Summary

In this thesis I have addressed two main problems of the current school chemistry curriculum. The first problem is the *problem of structure*: What is the structure of the chemical concepts and chemical relationships present in school chemistry textbooks? The second problem is *the problem of escape*: Why do reforms of the current school chemistry curriculum lead to only marginal changes? Attempts to escape are more likely to succeed if one knows what to escape. This raises the question whether the structure of the current school chemistry curriculum is an asset or an obstacle for reforming school chemistry. The solution of the problem of escape thus bears on the solution of the problem of structure.

The first condition for realising a more successful reform in chemistry education is to understand the structure of the current school chemistry curriculum. The second condition concerns the development of a coherent vision on secondary chemistry education, that is, on where to escape to, and the third condition concerns a systematic method about how to escape from the currently dominant school chemistry curriculum. In this thesis I have answered the seven research questions listed below, dealing with the problem of structure (1-3), and the problem of escape (4-7).

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?

In Chapter 1, Problems of current school chemistry, a preliminary answer has been given to the first question in the form of an initial hypothesis on the Coherent Structure of the School Chemistry Curriculum. By analysing school chemistry textbooks and syllabi from the point of view of *learning to explain and predict chemical phenomena* we arrived at a reaction-chemical structure of the current school chemistry curriculum with the following structural features:

- demarcation of everyday life, school physics and chemical technology
- relationships between macroscopic concepts with the concepts of chemical reaction, chemical substance, and chemical element at the heart of this macroscopic substructure

- three conditions for reactions
- – conservation of chemical elements
- – decrease of chemical or Gibbs energy
- – kinetic instability
- theories of structure and bonding.

The reaction-chemical view on Coherent School Chemistry was summarized in Ten Statements and submitted it to an International Forum (IF) and a Dutch Forum (DF) of chemical educators, developers, and researchers, for comments and criticisms.

The curriculum theoretical framework developed in this thesis consists of the substantive, philosophical and pedagogical structure (based on Schwab) which in a coherent combination make up a curriculum structure, which pertains to a number of curriculum levels (based on Goodlad). These substructures and levels apply to the curricula of any discipline not just to the curricula of the natural sciences (formal part of the theoretical framework). Both the concept of curriculum emphasis, as elaborated by Roberts and the concept of Normal Science Education as developed in this thesis (based on Kuhn) do apply to, or are specific to the domain of the natural sciences (material part of the curriculum framework). The curriculum framework appeared to be fruitful for describing, analysing and explaining the curriculum data in this research.

Kuhn's view on scientific training as puzzle-solving within the paradigm of normal science made it possible to single out, characterise, and explain the *dominant* emphasis and structure of the current school chemistry curriculum. This led to the formulation of the concept of Normal Science Education, more particularly for chemical education to Normal Chemistry Education.

Following Goodlad several curriculum *levels* in school chemistry curricula were distinguished:

- *visionary* or *intended curriculum*: the formulation by the developers of a number of design criteria
- *designed curriculum*: the operationalization of the design criteria by the developers in teaching materials
- *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
- *taught curriculum*: teachers in the classroom executing the curriculum units
- *experienced curriculum*: students in the classroom experiencing the teaching of the curriculum units.

Lastly, Roberts' concept of *curriculum emphasis* is used in order to characterise the school chemistry curricula I am dealing with in this thesis. Roberts distinguished seven types of emphases for science curricula:

- *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.

In Chapter 2, **Normal Science Education and its dangers: The case of school chemistry,** I describe first the research design and method used in the testing of the hypothesis on Coherent School Chemistry and the theoretical curriculum framework used in the analysis of the research data. The IF and DF responses are analysed in terms of a this framework in which the curriculum structure of science curricula is subdivided in the substantive, philosophical, and pedagogical substructures. 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 claims, and to the concept of Dominant School Chemistry. Contrary to what we assumed, current school chemistry is not about learning to explain and predict chemical phenomena in terms of a reaction-chemical approach. Instead, all current school chemistry curricula belonging to the dominant version:

– are being taught and learned as *propositions and algorithms* to students seen as future chemists.
– have a *corpuscular theoretical* focus on chemical substances and their properties.
– deal with explanations and systematisation of chemical information largely in terms of *corpuscular theory*.
– make a distinction between a level of *phenomena* and a level of *corpuscula*. The introduction of corpuscular theory in books and classroom is not consistent nor accurate, and hence not effective.

