Learning Chemistry at the University level

Student attitudes, motivation, and design of the learning environment

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Abstract
The main purpose of the research this thesis is based upon was to study students' attitudes towards learning chemistry at university level and their motivation from three perspectives. How can students' attitudes towards learning chemistry be assessed? How can these attitudes be changed? How are learning situations experienced by students with different attitude positions?

An attitude questionnaire, assessing views of knowledge, learning assessments, laboratory activities, and perceived roles of instructors and student, was used to estimate students' attitude positions. It was shown that a positive attitude was related to motivated student behaviour. Furthermore, it was shown that factors in the educational context, such as the teachers' empathy for students learning chemistry, had affected the students. It was also found that students holding different attitude positions showed different learning outcomes and differed in their perceptions of the learning situation. Students' holding a more relativistic attitude more readily accepted the challenges of open experiments and other more demanding tasks than those holding a dualistic attitude.

In addition, the teachers were found to play important roles in the way the tasks were perceived and the development of students' ideas. In studied laboratory activities open tasks resulted in positive student engagement and learning outcomes. Preparative exercises, such as a computer simulation of the phenomena to be investigated, affected students' focus during laboratory work, encouraging them to incorporate more theoretical considerations and increasing their ability to use chemical knowledge. Finally, it was shown that students' focus during laboratory work is reflected in the questions they ask the teacher, implying that questions could be used as tools to evaluate laboratory teaching and learning processes.

The findings imply that students' attitudes towards learning and motivation, and the design of learning situations, are key factors in the attainment of desirable higher educational goals such as the ability to judge, use, and develop knowledge. For universities encountering students with increasingly diverse attitudes, motivation and prior knowledge, these are important considerations if they are to fulfil their commissions to provide high quality learning environments and promote high quality learning.

Keywords: laboratory work, open experiments, attitude, university level, motivation, cognitive load, laboratory instruction styles, attitude change, design of learning situation, student questions.

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Table of contents

1. List of papers

This thesis is based on the following articles, which are referred to in the text by the corresponding Roman numbers:

I. **Berg C. Anders. R.**, Bergendahl V.C.B., Lundberg B.K.S., and Tibell L.A.E. (2003) Benefiting from an open-ended experiment? A comparison of attitudes to, and outcomes of, an expository versus an open-inquiry version of the same experiment. *International Journal of Science Education, Volume 25, Number 3, 351-372*

II. Winberg T.M., **Berg C. Anders. R.** (2005) Effects of pre-lab simulated acid-base titration and student attitudes toward learning on students' cognitive focus and knowledge usability. *Journal of Research in Science Teaching (In progress)*

III. **Berg C. Anders. R.** (2005) Analysis of university chemistry students' questions and focus during laboratory work. *(Manuscript)*

IV. **Berg C. Anders. R.** (2005) Factors related to observed attitude change toward learning chemistry among university students. *Chemistry Education Research and Practice Volume 6, Number 1, 1-18*

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2. Preface

If experienced teachers are asked, “What is the single most important student characteristic for successful studies in chemistry?” their answer is often something like: “Being motivated”, “Having a genuine interest in the subject”, or “Showing willingness and a desire to learn”. The research underlying this thesis was prompted by this question and is aimed at understanding and expanding those “suggested answers” offered by experienced teachers.

2.1. Motivation for the research

Before starting my chemical education research, I also thought that factors like attitude and motivation are the most important student characteristics for learning chemistry. This belief was based on my experiences of teaching in compulsory, upper secondary school, and at university levels, along with experiences of planning, implementing, and teaching programs such as Interclass (a version of the Swedish Science program taught in English), engineering and civil-engineering courses. Hence, investigating issues related to motivation and attitude was a logical development, when I had the opportunity to do so. Apart from my experiences of planning educational exercises and actual instruction, my experiences as an advisor for students studying civil-engineering were also important in my choice of a research area. During many hours of individual counselling with students, the importance of students’ attitude and motivation struck me repeatedly.

2.2. Straightforward questions about attitude and motivation

Given my background and experiences, three questions provided the starting point for my research.

1. Is it possible to assess students’ “attitude”, which teachers say is important for learning? If so, how?
2. Is it possible to make favourable changes to students’ attitudes? If so, how?
3. How are different learning situations experienced by students with different attitude positions?

Did these questions and answers to seemingly straightforward questions become the endpoint of my thesis? Yes and No. “Yes”, since these questions remain central concerns, albeit in somewhat modified form. “No”, since the pre-conceived notions of a “hard core chemist” who begins researching phenomena as complex as human attitudes, motivation, and learning, inevitably mature, and, thus the questions considered and issues that can be resolved also change.

2.3. Who should read this thesis and why?

If you are a chemistry teacher, or teach some other subject at any level and share the same conviction that I held, that “attitudes and motivation are important for learning” I hope that what I have found may interest you. A warning, however, is appropriate—things may be more complex and less straightforward than originally anticipated. That said, I hope you will enjoy sharing some thoughts with me.

If you are in the fortunate position that you can do research in chemistry education (or science education) my focus on student attitudes and motivation may hold interest for you. Perhaps you will notice along with me that much educational research focuses on the "same things", but from different perspectives. My perspective may challenge your own views, or you may disagree to some extent, nevertheless I hope that my research will help you in some way or other.

2.4. How should this thesis be read?

> *"If we had to reduce all of educational psychology to just one principle, we would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly."* (Ausubel, Novak, & Hanesian, 1968, p.361).

This famous quotation could perhaps also be applicable to writing a thesis. There is, however, a problem—I do not know what you already know. I realize that knowledge varies among potential readers. If you are familiar with chemistry education research (or science education research), you may find my summary of articles and main conclusions most interesting. If, on the other hand, your knowledge of concepts and research procedures in chemistry education is weak, I hope that the section entitled, *Theory and Research Related to This Thesis* (Section 4), may be helpful. You will notice that I have tried to provide substantial amounts of information in tables and figures; perhaps you can understand the thesis by studying these summaries.

3. Introduction

The research summarized in this thesis is positioned at the crossroads of chemistry, pedagogy, teaching practice, laboratory work, cognition, epistemology, motivation, and attitude. This research could benefit from other research findings in fields as diverse as atomic models and philosophy. In other words, this research is interdisciplinary, and pathways to other potentially important subjects are not self-evident. To situate the research presented in relation to other research areas and provide the reader with an overview, two main figures are suggested for your attention, Figures 1 and 2. In these figures, three areas that are important to learning in general are presented (*attitude position, motivation* and *learning outcome*; Figure 1), and three areas associated with the learning situation (*cognitive load, focus during laboratory work*, and *laboratory instruction styles*; Figure 2)

The descriptions of these six areas comprise the major part of the next section, *Theory and research related to this thesis*.

After this section the articles are summarized in two ways, first in Table 6 where short descriptions of each article's research questions and major findings are presented, and then in extended abstracts of the four articles.

In the following section, *Methodological approach*, the research methods employed are summarized in Table 7 and two of the methods, interviews and attitude questionnaires, are discussed in further detail.

Finally the three original questions, presented in the preface, are revisited and considerations related to them, together with their implications for learning and research, comprise the last section; *Main conclusions and discussion*.

In Appendix A, a full version of the attitude questionnaire is presented (in Swedish), and in Appendix B a translation is included of some science-education terms that may help readers who are unfamiliar with science education research and its terminology.

3.1. Two figures that provide overview of the thesis

Figure 1 indicates that students' attitude positions affect motivation, which then affects learning outcomes. The influences have been presented in this linear fashion for convenience, but they could also be mapped in the other direction. For example it has been shown that good examination results (learning outcomes) have been shown to positively affect student motivation (Pintrich, 2003). At the top of Figure 1, articles related to students' attitude positions, motivation, and learning outcomes are shown (in order of the relative importance of their contents, e.g. Article 4 is most relevant to Attitude position and Motivation). At the bottom of Figure 1, references are made to sections of the thesis where the meanings of attitude position, motivation, and learning outcomes, as used in this thesis, are developed and clarified.

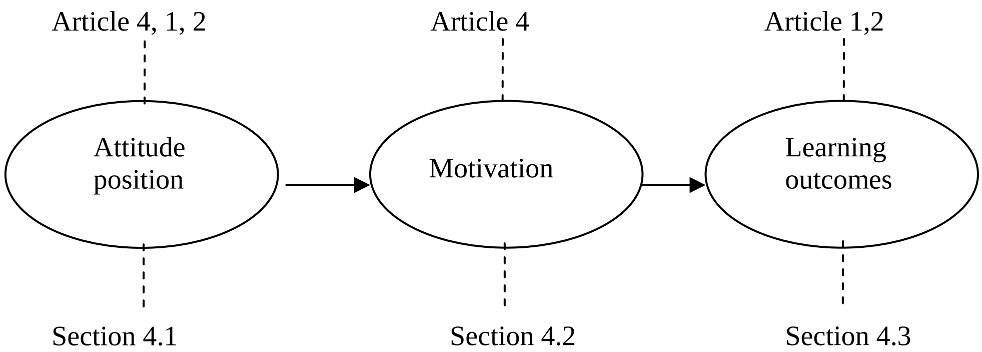

Figure 1. Attitude position, motivation and learning outcomes, three important areas in this thesis.

