Summary

This thesis reports on a research aimed at identifying features that make a design of chemical education for ‘learning to inquire’ in upper secondary school effective. The thesis consists of nine chapters.

Introduction (Chapter 1)
The central research question is:

What features make a design of chemical education for ‘learning to inquire’ in upper secondary school effective?

Inquiry skills are part of the upper secondary school science examination programmes in the Netherlands. Nationally as well as internationally curriculum developers and educational researchers agree on the importance of students acquiring inquiry skills.

Teachers have as yet little grip on the learning aims of ‘learning to inquire’. They do not quite know which tasks, instruction and coaching are effective in the learning process of ‘learning to inquire’ nor what the assessment needs to focus on. Science educational research has not yet yielded an adequate didactical approach for ‘learning to inquire’ in chemistry teaching. The present research attempts to fill this gap. In order to involve educational practice effectively in the research the researcher established a teacher network with 5 chemistry teachers in different schools.

Theoretical perspective and research design (Chapter 2)
The researcher has opted for developmental research consisting of an exploratory phase, a design focused phase, a phase of testing in the educational practice and a phase of identifying the features that make an educational design for ‘learning to inquire’ effective.

On the basis of the theoretical exploration doing inquiry is considered as a cyclic, iterative, social and personal activity, to which not one specific method or succession of actions applies. Furthermore a model for designing chemical education for ‘learning to inquire’ has been constructed. In this model students are ‘researchers’ in a simulated ‘research community’. They work in teams on the same inquiry problem and go through an inquiry learning process, in which they themselves ask inquiry questions, formulate and carry out their inquiry plan as well as evaluate their inquiry results in a critical discourse with ‘fellow researchers’. In this process of inquiring and learning students will use ‘wanting’, ‘knowing’ and ‘ability’ to acquire ‘new’ knowledge and abilities. The insight that ‘learning to inquire’ should take place in a ‘research community’ is supported by the social constructivist point of view. This point of view also implies that the educational design should meet what students ‘want’ and already ‘know’ and ‘are able to’. As for ‘wanting’, further literature research concerning students' ‘wanting’, ‘knowing’ and ‘ability’ when they inquire, has only yielded insights on student motivation with regard to learning in general. As for the components ‘knowing’ and ‘ability’ the procedural and conceptual knowledge in science (PACKS) model seems to be a suitable framework to concretise these components in a design of chemical education for ‘learning to inquire’. According to this model ‘knowing’ and ‘ability’ when doing inquiry mean that students need to understand aim and nature of the
research task as well as relevant subject knowledge and empirical evidence in order to adequately conduct the task.

A design strategy has been chosen in which an interaction between theory and practice takes place. This choice has been given shape by setting up a network consisting of the researcher and 5 chemistry teachers. It was assumed that working together in the network would lead to a design for ‘learning to inquire’ that is feasible in the chemical education practice and effectively makes students ‘learn to inquire’.

The theoretical exploration yielded provisional guidelines to designing chemical education for ‘learning to inquire’.

**Starting situation of the teachers and the first educational design (Chapter 3)**

The *exploratory* research on the actual practice of teaching ‘inquiry skills’ to upper secondary students has shown that the teachers have experience with hardly anything but prescriptive practical work that aims at verification of theory and acquirement of experimental skills. For this reason the *design-focused* phase of the research has been moved ahead: a research on designing, implementing, evaluating and adjusting a first educational design for ‘learning to inquire’. In network meetings eight inquiry tasks have been designed. The implementation of three of these tasks in Form IV classes has been observed and then discussed in the network meetings. Of all teacher meetings reports have been made, analysed and interpreted; the results have been presented to the teachers for verification. It has been found that the approach of the teachers in designing inquiry tasks can be characterized as follows:

- the teachers first want to determine in mutual agreement the requirements for the inquiry tasks;
- they think that the learning process in which the students ‘learn to inquire’ can best take place by having them do an actual inquiry;
- they think that students should have their freedom and responsibility in planning and conducting inquiry tasks;
- they connect inquiry tasks to topics in the textbook;
- they prefer small scale changes in their practice of teaching;
- they consider guidance and quality control of the learning process of great importance.

With regard to the implementation of the inquiry tasks in class the research has established that the teachers first focus on the practical feasibility, next on the coaching strategy and finally on the key issue: the quality of inquiring.

