure of school chemistry, the problem of the structure, and the problem of escape, it seems useful to give the reader a general idea of the views of Kuhn on science education as contrasted with those of Popper and Schwab.

The views of Thomas S. Kuhn, an ex-physicist famous for his work in the history and philosophy of science, are well known, especially those views pertaining to the dynamics of science. Since the publication of his book *The Structure of Scientific Revolutions* (1962, 1970a), terms like *normal science* and *revolutionary science, paradigm* and *anomaly* have entered common usage in meta-science as well as in science circles (Horwich, 1993; Nye, 1993; Hoffmann, 1995).

According to Kuhn (1959), the characteristic problems a normal scientist has to deal with in pure or basic science are "almost always repetitions, with minor modifications, of problems that have been undertaken and partially resolved before". Kuhn (1970b) further elaborates on this:

> [A normal scientist's] 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*.

Thus, normal science is about puzzle-solving: "an enterprise which accounts for the overwhelming majority of the work done in basic science" (Kuhn, 1970b).

At an international colloquium held in London in 1965, one of the symposia was devoted to Kuhn's work. The chairman of the symposium, Sir Karl R. Popper, an ex-science teacher renowned for his work in the philosophy of the natural and social sciences, took issue with Kuhn's characterization of science. In his contribution, entitled "Normal Science and Its Dangers", Popper (1970) admitted that he had been:

> (…) only dimly aware of this distinction between normal science and revolutionary science.

However, Popper admitted, that: "what Kuhn has described does exist (…), it is a phenomenon which I dislike (because I regard it as a danger to science)". And he continued:

> 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'.

In Popper's view, training students for normal science leads to scientists who "merely want to know the facts, and who have just learned a technique". This results in an uncritical or dogmatic attitude which is "a danger to science and, indeed, to our civilization".

Thus, whereas for Kuhn (1970b): "it is precisely the abandonment of critical discourse" which characterizes mature, productive science; for Popper it is critical thinking which is essential for the growth of scientific knowledge. Please note that the marked differences between Kuhn's and Popper's philosophies of science are associated with equally different views on science education.

Schwab's view on secondary science education

As we saw in section 1.3.2, Schwab's thinking on matters of curriculum is subtle and complex. Therefore, I will now insert a rather large quotation which will make clear in what way Schwab analyzed the school science of his day.

> These three properties of scientific knowledge, its special reference, its revision, its plurality, confer on the scientific enterprise a character alien to that conceived in the nineteenth century. The latter was naively literal. Science was supposed to study a permanent, inflexible, given world. Research was taken as a matter only of seeing what was there, recording and codifying as it went. Science, therefore, was supposed to seek and find inalterable truths. The education appropriate to such a view of science was clear enough: mastery of the true facts as known by science. For such an education, the best possible material was one kind only: a clear, unequivocal, coherent organization and presentation of the known: a pure rhetoric of conclusions. For neither doubt nor ambiguity characterized what was known. A declarative rhetoric of conclusions, omitting all evidence, interpretation, doubt, and debate, sufficed. For, presumably, no interpretation was involved, no doubt existed. The conclusions of science merely presented what the scientist had seen. For such an education the proper method was equally clear: inculcation and exercise. First, the conclusions were to be learned and remembered as given. Then, in the laboratory, their subjects were to be identified and their predicates seen to be true. For this purpose precise and exact instructions told the student what to look at and what to look for. Then came exercises inviting the application of these truths. These, too, would

> be inculcative, for application of scientific truths to particular instances involved neither adaptation of truths to the instance nor to each other. Any practical, particular problem exemplified precisely the general truth of which it was an instance.
>
> *A dogmatic education, then, embodied in authoritative lecture and textbook, inflexible laboratory instructions, and exercises presenting no problems of choice and application was the education appropriate to this nineteenth-century view of science* (Schwab, 1958, p. 375-376; my italics).

Thus, there appears to be a remarkable agreement in the diagnosis or characterization of (school) science education by Kuhn, Popper, and Schwab. It is also clear from this brief review that Popper and Schwab were strongly in favor of a thorough reform of current school science education, while, as I will argue in Chapter 2, Kuhn was not.