In Figure 2 aspects of the learning situation that are central to one or more of the articles are presented, and as in Figure 1, references are made to sections in the thesis that further describe cognitive load, focus during laboratory work, and laboratory instruction styles.

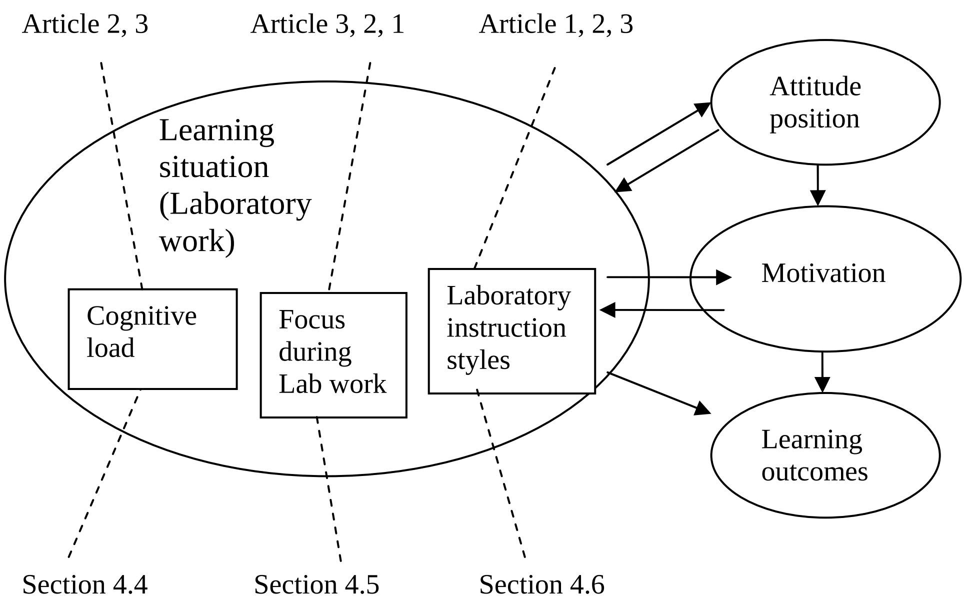

Figure 2. Aspects of the learning situation that are central to one or more articles.

4. Theory and research related to this thesis

4.1. Attitude position

In this thesis and the articles presented in it attitudes toward learning chemistry is a central concern, defined as the students' views of knowledge, assessment, laboratory activities, and the roles of instructors and students. The definition of attitudes and their relationships to other research areas are discussed below.

4.1.1. What is an attitude?

Attitudes convey our evaluation of something or someone. Since attitudes affect many aspects of society, such as political preferences and consumers' choices, attitudes have attracted substantial research interest since the 1920s (Eagly & Chaiken, 1993). Central questions in attitude research include "What are attitudes?", "How are they formed?" and "What constitutes an attitude object?" A short description of attitudes and related concepts is presented below.

The notion "I like laboratory work" is an expressed attitude, from both a research perspective and according to the everyday use of the word attitude. An example of a scientific definition of attitude is, "*Attitude is a psychological tendency that is expressed by evaluating a particular entity with some degree of favor or disfavor*". (Eagly & Chaiken, 1993). The word entity here refers to the object toward which the person has formed an attitude, and evaluation could be a cognitive, affective or behavioural response. These basic aspects of attitudes are illustrated in Figure 3.

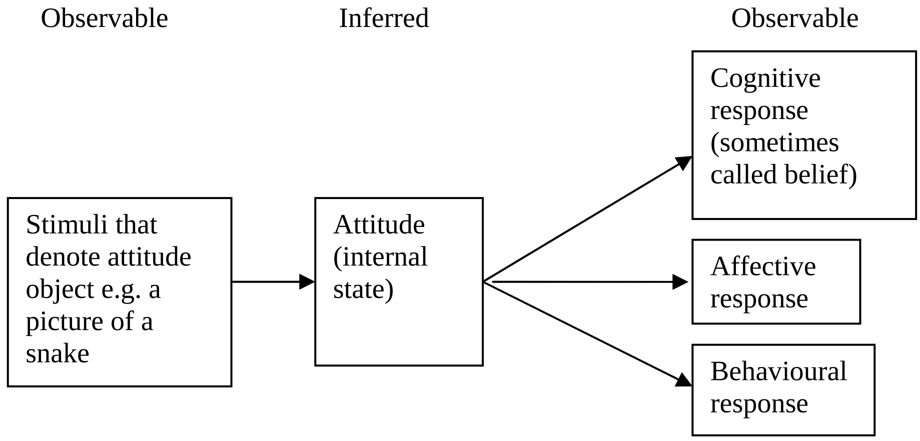

Figure 3. Attitude as an internal state, with evaluative responses divided into three categories.

The attitude object can be virtually anything; two examples are *liberalism* (an abstract attitude object) and a *dog* (a concrete attitude object). Behaviours and classes of behaviours can also serve as attitude objects, e.g. playing volleyball, participating in athletic activities, or learning chemistry.

The three types of evaluative response (cognitive, affective and behavioural) are three ways that attitude towards an object (entity) can be expressed. The attitude towards laboratory activities could be expressed as a cognitive response "I will try to really understand what I am doing in the laboratory since when I can see something concrete I usually understand the theory better". An affective response could be that the student feels comfortable and enjoys laboratory work, and a behavioural response could be that the student immediately starts handling equipment in the laboratory and organizing the laboratory activity. The view that attitude responses can be divided into three classes has a parallel in assumptions about how attitudes are formed. Attitudes are believed to be formed by cognitive, affective and behavioural processes. A student's attitude towards laboratory work could be formed by the thinking, knowledge and information he or she possesses about laboratory work. This would illustrate cognitive processes affecting the attitude. If the student has repeatedly experienced joy and satisfaction when doing laboratory work this could be an example of an affective process involved in attitude formation. The behaviour, (doing laboratory work) can also affect attitudes and it has been proposed that people tend to possess attitudes consistent with their prior behaviour, e.g. "I have spent a lot of time doing laboratory work; laboratory work is something I like."

In attitudes toward learning chemistry, as used in this thesis, the attitude object is *learning chemistry*, which is an abstract attitude object including views of knowledge, assessment, laboratory activities, and the roles of instructors and students.

4.1.2. Attitudes toward learning chemistry and attitude research in science education

Much “attitude” research activity in science education focuses on a problem experienced worldwide – that young people show little interest in science – which has prompted a number of studies on young people’s attitude towards science in general and specific scientific subjects. In this line of research the attitude under study is frequently, *do students like science*, and issues considered include how their attitude is formed and how it can be changed. However, aspects of scientific knowledge and students’ own thinking in science are often excluded (Osborne, Simon, & Collins, 2003). The research reported in this thesis departs from this (mainstream) research somewhat, since it includes cognitive aspects and students’ epistemological positions (views of knowledge), which are further discussed below.

4.1.3. Attitudes toward learning chemistry and research in epistemological beliefs

In *attitude towards learning*, as used in this thesis, views of *knowledge* are central concerns, and are thus closely related to research into personal epistemological beliefs. *Epistemology* concerns the nature and justification of human *knowledge*, while *epistemological beliefs* denote “the theories and beliefs they hold about knowing, and the manner in which such epistemological premises are a part of and an influence on the cognitive processes of thinking and reasoning” (Hofer & Pintrich, 1997).

How this may apply to chemistry can be illustrated by an example. The way a student approaches and views laboratory activity is affected by the student’s epistemological belief. The view that knowledge is a set of accumulated facts and the student is a receptor of knowledge may create a view of laboratory activity as an illustration of facts and learning of routine procedures. On the other hand, a view that knowledge is an integrated set of constructs and that the student constructs knowledge may promote a view of laboratory activity as an endeavour in which knowledge is generated and the student learns not only procedures, but also scientific methods.

In research into epistemological beliefs aspects of knowing and knowledge are central features. Research pays attention to the definition of knowledge, how knowledge is constructed, how knowledge is evaluated, where knowledge resides and how knowing occurs. Aspects such as views of the role of teachers and students and views of the learning situation are *not* usually included in epistemological beliefs, even if it is postulated that they are affected by epistemological beliefs. The importance of epistemological beliefs for student learning and motivation has been described in a working model by Hofer (2001) in which epistemological beliefs are postulated to affect student motivation and strategy selection, which then, separately and in conjunction, affect learning. This working model is presented in Figure 4.

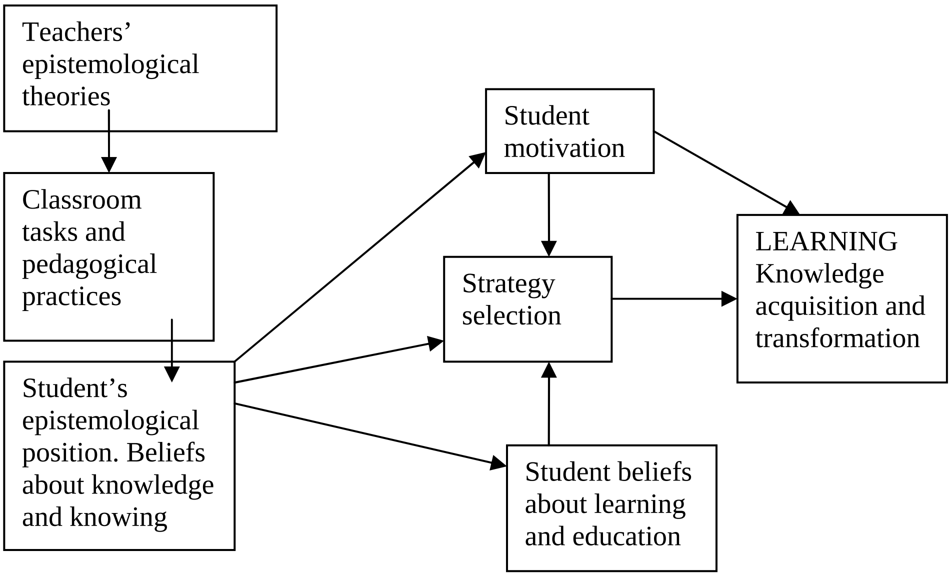

Figure 4. Working model of how epistemological theories influence student learning (Hofer, 2001, p.372).