The first research question was: What is the structure of the current school chemistry curriculum? The IF and DF survey led us to the answer that all current school chemistry curricula have a dominant substantive structure, based on *corpuscular theory*, which is *rigidly* combined with a specific philosophical structure, that is, *educational positivism*, and a specific pedagogical structure, that is, *initiatory and preparatory training* of future chemists.

Further, the structure of Dominant School Chemistry as a whole suffers from a sevenfold *isolation*: from common sense, everyday life and society, history and philosophy of science, technology, school physics, and from chemical research.

The second research question was: Why is this structure the way it is? This question is answered by giving an explanation of the main characteristics of Dominant School Chemistry, rigidity and isolation, in terms of Kuhn’s theory of science and science education. This leads to the concept of Normal Chemistry Education. As I argue in Chapter 2, a radical reform, or an escape from Dominant School Chemistry is only possible through a *co-ordinated replacement* of the currently rigid combination of a substantive, philosophical, and pedagogical structure of school chemistry.

This leads then to a discussion of the third research question, Is this structure a desirable structure?, 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.

Dominant School Chemistry fails to realise its own set goal, that is, teaching and learning all pupils the understanding, prediction and explanation of chemical phenomena. What it does teach and learn instead is a set of propositions and algorithms. Neither the effectiveness of Dominant School Chemistry nor its superiority over more critical forms of secondary chemistry education has been conclusively demonstrated. The conclusion, therefore, is that it is not possible to justify, *by* argument or experiment, an Normal Chemistry Education based chemistry course that is suitable for all pupils. At most this might be realized for the small minority of students who will study chemistry at a further level, some of whom might become chemists. Normal Chemistry Education cannot be regarded as a form of chemistry education appropriate for all pupils, exactly because it consists of a dogmatic, domain-specific training for future chemists. Therefore, at the secondary level, the initiation into normal chemistry should be largely replaced by an education in or through fluid, critical or creative chemistry, together with an education in or about the relations between chemistry, technology, and society.

In Chapter 3, Conditions to escape from and to escape to, I discuss the conditions for escape from the currently dominant school chemistry curriculum (research question 4).

A brief review of some attempts to reform the dominant school science curriculum, in terms of the concept of Normal Science Education, gives an idea of the many difficulties involved when trying to realise a desirable reform in science education. These manifest themselves at the various curriculum levels involved. For example, researchers have pointed to factors at the level of the:

- *visionary curriculum*: misplaced goals, lack of involvement teachers in policy making, inadequate views of scientific method;
- *designed curriculum*: a lack of consistency between vision project and teaching materials, text do not reflect vision, exercises do not reflect idea of enquiry, lack of involvement of teachers in developing process;
- *formal curriculum*: professionalization of school science;
- *interpreted curriculum*: lack of consistency vision and in-service training, lack of 'practical on-site experience' for teachers;
- *taught curriculum*: resistance of teachers and lack of consistency between vision and views of teachers.

Analysing why it is so difficult to escape from Dominant School Chemistry, given its rigid and isolated character, leads to an initial formulation of the *first condition* for escape which has to do with the analysis of the structure of the currently dominant school chemistry curriculum. In Chapter 6, I come back to the first condition of escape, which we have to take into account while planning to reform current school chemistry. In Chapters 4 and 5 I argue, based on the analysis of the process of development of the Salters Chemistry curriculum, that condition one is often neglected.

In Chapter 3, the curriculum framework of Roberts, centered around the conceptual lens of curriculum emphases, is discussed in order to give a first charac*terization of the second condition of escape,* the development of a vision, and the *third condition* of escape, the method of development.