The exploratory phase of the research yields the following requirements for the second educational design:

a. the educational design should make the concept of a ‘research community’ of students operational;

b. accuracy, reliability and validity (abbreviated as: a, r and v) should hold an important position in the design;

c. with regard to subject knowledge and empirical evidence the learning aims should be specified and made explicit;

d. the design should contribute to the teachers’ insight into the meaning of a, r and v in empirical evidence as well as into the didactical aspects;

e. strategy and content of the guidance of the students with regard to the aim of the inquiry task, the relevant subject knowledge and empirical evidence should be laid down;
f. the design should determine with regard to each of the planned student activities whether differentiation is necessary.

**Starting situation of the students in ‘learning to inquire’ (Chapter 4)**

In the *exploratory* research on the starting situation 148 students from 7 different Form IV classes have independently, in pairs or threesomes, conducted an inquiry task (‘mineral water’ and ‘desiccants’). In each class, the discourse on designing and conducting their work plan of one pair of students has been audio taped. These pairs have also been observed. During the implementation of their work plan 47 students have been interviewed concerning their motivation about doing an inquiry. Furthermore the students’ work plans and reports have been collected in order to get insight into their understanding of the aim of the inquiry, the relevant subject knowledge and empirical evidence, i.e. the aforementioned three domains of understanding from the PACKS-model. The students appear to have difficulty fathoming the aim of the inquiry, identifying the relevant variables, formulating an adequate inquiry method and adjusting an inadequate method. Moreover students have little knowledge of accuracy, reliability and validity in an inquiry.

The motivation of students to do inquiry is influenced by:
- the freedom of action they are allowed in an inquiry;
- their understanding of what they are doing;
- whether they learn ‘something new’;
- variation of doing inquiry with other activities in chemistry lessons.

The research has resulted in additional requirements for the educational design. The design should give students the opportunity:

**The second educational design for ‘learning to inquire’ (Chapter 5)**

In the *design-focused phase* of this research the second educational design has been formulated on the basis of the provisional guidelines that are the result of the theoretical exploration, and the requirements a. through k. mentioned above. This design contains the learning teaching strategy, the planned student and teacher activities, and the learning teaching materials.

The designed teaching learning strategy includes the following phases:

1. introduction to chemical research and the inquiry problem, including motivation;
2. introduction to and acquisition of chemical knowledge, including motivation;
3. introduction to and acquisition of experimental skills, including motivation;
4. introduction to and acquisition of the concepts accuracy (*a*), reliability (*r*) and validity (*v*), including motivation;
5. application of chemical knowledge and knowledge of *a*, *r* and *v*, including motivation;
6. application of experimental skills and knowledge of *a* and *r*, including motivation;
7. reflection on chemical knowledge, knowledge of $a$, $r$ and $v$ and experimental skills, including motivation.

The learning activities planned in the design and incorporated in a workbook concern an inquiry into ‘Diffusion: moving particles’. They include that students individually:
- read on chemistry research in general;
- think of examples related to the subject content;
- predict, observe and explain a demonstration experiment;

and as a team:
- conduct a guide experiment;
- judge an exemplary research on accuracy, reliability and validity;
- formulate an inquiry question;
- draw up and conduct an inquiry plan;
- write an inquiry report submitting it for publication;
- discuss the inquiry results with another team in an Internet symposium;
- rewrite the report into an article, submitting it again for publication and competing for the inquiry award.

The planned teacher activities are geared on the student activities and laid down in a teaching scenario.

The learning teaching materials consist of the student workbook, the teaching scenario and the website with the Internet symposium.

**The feasibility of the second educational design (Chapter 6)**

In the *phase of testing* the educational design of ‘diffusion’ in practice, in 2002, the six planned lessons have been observed in five Form V classes. The activities of the 5 teachers and 3 groups of students (N=31) have been audio taped. The teachers have been interviewed at the end of each lesson. The students rated both the activities they conducted themselves and the activities conducted by the teachers. The worksheets filled in by the students have been collected. The teachers have filled in a questionnaire concerning the inquiry project. Printouts have been made of the team reports, the articles and the website discussion.

The analysis and interpretation of the various data show that the students as well as the teachers have for the most part implemented the activities planned in the design as intended. For two activities student participation and application are less than the set standard. The Internet symposium and the rewriting of the inquiry report are just below, respectively far below the participation standard of 90%. The average ratings that the students attribute to their own activities and the teacher’s activities for being motivating, interesting and of learning value, in all cases exceed the set standard of 6.5. On this basis the conclusion is that the students have both become and stayed involved in the inquiry project. The appreciations of the teachers also prove that the educational design has been implemented as intended. All this has made it significant to further analyse the students’ learning results and connect them with features of the educational design.