The tendency to focus on knowledge and exclude other aspects of learning has been expressed by Hofer in these words. "Beliefs about learning and education are peripheral to this particular model, however. These beliefs are central to the original Perry scheme of development but appear more as outcomes of the core beliefs and dimensions in most models". (Hofer, 2001, p.361)

Attitudes toward learning as used in this thesis *include* these beliefs about learning and education, as did Perry (1970), from whom much of the research activity in the field originated. These two somewhat different perspectives need not necessarily be in opposition but may reflect the perspective from which a researcher approaches the field. In my case, given my close association with a specific subject (chemistry), including aspects of the learning situation are appropriate. The perspective that the nature of knowledge and the nature or process of knowing comprise the area of study is simply a more general perspective that is reasonable for educational psychologists interested in fundamental aspects of knowledge and knowing to adopt. Beuhl and Alexander (2001) describe a model illustrating the multilayered nature of epistemological beliefs, with domain-specific beliefs as part of a full epistemological belief system (Figure 5). The focus of the present research is on domain-specific beliefs, as reflected in views of knowledge, assessment, laboratory activity, and the roles of instructors and students.

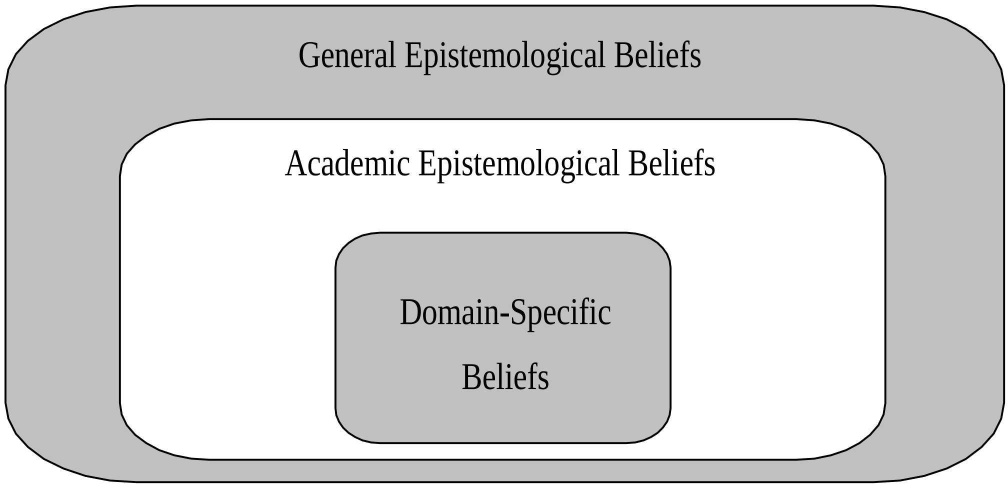

Figure 5 Model of an epistemological belief system (Buehl & Alexander, 2001).

4.1.4. Lopos, Hipos and Perry position.

To classify attitudes towards learning chemistry the abbreviations LoPos and HiPos, indicating lower and higher attitude positions, respectively, have been used as descriptions of students' views of chemistry studies. HiPos show a more relativistic and LoPos a more dualistic view. LoPos show a low attitude position *in relation to other students* in the group and HiPos a higher attitude position. Low and High here refer to Perry's scale (Perry, 1970) but are *not* assigned specific numbers on the scale 1-9. However, based on answers to the attitude questionnaire and interviews, the relationships between LoPos and HiPos in this research and Perry positions could however be estimated. LoPos could be assigned a position in the range 2-3 (dualism-early multiplicity) while HiPos could be assigned a position in the range 4-5 (late multiplicity-contextual relativism) on the Perry scale. In Table 1 a short description of the Perry positions 2-5 is presented. This description is based on characteristics described by researchers following Perry (Finster, 1991; Moore, 1994) and Knefelkamp's introduction in the 1999 edition of Perry's original book (Perry, 1999).

Table 1. Student perceptions of educational characteristics along the Perry scheme.

	Attitude position			
View toward	Dualism Position 2	Early Multiplicity Position 3	Late Multiplicity Position 4	Contextual Relativism Pos. 5
Knowledge	All knowledge is known. Right and wrong answers exist for everything.	Most knowledge is known. Truth exists, but it is incomplete.	In some areas we have certainty of knowledge. In most areas we really don't know. Anything goes.	All knowledge is complex and contextual. Right and wrong can exist only within specific contexts.
Role of instructor	Source of knowledge. Role is to give knowledge.	Source of right way to find knowledge. Role is to tell us how to learn.	Source of process of thinking, modelling the use of evidence.	Source of expertise. A guide or consultant. Mutuality of learning is sought.
Role of student	Role is to receive information or knowledge and to demonstrate having learned the right answers.	To learn how to learn the truth and work hard. Express oneself well.	Role is to learn to think for oneself and to use evidence. Independence of thought is valued.	Role is to exercise the use of the intellect. To identify the conditions and choose the best ideas.
Assessment	Right is good, wrong is bad. Questions and answers should be clear-cut. Hard work should be rewarded.	Assessment is the prime issue. Is the test "fair" in terms of knowable right answers? Hard work=good mark.	Independent ideas equal good mark. Can separate assessment of work from personal worth.	See evaluation as opportunity for feed-back. Testing is part of the learning process. Quality of answer is important.
Intellectual tasks	Learn basic information. Distinguish right from wrong.	Compare and contrast multiple perspectives.	Analysis. Use supportive evidence. Relate academics to "real life".	Synthesis. Relate ideas between contexts.

4.2. Motivation

As indicated by the present author (Figure 1) and Hofer (Figure 4) motivation could be influenced by attitudes or by the related construct epistemological positions. In article IV this was found, since a positive shift in attitude toward learning was accompanied by more motivated student behaviour. In the work underlying this thesis, no research focused solely on motivation was conducted, and the finding of connections between motivation and attitude emerged from data found in the studies. When this connection was detected in interviews a model for student motivation presented by the educational psychologist Pintrich was useful for interpreting the interviews (Table 2).

In Pintrich's model three major components are *contextual factors, internal factors* and *motivated behaviour*. Contextual factors include features of the learning environment assumed to influence internal factors, such as students' motivational beliefs and emotions. These internal factors together with contextual factors affect the third component, motivated behaviour. Pintrich emphasizes that this relation is reciprocal, for instance student behaviour could affect teacher behaviour. This integrated model was found to be useful, since it describes the dynamic and interacting system of the learning environment, students' motivational beliefs, and their behaviour.

Table 2. Model for student motivation, after Pintrich (1994) (slightly modified).

Contextual Factors Factors influencing student motivation	**Internal Factors** Factors assumed to mediate between context and behaviour	**Motivated Behaviour** Observable behaviours that can be used as indicators of motivation
Nature of Tasks - Content/Product	**Expectancy Components** - Control beliefs - Attributions - Learned helplessness - Self-efficacy	**Choice Behaviour** - Working on course instead of leisure activity - Electing to take another course in discipline - Selecting discipline for a major or going on to graduate school or pursue a career in area
Reward/Goal structures - Individualistic - Cooperative or Competitive	**Value Components** - Intrinsic/Extrinsic goals - Task value - Personal interest	**Level of activity and Involvement** - Trying very hard - Studying effectively, use of learning strategies - Thinking deeply, critically about material - Asking questions, taking risks in expressing ideas - High level of performance/achievement
Instructional Methods **Instructor Behaviour**	**Affective Components** - Test anxiety - Self-worth - Other emotions (pride, shame)	**Persistence Behaviour/Regulation of Effort** - Maintaining effort in face of difficulty - Maintaining effort on "boring" tasks - Maintaining effort even when fatigued

4.3. Learning outcome

Bloom's cognitive taxonomy (Bloom, Engelhart, Furst, Hill, & Kratwohl, 1956) was used in this research as a basis for categorizing learning outcomes in article I, and a classification scheme resembling the SOLO (structure of the observed learning outcome) taxonomy (Biggs & Collis, 1982) was employed in article II.

Both taxonomies are used as tools to compare learning outcomes and to communicate results of educational evaluations. Bloom's taxonomy aims to classify cognitive activities ranging from simple recall of facts to highly complex ways to combine and synthesize new ideas (see Table 3 for summary of old and new versions of Bloom's taxonomy). The SOLO taxonomy is used to classify the structural complexity of students' responses, usually in answers to questions.