Roberts defined the concept of curriculum emphases as a coherent set of messages to the students about science, answering the students' question: Why he or she had to learn this? The concept of curriculum emphasis can be used for both analytical and developmental purposes:

– as a theoretical instrument to describe, analyze and explain the *vision* and structure of past and current science curricula, documents, and textbooks
– as a practical instrument to deliberate, choose, develop, sustain, and evaluate in a structured way a *vision* on new science curricula.

The discussion of the first, theoretical function, and more in particular of the second, practical function lead to important insights with regard to the second and third condition of escape, the development of a vision and the method of development. These conditions are further discussed and elaborated upon in Chapter 6.

In Chapter 4, Salters' Chemistry: An analysis of its process of development, I focus on research question 5: To what extent does the Salters' Chemistry curriculum escape from Dominant School Chemistry, as it existed in England at the time? I focus on the development of units of the Salters Chemistry course as a whole in Chapter 4, while focus on the lessons of the unit Metals of the Salters' Science course in Chapter 5.

The process of the Salters' Chemistry developmental project is analyzed in terms of the curriculum theoretical framework: the substantive, philosophical, and pedagogical structure as pertaining to the curriculum levels involved, the concept of curriculum emphasis and the concept of Normal Chemistry Education. The Salters' Chemistry course combines a curriculum emphasis on *Everyday Applications*, using chemical knowledge to understand everyday occurrences, a curriculum emphasis on *Science, Technology, Decisions*, stressing the role of chemical knowledge in decisions with social relevance and a curriculum emphasis on *Science Skill Development.* The course is further categorized as a "Science through STS" curriculum (Aikenhead) in terms of the ratio between STS and Pure Science content.

The developers of the Salters' Chemistry course use *a design criteria approach*, that is, general criteria providing direction but not limiting the outcomes at the level of detail. Initially, three design criteria: *no preconceptions, relevance* and *context-led development of concept* were formulated, while in the process two other design criteria: *variety-cum-activity* and *flexibility* were added. A consistency analysis on relevant curriculum documents and transcriptions of interviews with developers, is performed in order to see whether and to what extent the design criteria are consistently realized in the development of Salters' Chemistry course. This curriculum analysis concerns the visionary, designed, written, formal and experienced curriculum level. The analysis showed that design criterion 1, *No preconception*s has gradually been replaced by a guiding conception, internally by what the developers perceived to be *the structure of chemistry*, and externally by the GCSE exam demands.

The application of design criterion 2, *Relevance,* in the transformation of the visionary to the formal curriculum led to a choice of relevant contexts but it was constrained more and more, both internally by what the developers perceived to be *the structure of chemistry* and externally by GCSE requirements of content or process. This has given rise to tensions in the course between the original context oriented approach and the traditional emphases on chemical content and skills and science processes.

The application of design criterion 3, *Context-led development of chemical concepts*, led to an increased emphasis on chemical concepts and their sequential and / or logical development. Important too was a greater emphasis on scientific processes over and above the initial emphasis on chemical techniques and associated practical skills.

Further, by categorizing the visionary, designed, written and formal curriculum of the Salters' Chemistry course in terms of the substantive, philosophical, and pedagogical substructures, I identified the changes in the components of these substructures. The main changes in the process of transformation of one curriculum level to another are the following.

The *substantive structure* of the Salters' Chemistry GCSE course initially contained, compared to a traditional O-level course, a somewhat *reduced* load of chemical concepts and relationships, while retaining about the same set of standard chemical techniques. The concepts and relationships were put in a teaching sequence partly informed by, and consistent with, the structure of chemistry as the developers perceived it, not in a top-down hierarchy, but bottom-up led by contexts and activities, and starting at the observational and manipulative level via low-level generalizations moving to more abstract relationships and theories. The developers did not escape *fully* from substantive structure of Dominant School Chemistry, but only to a certain degree. The ruling of an exam committee brought back the chemical concepts initially excluded by the developers.

The *philosophical structure* of Salters' Chemistry moved away from theoretical chemistry towards applied chemistry emphasizing relevance and use. The developers did not escape *fully* from traditional philosophical structure, but they did use applications of chemical knowledge to familiar phenomena and materials, so not using just 'academic' applications as had been customary in traditional O-level chemistry.