1.4 Overview of thesis

This thesis deals with two central questions of the current school chemistry curriculum: the question of the structure of current school chemistry and the question of the escape from the traditional structure of school chemistry. These two main research questions are subdivided here in the seven subquestions listed in Figure 1.6. The first three of these questions deal with the *problem of structure*, the last four with the *problem of escape*, It is good to bear in mind, though, that these seven subquestions differ with respect to their character or status.

The questions 1 and 5 are *empirical* research questions answered by empirical means. The questions 2 and 6 are *theoretical* research questions, arising from the empirical research performed, and asking for an explanation. They are answered in terms of the curriculum theoretical framework developed in this thesis based on the work of Goodlad, Schwab, Roberts and Kuhn. The questions 3, 4 and 5 also have a *theoretical* character, albeit more tentative. In the case of question 3, the answer will lead us into a normative discussion in terms of the means and ends of science education, informed by the empirical and theoretical considerations discussed in this thesis. In the case of question 4 and 7, the answer consists of an argued elaboration of three conditions of escape, which in the latter case will lead to a discussion on recommendations for more successful attempts to escape.

Figure 1.6 Research questions

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

I will now indicate which sub-question is answered where in this thesis, using some of the key terms of the curriculum framework and the research methods introduced above.

A preliminary answer to *research question 1* has been given above (1.2.2) in the form of the initial hypothesis on the Coherent Structure of School Chemistry based on the work of De Vos and Verdonk (1990, 1994). This hypothesis, summarized in Ten

Statements, has been put to an empirical test by submitting it to both an International and a Dutch Forum on the structure of school chemistry. The comments and criticisms made by the members of these two forums – experts in chemical education: researchers, developers, teachers – led to a major revision of the initial hypothesis and to the reformulation of the structure of the current school chemistry curriculum, that is, to what I have called Dominant School Chemistry.

In Chapter 2, I will describe in further detail the research design used in the testing of the hypothesis on Coherent School Chemistry and the theoretical curriculum framework used in the analysis of the research data. I will also describe Dominant School Chemistry in the form of five revised core statements of Coherent School Chemistry.

Research question 2 is also answered in Chapter 2 by giving an explanation of the characteristics of Dominant School Chemistry in terms of Kuhn's theory of science and science education.

This leads then to a discussion of *research question 3,* that is, whether the structure of school chemistry, thus described and explained, is a desirable structure from the point of view of teaching chemistry for understanding chemical phenomena and from the point of view of teaching chemistry to future citizens.

In Chapter 3, I will reflect on the findings and conclusions of Chapter 2 in order to find a first answer to *research question 4*: "What are conditions for escape?", that is, conditions for a radical reform of the current school chemistry curriculum which would provide a relevant and meaningful chemical education to *all* students of secondary schools, whether they are potential future chemists or future citizens living in an increasingly scientific and technological world in which chemistry occupies an important place. I arrive at a preliminary formulation of three conditions for escape which revolves around the keywords *structure*, *vision*, and *method* (3.4). These conditions will be informed by the empirical research on the current structure of school Chemistry as reported in Chapter 2. They and are given in Chapter 3 a theoretical interpretation in terms of the concept of curriculum emphasis as put forward by Roberts (1988) and in terms of the concept of normal science education based on Kuhn's work (1970).

Research question 5 and research question 6 are answered in Chapter 4, respectively in Chapter 5, where I report on the extent to which an innovative, society-oriented school chemistry curriculum, Salters' Chemistry, succeeds in escaping from Dominant School Chemistry. In a research design which combines document analysis, interviews, and classroom observation of the taught and experienced lesson materials, it becomes visible to what extent the visionary, designed, interpreted, taught, and experienced curricula of Salters' Chemistry deviates from the traditional concept-oriented school chemistry curriculum. In Chapter 6, I will try to answer *research question 7* by reflecting on the empirical findings and conclusions of Chapters 4 and 5 in combination with the findings and conclusions of Chapter 2. I will also return to the preliminary conditions for escape as put forward in Chapter 3. This will result in a further elaboration of these conditions for escape, and to a number of recommendations for escaping from Dominant School Chemistry taken as a form of Normal Chemistry Education.