4.3.1. Bloom's cognitive taxonomy

In the study summarized in article I, students completed a self-evaluation of their learning outcomes from different versions of the laboratory procedure. The students were given Bloom categories (knowledge, comprehension, application, analysis/ synthesis, and evaluation) to characterize their learning outcomes. To help students understand the meaning of each category, keywords were also provided. Two examples are: *Knowledge* (to learn, remember, understand, recognize facts, terms and phenomena), and *Comprehension* (to interpret, to be able to explain knowledge gained to other students in your own words so that they understand). The students evaluated their own learning outcome on the scale: *very much, much, some, a little or nothing* for each of the Bloom categories.

In 2001 a revised version of Bloom's taxonomy was published (Anderson et al., 2001). The main change from the previous version was that a two-dimensional format was introduced, in which the subject-matter content formed one dimension, (the *knowledge dimension*), and the description of what is to be done with or to that content formed the second dimension, the *cognitive process dimension*. An additional change made was that metacognitive knowledge (knowledge about cognition in general as well as awareness of and knowledge about one's own cognition) was added to the knowledge dimension. In Table 3 a comparison between the new and old versions of Bloom's taxonomy is summarized.

Table 3. Original and revised versions of Bloom's taxonomy.

Bloom's original levels (1956)	**Revised version of Bloom's taxonomy (2001)**	
	Cognitive process dimension	The Knowledge dimension
Knowledge (12 sublevels)	**Remember** (2 sublevels)	**Factual knowledge**
Comprehension (3 sublevels)	**Understand** (2 sublevels)	**Conceptual knowledge**
Application	**Apply** (2 sublevels)	**Procedural knowledge**
Analysis (3 sublevels)	**Analyze** (3 sublevels)	**Metacognitive knowledge**
Synthesis (3 sublevels)	**Evaluate** (2 sublevels)	
Evaluation (2 sublevels)	**Create** (3 sublevels)	

At the time of the investigation described in article I, this new version of Bloom's taxonomy had not yet been published, hence the available (original) Bloom version was employed. A strength of both the old and new versions of the taxonomy is that they are relatively easy to interpret and are widely used by university teachers. Bloom's taxonomy is also helpful when communicating teaching and learning goals to students and teachers.

4.3.2. SOLO taxonomy

In article II a classification scheme originating in the interviews was used to assess the extent to which, and the level of complexity at which, students used their knowledge in an interview situation. This classification was found to bear close resemblance to the SOLO taxonomy. Our attempts to classify the learning outcome after the simulation and the subsequent laboratory exercise resulted in a "reinvention" of the SOLO taxonomy. We interpreted its close resemblance to the SOLO as a verification of our classification scheme. Our classification scheme and the SOLO taxonomy are presented side by side below to facilitate comparisons (Table 4).

Table 4. Categories used to analyse student verbal discourse and related SOLO categories.

Categories* used for analysing student verbal discourse in article II	**Related SOLO categories for comparison ****
1. Misses the point, expressing misconceptions	**Prestructural** Avoids the question (denial); repeats the question (tautology); makes an irrelevant, personally based, association (transduction)
2. Describes the experimental procedure	**Unistructural** Selects one relevant datum from the display and closes on that
3. Mentions relevant concepts and/or ideas	
4. Comments on concrete aspects of phenomena	
5. Uses isolated concepts or ideas in a relevant way	**Multistructural** Selects two or more relevant points from the display but ignores any inconsistencies and makes no integration
6. Uses two or more concepts or ideas, well integrated, in a relevant way	**Relational** Uses all or most of the relevant information and integrates it with a relating concept, reconciling any conflict but remaining within the given context

7. Implements concepts or ideas outside the context defined by the course	**Extended Abstract** Uses abstract principles that show the example is just one of many possibilities results or explanations; no firm closure; appeals to hypothesis and to examples not given in the original

*For a fuller description of categories see article II in this thesis.
**The descriptive texts for each category are those presented for geography (Biggs & Collis, 1982), the subject of those presented, judged to be most similar to chemistry.

4.4. Cognitive load theory

When people engage in learning they use varying degrees of their thinking capacity. This thinking is labelled cognitive load in educational psychology. Cognitive Load Theory (CLT) (Sweller, van Merrienboer, & Paas, 1998), is a framework that describes the cognitive load and the mental structures where the thinking takes place. According to cognitive load theory, *working memory* is where conscious "thinking", e.g. organizing, comparing, and elaborating on information, occurs. A central assumption in CLT is that working memory has only a limited capacity to process elements of information. *Long-term memory*, on the other hand, can store large quantities of information organized into *schemata*, which are treated as single information elements by working memory (Kirschner, 2002).

An example from laboratory work could illustrate these principles. For a novice, the concept of buffer capacity could be composed of several *separate* schemata, comprising information such as the Henderson-Hasselbach equation, molecular structures, and pKa. If the novice is performing a pH titration the cognitive load during the work consists of practical considerations together with the separate schemata pKa, Henderson-Hasselbach equation etc., which all impose a (high) load on working memory. For the expert, on the other hand, these elements make up a single structure in which all elements are interrelated – a schema. Hence an expert performing the same activity would experience a lower load on working memory. By constructing schemata, working memory limitations can be circumvented, allowing learners to allocate more capacity to learning (Kirschner, 2002). Functional schemata also increase performance speed (Carlsson, Chandler, & Sweller, 2003) by making information more easily accessible (Sweller et al., 1998).

Cognitive load, or working memory load, arise from three sources (Bannert, 2002): (a) *Intrinsic cognitive load* (ICL), which depends on the degree of interactivity among elements related to the task and whether the learner is familiar with the domain or not. Familiarity with the domain, i.e. having appropriate schemata, reduces ICL. Furthermore, extensive practice may lead to automation of schemata, allowing automatic, partly non-conscious, retrieval and application of procedures. Thus, automation also reduces ICL, in addition to "speeding up" problem-solving processes (Sweller et al., 1998). Consequently, experienced learners may engage in tasks with high element interactivity but still have working memory capacity left for schema construction (learning). (b) *Extraneous cognitive load* (ECL), caused by environmental factors such as poorly organized laboratory settings or the instructional format. For example, ECL could arise from learners' attempts to find a missing burette or to understand how a diagram should be read. ECL is an ineffective load since it does not contribute to learning. (c) *Germane cognitive load* (GCL), resulting from learners' effort to construct schemata and thus regarded as the cognitive load associated with learning.

ICL, ECL, and GCL are assumed to be additive. Thus, the experienced load, interfering with the limited capacity of working memory, is the sum of all sources (Sweller et al., 1998).

A graphical representation of ICL, ECL, and GCL is presented below. The additive character of the loads is illustrated, and the limit of working memory is indicated. The loads during the laboratory activity in Figure 6 are hypothetical, although data presented in article III indicate that a scenario of the type presented is plausible.

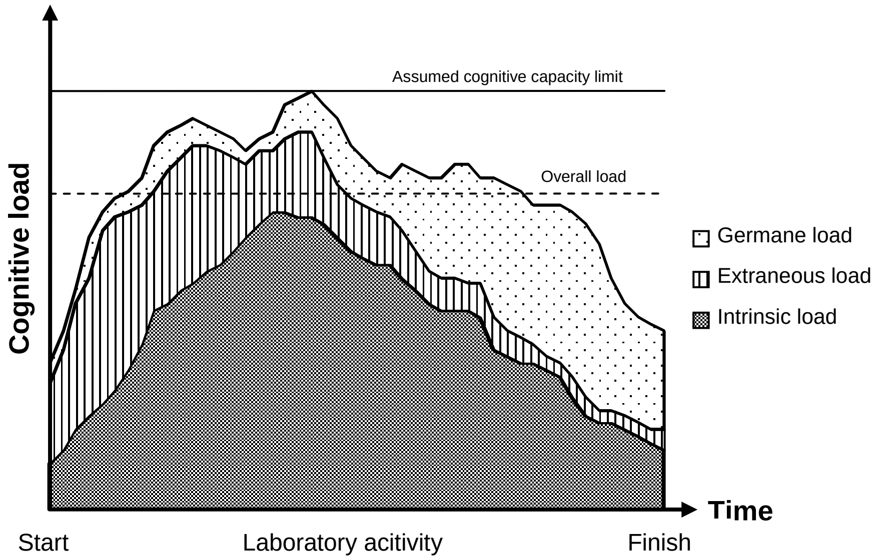

Figure 6. Graphical representation of ICL, ECL, and GCL during a hypothetical laboratory activity. The additive character of the loads is illustrated, and the limit of working memory is indicated together with overall load. The figure is an adaptation of a general figure presented by Paas et al. (2003).

In the research this thesis is based upon CLT was found to be useful for describing and understanding the thinking, and limits for thinking, that could occur during laboratory work. A recent development in CLT research is to investigate complex learning as seen in authentic learning tasks (Merrienboer, Kirschner, & Kester, 2003). This focus on more complex learning situations could make the CLT line of research even more valuable for chemical education research, since authentic real-life tasks are often included in chemistry education at university level.

4.5. Focus during laboratory work

In article III the term focus is used for describing the concentration of a student on different aspects of laboratory work, such as accomplishing the task, trying to relate the experiment to what he or she already knows, planning and dividing the work with a laboratory partner, and so forth. This focus changes with time, and often, as different aspects of the laboratory work are encountered, the student can hold multiple (perhaps conflicting) foci.