The *pedagogical structure* of the Salters' Chemistry GCSE course initially focused on the needs of the majority of students, the less and moderately able, but at a later stage had to consider the needs of the most able students as well, in particular by incorporating explanation using abstract chemical concepts. And at a later stage the original aim of chemical awareness for the future citizen had to compete with the traditional aim of preparing future A-level candidates, by an exam course for the full range of grades. The context-led teaching approach evolved into, what the developers called, a *context and activity led* teaching approach using a varied set of learning activities including customary laboratory experiments. The developers did escape from the pedagogical structure of Dominant School Chemistry by devising a context-led teaching sequence which differed from the traditional theory-based sequence.

In Chapter 5, Metals: A Chemical unit of the Salters' Science curriculum, I answer research question 5: To what extent does the Salters' Chemistry curriculum escape from Dominant School Chemistry? The analysis concerns the curriculum unit Metals as interpreted and taught by a teacher, and experienced and learned by students in the classroom.

A detailed consistency analysis was performed on a unit of the written curriculum as operationalized in the eight lessons of the unit Metals of the Salters' Science course. Following Aikenhead, the Salters' Science course is categorized as a "Science through STS" curriculum in terms of the ratio between STS and Pure Science content which I use as a measure of the degree of escape of the unit Metals from Dominant School Chemistry. This way we can follow the subsequent transformations of the written, interpreted, and taught curriculum levels, to compare these with the formal curriculum level of the unit Metals, and with the currently dominant school chemistry curriculum. The consistency analysis made it also possible to investigate more precisely to what extent the developers were able to fulfil in a *consistent* way the adopted design criteria. The analysis focused on the two central Salters' design criteria of *relevance* and *context- led development of concepts*, while trying to answer the following two subquestions:

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

The consistency analysis of the lessons of the unit Metals showed, firstly, that more Pure Chemistry (PC) content and less Chemistry-Technology-Society (CTS) content was developed than was needed, that is, than was consistent with design criteria 2 and 3. The CTS/PC ratio, taken as a measure of the degree of escape, decreased substantially going from the formal to the written curriculum. In doing so, the developers went against design criterion 1, *no preconceptions*, making it thereby very difficult to uphold the central design criteria 2 and 3. While designing the lessons of the unit Metals, the developers *retained* a number of PC concepts traditionally part of dominant school chemistry, that is, concepts developed though not needed to make sense of the selected contexts. Consequently, some lessons of Metals (1989) suffer from a tension between the PC content developed and the CTS content needed.

In the transformation from the written to the interpreted curriculum, it turned out that the teacher added some PC content although not needed, and deleted some CTS content, although needed to make sense of the contexts selected, decreasing thereby again the CTS/PC ratio. Design criterion two, *relevance*, and design criterion three, *context-led development of concepts* were not consistently upheld. Subsequently, the teacher added during his teaching again some PC content not needed, while he did not teach some CTS content that was needed to make sense of relevant contexts. This is inconsistent with design criteria two and three, and the CTS/PC ratio therefore decreases further in the transformation from the interpreted curriculum to the taught curriculum. Thus, here we have for developers and teachers specific illustrations of what Goodlad called "slippage" from one curriculum level to another.

In this process of *slippage*, the tension between the PC content developed and the CTS content steadily increases in the case of Metals. This tension is connected with a corresponding tension in the philosophical structure: between the cognitive process of explanation on the one hand and the process of application on the other hand. It is also related to a tension in the pedagogical structure: between the aim to train future A-level chemistry students and the aim to educate future citizens in chemical literacy. A successful escape from Dominant School Chemistry requires, therefore, a *co-ordinate replacement* of the currently rigid combination of substantive, philosophical, and pedagogical structure of school chemistry. This appeared to be difficult task to perform. The concept of normal chemistry education based on Kuhn's functional theory gives another reason why is it so hard to escape. It is predominantly the tension or dual emphasis in the pedagogical structure which determines the dual emphasis in the philosophical structure and the PC-CTS tension in the content of the substantive structure. In brief, function determines structure of the curriculum.