**The learning results in the second educational design (Chapter 7)**

To determine the contribution of the educational design to the students’ (N=80) learning results the discussions among 3 groups of students in each class have been audio taped. At the end of each lesson the students have written down what they themselves saw as the learning aims of that lesson. The worksheets of the students have been collected. The students who participated in the inquiry project as well as
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a control group (N=16) have taken a pre-test and post-test on ‘accurate and reliable experimenting’. The team reports, the discussion on the Internet and the team articles (N=34) have been judged for quality.
For all lessons, except the third, the congruence between the planned learning aims and what the students learned according to themselves exceeds the set standard (80%).
With regard to the contribution of the planned activities in the educational design to the students’ learning results it is established that in seven of the eight activities the set standard (75% of the students) has been achieved. The activity in which the set standard has not been met concerns the quality of the team articles. In the end, 63% of the students have written an article of sufficient quality. The students have difficulties especially with the following constituent activities: to formulate unambiguous, relevant and concrete inquiry questions, to convert data into a correct graph and to apply the concept of reliability. Their answers in the post-test on ‘accurate and reliable experimenting’ show that by performing the planned activities from the educational design students have learned something about accuracy and reliability in a research. They have improved their average score in the post-test, whereas the control group who did not carry out the activities from the design, does not show a significant difference with the pre-test in their average score.

Evaluation of the second educational design as a whole (Chapter 8)
The evaluation of the second educational design for ‘learning to inquire’ gives cause only to minor adjustments of the learning teaching strategy, the planned student and teacher activities and the learning teaching materials.
With regard to the learning teaching strategy the seven characteristic phases do not need supplementation. In general all phases have worked out effectively. For the planned functions (motivation, orientation, acquisition, application and reflection) of the learning process only a few parts from the application phase have proven to be less effective. These concern the students’ application of subject knowledge as well as their application of knowledge of reliability of measurements and the handling of measured data. The reflection phase is effective enough concerning the subject knowledge – all students show that they know and are able to apply the subject knowledge in the inquiry problem – but insufficiently effective as regards knowledge on reliability of measurements and the handling of measured data.
With regard to the learning and teaching materials suggestions for improvement are made for the following activities: judging the reliability in the exemplary research, formulating inquiry questions, graphically representing the measured data and having a critical discourse in the Internet symposium.

The educational design in theoretical perspective (Chapter 9)
In the final and identifying phase of the research, on the basis of the evaluation it has been established that the second educational design for ‘learning to inquire’ will work in practice, i.e. it is feasible and on implementation it will yield to a large extent the intended learning results. Reflecting these outcomes against the model of designing chemical education for ‘learning to inquire’ leads to a fine-tuning of the model.
The conclusion is that an effective design of chemical education for ‘learning to inquire’ is to a considerable extent determined by the high level of authenticity of the students’ inquiry actions. Through a full inquiry process they work on a ‘real’
problem within a simulated research community. In order to realize this, students need to be familiarized with doing inquiry by introductory and supporting activities. The learning teaching strategy should focus on each of the components ‘knowing’, ‘ability’ and ‘wanting’ as distinguished in the model for designing chemical education for ‘learning to inquire’, thus identifying that make a design of chemical education for ‘learning to inquire’ effective.

On the basis of the fine-tuned model the provisional guidelines have been converted into guidelines based on theory and practice for designing chemical education for ‘learning to inquire’ in upper secondary school. These guidelines concern the process of designing and the content of the educational design with regard to students and teacher. The feasibility of these guidelines is visible in the design of two other designs for ‘learning to inquire’ in chemistry education: “Traditional and modern soap: washing power” and “Cola and Teeth”. These have been implemented in 2003 and 2004 and are outside the scope of this research.

The model for designing chemical education for ‘learning to inquire’ has proven to be feasible regarding different topics of inquiry. Its teaching has led students to acquire (some) insight into the essence of doing inquiry. Further research is needed to investigate the extent to which this model is applicable to all science subjects and possibly other subjects as well.

Finally, the ‘inquiry skills’ formulated in the Dutch science curricula need to be reconsidered. They should put more emphasis on the cyclical character of doing inquiry and also include empirical evidence.