Using the terminology from cognitive load theory (CLT) focus is defined as what the student is using working memory for. An alternative word that was considered for the term *focus* was attention, but since that term is mainly used in connection with attention deficit hyperactivity disorder (ADHD) and other clinical descriptions it was considered unsuitable in our context.

Focus as defined here is internal to the student and as such is not directly accessible. We can never know (for sure) what occupies a person's thought. If not directly accessible how then can focus be investigated? It is assumed that focus could be revealed by certain indicators, even if hidden. This is analogous to indicators of motivation (e.g. choosing further studies in a subject or persistence in the face of difficulties), which are signs of motivation that can be used to identify motivation; another internal state that is not directly accessible (Pintrich, 1994). In attitude research a similar construct is used since attitudes, which are also internal, manifest as three types of responses – cognitive, affective and behavioural (Figure 3) – that can be reported or studied (Eagly & Chaiken, 1993).

Figure 7 presents a *working* model for the construct focus, together with some examples of potential factors that could affect it, and how it could manifest in students.

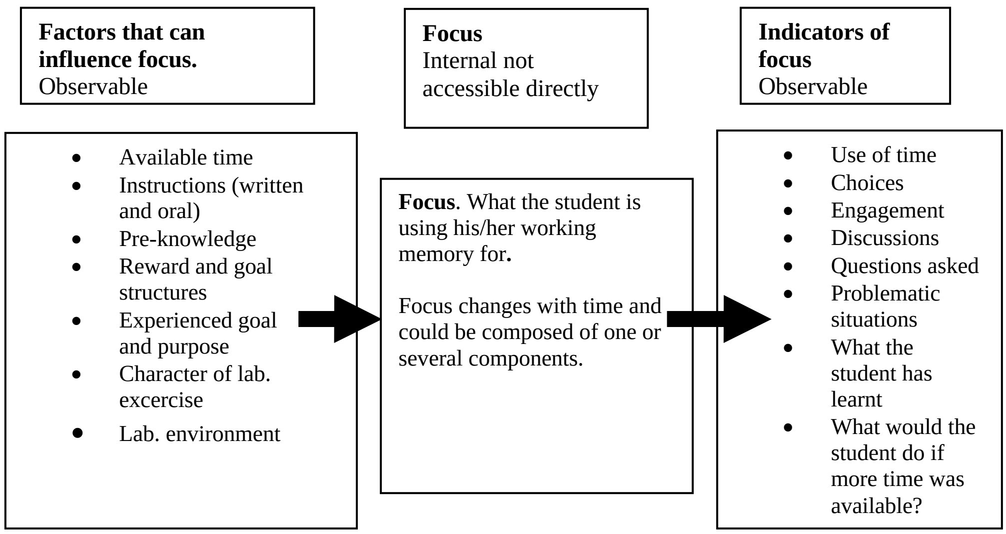

Figure 7. Student focus during laboratory work, with examples of factors that could affect it and examples of how it could be inferred.

4.6. Laboratory instruction styles

In three of the four articles this thesis is based upon (I, II, and III) laboratory work is a central element. There is a rich terminology to describe different types of laboratory work: cook book, open, traditional, problem-based and discovery, to mention just a few. In 1999 an article was published presenting a taxonomy for laboratory instruction styles (Domin, 1999), and has been frequently cited since then. The present author also found the taxonomy useful and has used it to classify the type of laboratory work under investigation.

The taxonomy distinguishes between four different laboratory instruction styles: expository, inquiry (or open-inquiry), discovery and problem-based. Each instruction style is characterized by three descriptors: outcome (predetermined or undetermined), approach (deductive or inductive) and procedure (given or student generated). In Table 5 the taxonomy is presented with an additional descriptor, theory known, which is complementary to Domin's descriptor, deductive or inductive approach, but is added for the convenience of the reader.

Table 5. Descriptors of laboratory instruction styles (Domin, 1999, p. 543).

Style	Descriptor			
	Outcome	Approach	Procedure	Theory known*
Expository	Predetermined	Deductive	Given	Yes
Inquiry (open inquiry)	Undetermined	Inductive	Student generated	No
Discovery (guided inquiry)	Predetermined	Inductive	Given	No
Problem-based	Predetermined	Deductive	Student generated	Yes

* Descriptor not present in Domin's original table

Expository instruction, sometimes called traditional, is the most common instruction style. Here the teacher defines the topic, the outcome, and directs the students' action. Expository approaches have been criticized for placing little emphasis on thinking skills and planning. They are also judged to be ineffective for concept building.

In open-inquiry laboratory instruction the students formulate the problem within broad given areas, and the outcome is undetermined. The students generate their own procedures, and the inquiry-based activities are inductive. This effectively gives students ownership of the laboratory activity, but it requires them to relate the investigation to previous work, to state the purpose, predict the results, identify the procedure, and perform the investigation. This type of laboratory work is designed to help students develop their thinking process and to engage in an authentic investigation process. However, the open-ended inquiry approach can be criticized for placing too much emphasis on the scientific process (at the cost of content), and for being time consuming.

In the discovery approach, the teacher guides the learner towards discovering a desired outcome. The discovery approach is inductive and the students don't know the theory associated with the experiment. This type of approach has been criticized for sharing some of the weaknesses of the expository style of instruction and for being relatively time consuming.

In problem-based instruction, the teacher provides a problem and the necessary reference material, and guides the students towards a solution. The problem has a clear goal, but there are several possible paths toward a solution. This approach is time consuming and poses high demands on both teachers and students. On the other hand it promotes the development of skill to apply, analyse, evaluate and create. The problem-based laboratory activity is deductive in approach. Therefore the students must have had some exposure to relevant concepts and principles before performing the experiment.

The laboratory activity presented in article I was carried out in two different versions. In one version the entire experimental procedure was described in detail, the outcome was predetermined, and the approach deductive. Following Domin's taxonomy this version of the laboratory activity was expository. In the other version of the experiment the task was to formulate a question that could be investigated experimentally. Students had to plan and carry out an experiment designed to answer the question and evaluate the experiment. This is a typical example of an open-inquiry laboratory activity.

In the study outlined in article II, a pre-lab simulation was introduced, and the laboratory activity consisted of two distinct parts. During the first part the students prepared and characterized a buffer solution for a specific pH given to them. The theory associated with this was known, the outcome defined and the procedure was given, even if the students had to adapt the procedure for their specific pH. This part of the laboratory activity was mainly of expository type. The second part had an open-inquiry character since students formulated their own questions related to the topic (buffers), generated procedures, and evaluated the results.

In the study described in article III the students performed four different organic chemistry experiments: three syntheses of expository type, and one separation that was problem-based, in which students had to separate three naphthalene derivatives. In doing this students had to plan the procedure for the separation and the necessary theory had been covered in advance.

5. Summary of articles

In Table 6 the research questions posed in Articles I-IV and the main findings are presented in a condensed format in order to provide an overview of the research. A fuller but still abbreviated description of each article is then presented.

Table 6. Summary of research questions and main findings.

Research questions *	Main findings*
Article I	
Expository versus open-inquiry version of same lab activity, different outcomes?	Open-ended more beneficial for student learning and motivation.
Is student attitude an important determinant for the type of lab activity they find most beneficial?	Open-ended better for all students, but HiPos more readily accept challenging activity.
How can an open-ended laboratory activity be improved?	Clear explanations of aims, and feed-back during the activity, are important.
Article II	
What effect does exposure to a pre-lab exercise have on students' focus during lab work?	A pre-lab aimed at understanding buffer capacity helped students to focus more on theoretical aspects during the laboratory activity
How is students' use of chemical knowledge influenced by exposure to a pre-lab?	Students that experienced the pre-lab were more able to discuss chemistry, as indicated by more frequent and integrated use of chemistry concepts in interviews.
How do students' attitudes towards learning affect their use of chemical knowledge after the pre-lab simulation?	Both students with more relativistic attitude positions (HiPos) and those with more dualistic attitudes (LoPos) display learning gains, although at different levels.
Article III	
Are student questions connected to students' focus during laboratory work?	During lab work, doing, understanding, and planning are students' main foci. Students ask questions on aspects that they focus on.
Article IV	
What factors are related to students' shifts in attitude in a chemistry context?	Positive attitude shift is related to motivated behaviour. All students are affected by similar factors in an educational context, but the balance in experiences differs.

* Research question and main findings in abbreviated form; for complete versions see corresponding articles.

5.1 Article I.
Benefiting from an open-ended experiment? A comparison of attitudes to, and outcomes of, an expository versus an open-inquiry version of the same experiment

Laboratory work is generally considered an essential part of science education. Thus, the time chemistry students spend doing laboratory work constitutes a substantial part of their total scheduled time. Since the 1960s, efforts have been made to implement more open laboratory activities. The learning outcomes reported from these more open activities have shown conflicting and not always encouraging results (Hodson, 1996). A report on laboratory work in Europe (Tiberghien, Veillard, Le Marechal, Buty, & Millar, 2001) concluded that, for university-level chemistry, the main learning objectives are generally to learn how to complete standard procedures, rather than learning to plan investigations to address specific questions or problems.

The aim of this study was to investigate whether applying different degrees of openness of instruction to the same laboratory activity would result in different outcomes depending on students' attitudes towards learning.