In Chapter 6, Beyond current school chemistry: Perspectives on chemistry at school, the focus is on research question 7, How can attempts to escape from the structure of the currently dominant school chemistry curriculum be improved?

Based on my research findings, its implications and explanations recommendations are formulated in order to reform the currently dominant school chemistry curriculum. This amounts to a strategy to escape from Dominant School Chemistry in terms of a framework for analysis, development, and developmental research. This is a further elaboration of the three conditions for escape as introduced in Chapter 3, thereby answering also research question 4, What are the conditions for escape? I have summarized the three conditions for escape as follows:

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

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

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

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

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

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

The recommendations about curriculum analysis, development and research can briefly be put as follows: articulate a new vision, prevent importing the old vision, and test and control the coupled processes of escaping from and escaping to by the methods of developmental research.

Secondly, I gave some suggestions for further educational research in the following areas. The research focus of my thesis being on curriculum continuity and not on curriculum diversity, it would be worthwhile to undertake, on the basis of the curriculum framework I developed, a more detailed history of Dutch school chemistry. Such a curriculum history would describe in more detail origin, curriculum changes and mechanisms of change.

Expertise from the disciplines of the history and philosophy of chemistry could support the chemical educational analysis of specific substantive and philosophical structures as contained in alternative or newly proposed curriculum emphases. For example, to elucidate further the reaction-chemical curriculum emphasis discussed in Chapter 2, or to explicate *the logic of* chemical practices such as quality control, chemical inquiry, chemical modeling and chemical technological design.

While designing and teaching units of a new school chemistry curriculum, it turned out to be difficult for both developers and teachers to escape from Dominant School Chemistry. The three conditions for escape, as applied to teachers as developers, are formulated as follows:

- *Condition 1: In order to escape, teachers have to know what to escape from.*
- *Condition 2: In order to escape, teachers have to know what to escape to.*
- *Condition 3: In order to escape, teachers have to know how to escape.*

Fulfilling these conditions will lead to the following recommendations for further research:

- Develop and research a teacher training course on the curriculum emphases of traditional, alternative and potentially possible school chemistry curricula.
- Develop and research a teacher training course, including an effective teaching strategy, which aims to empower teachers with competencies to select, envision, design, interpret and teach newly devised curriculum units.
- Perform a developmental research project on "Training Teachers as Developers" which accompanies a large scale curriculum developmental project.

Also, I discuss the *problems of consistency* of a context-led development of a chemical *unit* and, the *problems of coherency* of a context-led development of a chemical *course*. I have outlined some practical and theoretical ways to approach these problems of unit consistency and curriculum coherency.

In this thesis I have tried to show the *usefulness* of the curriculum framework as an instrument of analysis in the following ways:

- By uncovering the existence of the currently dominant school chemistry curriculum and its properties of rigidity and isolation.
- By explaining the dominance, rigidity and isolation of Dominant School Chemistry in terms of the concept of Normal Science Education.
- By using Dominant School Chemistry, taken as a form of Normal Chemistry Education, as a baseline for comparison with the curriculum levels of an innovative developmental project.

- By detailing the curriculum phenomenon of slippage, with regard to this baseline, in the developmental and teaching processes of an innovative developmental science project.

Finally, I have tried to argue for the *fruitfulness* of the curriculum framework developed in this thesis as an instrument for development and developmental research in the following ways:

- By formulating three conditions of escape which would, if adopted by a large scale innovative developmental chemistry project, lead to more successful attempts to escape from Dominant School Chemistry, taken as a form of Normal Chemistry Education.
- By applying the three conditions of escape to teachers in order to develop and research a teacher training course which aims to enhance the competence of teachers as developers.
- By pointing to the curriculum problems of consistency of a context-led development of a chemical unit and the problems of coherency of a context-led development of a chemical course.
- By pointing to the relevance of the field of the history and philosophy of chemistry for the analysis of the logic's of authentic chemical practices, other than the logic of puzzle-solving, the traditional practice of Normal Science and Normal Science Education.