This study involved 190 students in their first year of university chemistry studies, who were divided into three groups. The first was provided with expository instructions for the activity, the second was given an open-inquiry version, and the third was given a modified version of the open-inquiry instructions.

A questionnaire determined the students' attitudes towards learning chemistry, and the outcomes of the different laboratory-activity versions were evaluated using interviews, questions asked by students during the activity, and students' self-evaluations.

The main findings were that the revised open-inquiry version was associated with the most favourable outcomes in terms of learning, preparation time, time spent in the laboratory, and students' perception of the laboratory activity. The students with low attitude positions needed more support to meet the challenges of an open-inquiry activity. The support within the revised open-inquiry version provided a clearer explanation of the aims, and instructor feed-back was provided at a "check-point" during the activity. In a way, the research question was developed during the research due to new insights gained in comparing the expository and open-inquiry versions. The revised version was a "spin-off" of our attempt to compare expository and open-inquiry versions. The second part of the study, in which the revised open-inquiry version was introduced, was influenced by these insights and can be regarded as action research with an updated research question. The second part of the study illustrates the potential value of educational research, since minor but vital improvements in the laboratory activity were proposed, based on the data obtained in the first part.

5.2 Article II.
Effects of pre-lab simulated acid-base titration and student attitudes toward learning on students' cognitive focus and knowledge usability

Higher-education laboratory exercises have been claimed to have the potential not only to help students confirm, elaborate on, and place theoretical knowledge in a meaningful context, but also to learn scientific methodology and cultivate practical skills. Research, however, indicates that students often focus on manipulative details and other procedural concerns rather than elaborating on underlying theory and linking it to the exercise (Hofstein & Lunetta, 2004).

A course-development project in which the author was involved (Lundberg, 1998) revealed that the students' primary goal was to gather useful data during the laboratory activity; thinking occurred afterward, while writing their lab report. This tendency to "first do, then think" is perhaps not surprising since laboratory work has been described as a situation where cognitive load is high; many practical and theoretical tasks have to be tackled simultaneously and thus students may employ different strategies to avoid receiving too much information simultaneously (Johnstone & Wham, 1982).

To enhance student engagement in the theoretical aspects of laboratory work, a computer-simulated acid-base titration was introduced prior to the corresponding laboratory exercise. The pre-lab was intended to give students an opportunity to use and discuss previously gained knowledge in a setting where the "computer" presented titration curves and log diagrams based on titration parameters the students entered.

The effects of the introduced pre-lab on students' cognitive focus during laboratory work, and their ability to use chemical concepts in verbal interactions, were investigated. The influence of student attitudes toward learning on the outcome of the pre-lab exercise was also investigated.

The study involved 233 students in total, in two sub-studies, each involving one treatment group (engaged in the computer simulation), and a control group. Students' attitudes were, as in (Berg, Bergendahl, Lundberg, & Tibell, 2003) assessed with a questionnaire. Students' focus was investigated by noting the type of questions students asked while they were engaged in the laboratory activity. The students' ability to use chemical concepts verbally was investigated by interviewing 28 students who held contrasting attitude positions.

The main findings were that the simulation evoked a more theoretical focus during laboratory work, as indicated by more theoretical questions being posed after reflection.

Results from the student interviews indicated that treatment-group students were more able to discuss chemistry. This ability was manifested by a more frequent and integrated use of chemistry concepts.

Both findings can be explained by the hypothesis that the simulation promoted the development of more functional knowledge of theoretical aspects. This could explain the experimental group's superior ability to discuss chemistry in the interviews.

The change to a more theoretical focus during the laboratory task could be explained by the development of more functional theoretical knowledge, freeing working-memory capacity, and making theoretically oriented considerations possible in a laboratory setting involving high cognitive load.

The results indicate that, regardless of attitude, all students benefited from the pre-lab, although at different levels. The difference between groups is that students holding more relativistic attitude positions in interviews scored higher in our categorization of use of chemistry knowledge than students holding a more dualistic attitude.

In addition to these main findings, previous knowledge about the content area affected the usefulness of the pre-lab. The pre-lab could also give students a sense of direction regarding aspects to attend to during laboratory work, in addition to facilitating it.

5.3. Article III.
Analysis of university chemistry students' questions and focus during laboratory work

In this article the students' focus and the questions they ask during laboratory work in a university level chemistry course was investigated. The overall aim was to answer the question, "In what ways are questions addressed to the teacher connected to students' focus during laboratory work?"

To answer this main question, three research questions were addressed:

- What kinds of questions are asked during laboratory work?
- What types of student focus are found during laboratory work?
- What kinds of connections are found between questions and focus?

Answers to these questions could be of interest to teachers who are trying to understand the learning (or lack of it) that occurs in their laboratories. This is especially important, since answering and discussing questions are part of their normal instructional work.

In science education research, laboratory work is often evaluated indirectly by pre- and post-tests, interviews, questionnaires, and the written products of practical work (Rollnick, Zwane, Staskun, Lotz, & Green, 2001; Tapper, 1999). Data describing what happened *during* laboratory work are less often acquired, especially if natural laboratory settings are under study. This investigation attempted to describe the situation during laboratory work, as a supplement to more common indirect investigations.

The laboratory setting consisted of four sequential days of laboratory work, during an introductory chemistry course. During these four days, students completed four laboratory activities related to organic chemistry. All students completed a questionnaire at the close of each day where they rated how they had divided their laboratory time among tasks and their individual assessment of the workload associated with each task. In one group (n=12), all verbal interactions between students and their laboratory assistant were recorded.

It was found that the 12 students asked 922 questions during 20 hours of laboratory work. The number of questions per hour per student was 3.8, which was high compared to the 0.11-0.17 questions per hour per student, found in normal classroom situations (Graesser & Person, 1994). Questions about *practical, understanding, and planning issues* represented more than 90% of all questions asked, and questions about *how to accomplish practical tasks* were most prevalent, accounting for 48% of the total. The second most frequent type of question, accounting for 31% of the total, regarded *understanding what was happening/what did happen* and *explaining/understanding laboratory results*. The third most frequent type of question was about *planning the work* (13%). Remaining questions were categorised as *social interaction* (4%), and *other* matters (4%).

It was found that students focused on *accomplishing practical work* and *understanding the activity*. In addition to these predominating foci, students also focused on planning their activity and report. The foci of *social interaction* and *other* both received low ratings in terms of allocated time and mental effort experienced.

It was found that the questions and focus changed considerably over the four days of laboratory work in a common pattern, both practical focus and practical questions declining with time, while focus on understanding and questions aimed at understanding increased with time. An analysis of specific situations where focus and question were compared also revealed that student focus in the respective situations was related to the questions asked in the same situation. Taken together, these findings indicate that students ask questions about the things they focus on.

The connection identified between questions asked and student focus could be used by teachers evaluating laboratory work and could also form the basis for additional research strategies, aimed at studying laboratory work directly. Furthermore, since other studies have shown that questions hold evaluative qualities (Berg et al., 2003; Dori & Herscovitz, 1999; Graesser & Olde, 2003; Tapper, 1999), it also suggests that questions asked by students during laboratory work could be used as a litmus test for what students focus on.

5.4. Article IV.
Factors related to observed attitude change toward learning chemistry among university students

Students' motivation and attitudes towards learning are important and of general interest to teachers; these topics have also attracted considerable research attention. The relations between attitude (and attitude change), motivation and educational context are quite complex and hence not easily investigated. To "shed some light" upon this complex but important relationship, this study compared and contrasted students who showed *positive and negative attitude changes within the same course*. This approach was adopted since it can be informative to examine cases where marked changes have occurred when complex phenomena are under investigation.

Six students displaying major attitude changes were identified through a pre- and post-course attitude questionnaire administered to 66 first-year university chemistry students. Students with the largest attitude changes, both positive and negative, were selected to highlight the observed contrasts among students. The six students were interviewed, and descriptions of their one-semester chemistry course experiences were analysed to identify factors associated with their change in attitude.

Interview results were found to be congruent with a model of motivation described by Pintrich (1994). According to this model, contextual factors in conjunction with students' internal factors (motivational beliefs and emotions) affect motivation, which can be observed in motivated behaviour.

The relation identified between attitude shift and student motivation was that a positive attitude shift was associated with motivated behaviour, while a negative shift was linked to less motivated behaviour. This relationship held for all three motivational categories, choice behaviour, level of activity and involvement, and persistence.

The primary relationship found between attitude shifts and contextual factors was that students with negative shifts expressed negative views of context much more frequently, and more emphatically, than those with positive shifts, who expressed more positive views of educational factors. These trends were found for all four contextual categories, nature of tasks, reward and goal structures, instructional methods, and instructor behaviour.

Since the same factors (e.g. students' perceived level of teacher empathy for their chemistry-learning efforts) affected both groups, the findings indicate possible scope for changes in educational settings that would be beneficial to "all" students. Much of what was found could be summarized in a recommendation that instructors should *show the students respect* in the form of genuine interest in student learning, conveying clear expectations and instructions, expressly acknowledging that certain tasks can be difficult for students, and generally being available for them.

It is tempting, in conclusion, to speculate that university teachers should consider these aspects of student learning equally important to the course features already considered.

6. Methodological approach

In order to address the research questions raised in the four articles combinations of quantitative and qualitative methods were used (Table 7). The starting point in each research project was a question (or questions), and then appropriate methods to answer these questions were sought. In all four studies a mixture of quantitative and qualitative methods were used. For example, in article IV the relationships between attitude shifts and factors in the educational context were investigated. To *find* students who had undergone marked changes in attitude, a questionnaire and subsequent PCA, principal component analysis, (Eriksson, Johansson, Kettaneh-Wold, & Wold, 2001) was used. This is an example of a quantitative approach. When six students showing marked attitude change had been identified a qualitative interview-based approach was used to produce more *detailed information* about these students. In retrospect, this combination of methods was appropriate for the questions asked.

Table 7. Summary of data collection methods and data analysis methods.

Data collection method	Article				Data analysis method*
Questionnaires	I	II	III	IV	
Attitude questionnaire Likert format	x				Mean value of item responses Categorisation based on Perry's framework
Attitude questionnaire Two-sided Likert format		x		x	Principal component analysis Categorisation based on Perry's framework
Self-evaluation questionnaires for students	x				Categorisation based on Bloom's Taxonomy (I)
			x		Cognitive load and work time (III)
Check-sheets for student questions posed during lab. activity					
Three dimensions	x				Statistical, Chi-square
Two dimensions		x			Statistical, Chi-square
Interviews					
In-depth semi-structured interviews recorded and categorised digitally with QMA**	x				Thematic content analysis (I)
		x			Thematic content analysis, SOLO-like categorisation (II)
				x	Thematic content analysis, Pintrich-based categorisations (IV)
Recorded verbal interactions between students and lab. instructor			x		Categorisation based on thematic content analysis, influenced by a similar study by Tapper (1999)

*Numbers indicate article, e.g. I = article I ** Software for media analysis; Qualitative Media Analyser

Two types of methods, interviews and attitude questionnaires, are discussed in further detail below, since these methods were used extensively in the research conducted.

6.1 Interviews: rich data sources, analysis more problematic

In all four articles interviews or recorded discussions were used to acquire information, since interviews are rich sources of information and can add nuances to, and complement, other more quantitative sources, such as questionnaires. As Kvale states "If you want to know how people understand their world and their life, why not talk to them?" (Kvale, 1996, p. 1). The strengths of interviews are that the unexpected can surface, there is direct contact with the person from which information is collected, and clarifying questions can be asked during the interview. In contrast, if an answer in a questionnaire raises new/additional questions following up is not easy. One disadvantage of interviews is that they are time consuming, especially in the analysis phase. The seemingly straightforward approach, to ask people if you want to know something, is also seductive since even during the interview the interviewer receives so much interesting and valuable information. The next phase, more deeply analysing and then presenting the information from the interviews, is time consuming and no single, universally applicable method has yet been developed and adopted by all researchers in the field. In the literature an array of methods for interview analysis has been presented, for example Kvale (1996) lists condensation, categorisation, narrative, interpretation and a*d hoc* approaches.

In my research the interview formats used could be described as semi-structured, or open with an interview guide, since I always used an interview guide starting with broader more open questions and progressing to more specific questions. The exact order of questions was adjusted to the progression of the interview, in contrast to a more fixed format where questions are always asked in the same order. All interviews were recorded: for article I on tape and for articles II-IV digitally on mini-disc. The interviews described in article I were listened to and categorised using a tape recorder, paper and pencil, while the QMA, qualitative media analyser, (Skou, 2001) program was used for all of the other interviews. QMA is a computer program that associates text files (i.e. categories, notes or transcripts) with the original sound files. This provides great scope for listening again to passages of interest in a specific context, comparing and judging them using the original sound recordings. Once the categorisation is complete it is, for example, possible to listen to all sequences in which student(s) say(s) something classified in a certain category. Use of QMA avoids the losses of information that inevitably occur during transcription, since all information conveyed through nuances such as tone, hesitation and emphasis is available in its original form.

In all of the studies interviews were analysed essentially according to the same basic principle. First, interesting and/or information-carrying passages were marked in working categories, which were then reduced to more thematic categories. In the interview analyses, the thematic categories varied. In article I the categories originated from the interviews themselves. In article II the categories also originated from thematic patterns found in the interviews, interestingly enough these categories were found to bear close resemblance to SOLO (structure of observed learning outcome) categories (Table 4). In article IV the working categories were found to fit categories used by Pintrich in a model of student motivation. Hence, Pintrich categories were used in the final categorisation, and in addition a narrative approach was used for capturing more nuances. This two-fold analysis of the interviews in article IV was considered appropriate since interviews were the main source of information. In article III, where the objects of categorisation were not interviews, but recorded discussions between students and their laboratory instructor, the thematic categories used were the same as those used by the students to estimate cognitive load. In this case it was found appropriate to use the same categories for the two types of data to facilitate comparisons.

In essence, these examples of different types of thematic categories, originating from the data, or from previous research, illustrate that there is no single best method to analyse interviews. This is in accordance with the fact that there is a rich flora of interview analysis methods.

6.2. Attitude questionnaires: one way to measure students' attitudes.

In this research a questionnaire was used to assess students' attitude towards learning chemistry. The questionnaire was based on other questionnaires (Henderleiter & Pringle, 1999; Reid, 2003) and applications in chemistry of Perry's model for intellectual development (Finster, 1989, 1991). The 34-item version of the questionnaire used is presented in Appendix A (in Swedish).

The use of questionnaires to measure students' attitude positions makes it possible to investigate the attitudes of large samples of students. The original method of interviews used by Perry (1970) is more time consuming and would be impractical in investigations of large groups of students. In the research done by the present author the attitude questionnaire was used as a tool to identify students with different attitude positions (LoPos and HiPos), rather than to place students on an absolute Perry scale. However, it was interesting (and encouraging) to find that when interviews were conducted with students the high/low positions found in the questionnaire analysis were consistent with those found in the interview analyses. The interviewer did not know the students' attitude position beforehand.

An important notion about attitude measurement and classification of students as HiPos and LoPos is that this is *not* the same as classifying them as good and bad students, nor as high achievers and low achievers. HiPos and LoPos denote different positions regarding their views of chemistry studies, i.e. position refers to their perspective on the world (or specific components/aspects of it).

The use of questionnaires to measure attitudes is further discussed below, under the heading *Past and future refinements of research tools*.

7. Main conclusions and discussion

The starting point for my research and this thesis was my experience as a chemistry teacher. Therefore, it was important for the research to be relevant, directly or indirectly, to education. In this section, the research presented in this thesis is first discussed in relation to the three questions that were the starting points for my research. Then the implications of the studies for teaching and learning, and some of their implications for research are addressed. Finally, the importance of this research, and future research, in a changing society where demands on higher education are changing, is considered.

7.1. The straightforward questions about attitude and motivation revisited

In the preface three questions were presented that were the starting points for this research. It was indicated that the questions have changed to some extent during the research process and that my views of attainable answers have changed. In the following section these questions are revisited and a brief summary of the attained answers is presented.

1. *Is it possible to assess students'* "*attitude*"*, which teachers say is important for learning? If so, how?*

The characteristics that teachers say are important are not easily defined, since terms such as motivation, right attitude, interest, and willingness to learn may hold different meanings, even if they may have a common core. In order to overcome the problems associated with investigating factors that are important (according to teachers and my own experiences), but not easily defined, I have based my research on groundwork done by Perry that was subsequently extended and applied to chemistry by other workers (Finster, 1989, 1991; Fitch & Culver, 1984). The attitude under study, from these foundations, has been students' attitude towards learning chemistry, including their views of knowledge, assessment, laboratory activities, and perceptions of the roles of instructors and students. If this is the attitude under study how could it be assessed? In the research presented here a questionnaire covering the attitude components views of knowledge, assessment etc. was found to be valuable since (a) many students were under study (making interviews too time consuming), and (b) fine details of attitudes or attitude changes were *not* primary concerns, instead contrasting groups, i.e. LoPos and HiPos and students showing major attitude changes, were studied.

Within these limitations (many students under study and major attitude differences) the use of an attitude questionnaire was found to be appropriate. The pragmatic validity of the instrument is shown by effects of attitude on learning outcome (articles I, II), the finding that positive attitude shifts are accompanied by more motivated behaviour (article IV) and the consistency of the attitude positions identified by the questionnaires and interviews (articles I, II, IV).

2. *Is it possible to make favourable changes to students' attitudes? If so, how?*

The second starting point question is not easily investigated since we were dealing with students in natural educational settings and we did not know in advance all of the factors that could favourably affect attitudes. A biological analogue of the question could be, "Is it possible to increase the size of plants"? For this biological analogue two distinctively different approaches could be adopted. Variables affecting growth, such as light and nutrients, could be manipulated, based on previous research findings, or plants of varying sizes could be studied, and attempts could be made to identify and characterise the variables that resulted in their differences in size. Even if the biological analogue has (severe) limitations it may help identify possible approaches.

The second of these approaches was used in the study of students' attitudes described in article IV, where students showing marked attitude changes were identified and interviewed. (The possibility to interview students is an obvious limitation of the plant analogue). The interview findings provided basic information that could be used to address the questions, "Is it possible to change students' attitude?" and "How could attitudes be favourably changed?" For the first question it can be concluded that students' attitudes changed, implying that attitudes can be changed, in accordance with other studies that have shown educational settings to affect the orientation and study approaches of students (Hofer, 2004; Ramsden & Entwistle, 1981). No simple answer was found to the second question, but some factors related to the attitude change could be identified. Positive attitude shifts were associated with motivated behaviour, while negative shifts were linked to less motivated behaviour. The findings indicate that the relationship between attitude and motivation presented in Figure 1 is valid, and they are consistent with Hofer's working model of the relation between epistemological position and motivation presented in Figure 4.

With respect to factors in the educational setting, it was found that students with negative attitude shifts expressed negative views of educational factors much more frequently, and more emphatically, than students with positive attitude changes, who expressed more positive views. Since the same factors (such as the students' perceived level of teacher empathy for their chemistry-learning efforts) affected both groups, the findings indicate possible scope for changes in educational settings that would be beneficial to "all" students. These educational implications are presented in Table 8.

3. *How are different learning situations experienced by students with different attitude positions?*

The question of how the learning situation is experienced by students holding different attitude positions was a central issue in two of the articles (I and II). Article IV also touches on the question, although the emphasis there is not on students *holding* certain positions, but those that showed major *changes in position*.

The first conclusion that can be drawn from the results is that students holding different attitude positions experience learning situations differently. This was demonstrated in articles I and II, where attitude positions were shown to affect not only the way the activity was perceived, but also the outcome for students. In article IV it was shown that students holding different attitude positions differed strongly in their judgements of factors in the shared educational context of a full semester of chemistry studies. These findings can be seen as illustrations of Perry's original way to describe positions, as different positions to view the world. This may seem uncontroversial, nevertheless the findings could have implications for learning and research since *a learning* situation is really comprised of multiple *learning situations.* For teaching this implies that when we plan learning activities we should be aware that what we plan will be experienced differently by different students, and their learning outcome will differ. Thus, students' attitude positions should be an important consideration for teachers when they are planning activities. From my own teaching experience this could explain why presumably brilliantly planned learning activities failed; the activity may have been "good" but the students were not ready for the challenge.

For research, this notion that the way that learning situations are experienced is dependent on students' attitude positions implies that when we investigate educational phenomena it could be important to consider students' attitudes, and to avoid regarding them as an undifferentiated cohort.

7.2. Implications for teaching and learning

7.2.1. The learning situation.

In three of the four articles this thesis is based upon, the learning situation under study is laboratory work. The possible implications of the studies for laboratory work cover three main areas: the role of the teacher, openness, and the importance of pre- and post-laboratory work.

In article I it was shown that discussions with the teacher (and the interviewer) were important for promoting the learning and development of ideas among students. A check-point (discussion with the laboratory assistant halfway through the laboratory activity) was introduced mainly to promote this discussion. The positive outcome of the revised version of the open experiment (with the check-point) could be partly due to this "scheduled" discussion. Similar results are reported in article III, showing that the laboratory assistant promoted the development of students' reasoning about the results and theory connected to the laboratory activity. In article IV it was shown that the teacher also influences the way that students perceive their course and their behaviour (even though the focus of that article was not specifically on laboratory work). Taken together, these findings suggest that the teacher plays an important role in the students' learning and during laboratory work a teacher who is genuinely interested in the students' learning has a positive effect.

In article I the question of how openness of the laboratory activity affects students was addressed, and it was found that the open version showed the most positive learning outcome and engagement among students. In this case the activity may have been a challenge of appropriate complexity and students seem to have possessed enough knowledge and abilities to benefit from the activity. Another factor that may have contributed to the positive results is that the students "owned" the experiment in the open-inquiry version since they had planned it themselves. In article II the final part of the practical laboratory activity was open since students could choose what water solution to investigate and their own "research question". As in article I, this open activity generated an array of different investigations and most students were engaged in and had a positive attitude towards the activity.

These positive results do not necessarily mean that more open activities are always "better". A possible cause for concern is the mental load an open activity could impose on students. The planning and decision-taking that students are required to undertake during open activities could add to their mental load and possibly generate overload, especially if the procedures involved are complicated (generating intrinsic cognitive load) or the laboratory is poorly organised (generating extrinsic cognitive load). In addition to the risk of excessive mental load being placed on students, their attitude towards chemistry, and laboratory work in particular, could also be a cause for concern when more open laboratory activities are introduced. In article I it was found that LoPos students were reluctant to tackle the open activity since they experienced more demands (which could be partly attributed to mental load, as discussed above) and were not familiar with the demands associated with planning, conducting and evaluating experiments on their own. An encouraging finding was that a clearer description of this goal (a revised version of the open activity), to conduct their own experiment, rendered the students more prone to accept the challenge. In conclusion, open laboratory activities should be introduced to promote students' abilities to conduct "real" experiments, a target stressed in study programmes and goals for higher education, but the issues of mental load and whether or not the students are ready for the challenge (i.e. their attitude) should be considered. A clear statement of the experimental goals and relevant support are examples of the basic structures that may be required to help students attain both the experimental and the broader educational goals.

Regarding the importance of pre-and post-laboratory activities it was found in article II that a pre-lab exercise designed to give the students a more coherent understanding of theory connected to the laboratory activity positively affected their use of theory related to the practical laboratory work. The students that had undertaken the pre-lab exercise also showed a deeper understanding of what they had done and could make better use of their chemistry knowledge. In article III an indication of the importance of thinking after the practical part of the laboratory activity was found, since students concentrated on this while performing the practical components. Thinking, about the theory associated with the activity, mainly took place in later stages, when the majority of the practical work was finished.

Two conclusions about how to organize laboratory work can be drawn from these findings. Firstly, if students know the theory related to an experiment, and how to apply it, they will benefit more from the activity since they have mental capacity available for thinking about what they are doing in addition to doing it. Here, pre-lab activities could be helpful. Secondly, since the practicalities of laboratory work seem to occupy most of the students' thinking capacity while they are completing practical tasks it is important to allocate time for the students to work on their results and findings. This could be achieved by asking the students to present and discuss their results, or via feed-back and discussion about laboratory reports, and last but not least by giving the students enough time to complete the task *and* understand what they are doing.

7.2.2. Motivation

What factors may motivate students? This is a fundamental issue for teachers and researchers, but we should not expect to find “a silver bullet” answer to this question since we are dealing with humans who differ in ability, interest and age in different educational contexts. A list of suggested educational implications, based on the findings in article IV, is presented in Table 8. This list is an example of a specific researcher’s (the author’s) efforts to identify factors that could motivate students. Another list of *design principles* that could influence motivation, also based on research findings, was presented by Pintrich (2003), see Table 9. Pintrich’s design principles were presented in a review article with a lifelong perspective on motivational research (Pintrich died shortly before the article was published). Both of these lists could be seen as outcomes of our research efforts to answer the question, “What factors may motivate students?” Although Pintrich’s list is more detailed and covers more aspects it’s interesting to note that there are similarities between the two lists.

Table 8. Summary of suggested educational implications based on findings in article IV.

Stimulate situations/atmosphere like these	***Avoid situations/atmosphere like these***
Teachers being available (mentally and physically) for students, creating an atmosphere where it is acceptable to ask questions and it is accepted that everything may not be understood immediately.	Teachers just “teaching” with no genuine interest conveyed in student learning. Viewing student questions and problems as unwanted interruptions in their teaching.
Teachers being accessible especially when students approach demanding tasks.	Students not allowed contact with teachers especially during demanding tasks.
Opportunities for students to work collaboratively and exchange ideas.	Individualistic, competitive atmosphere producing only a few “winners”.
Where appropriate and possible, connect chemistry to other subjects and situations.	Chemistry viewed as an isolated subject with no applications to areas outside chemistry.
Convey clear instructions and goals especially when students are expected to accomplish intellectually demanding or new tasks – e.g. planning experiments or tutorial questions with no clear, single answer.	Assigning students ill formulated or badly planned experiments or tasks. This should not rule out ill “formulated” tasks if they are intentionally set and students are aware that reality is seldom simple and that they must learn to deal with such situations.
Allocate enough time for students to accomplish a task and communicate clear goals for what is expected.	Create real or perceived lack of time so that students feel that “*it’s useless for me to try*”.

Table 9. Design principles for instruction based on motivational research (Pintrich, 2003, p.672).

Design principle
Provide clear and accurate feedback regarding competence and self-efficacy, focusing on the development of competence, expertise and skill.
Design tasks that offer opportunities to be successful but also challenges students.
Provide feedback that stresses process nature of learning, including importance of effort, strategies, and potential self-control of learning.
Provide opportunities to exercise some choice and control.
Build supportive and caring personal relationships in the community of learners in the classroom.
Provide stimulating and interesting tasks, activities, and materials, including some novelty and variety in tasks and activities.
Provide content material and tasks that are personally meaningful and interesting to students.
Display and model interest and involvement in the content and activities.
Provide tasks, material, and activities that are relevant and useful to students, allowing for some personal identification with school.
Classroom discourse should focus on importance and utility of content and activities.
Use organizational and management structures that encourage personal and social responsibility and provide a safe, comfortable, and predictable environment.
Use cooperative and collaborative groups to allow for opportunities to attain both social and academic goals.
Classroom discourse should focus on mastery, learning and understanding course, and lesson content
Use task, reward and evaluation structures that promotes mastery, learning effort, progress, and self-improvement standards and less reliance on social comparison or norm-referenced standards

Both these lists represent attempts to give educational suggestions based on research findings. This kind of "advice" could generate at least two responses from experienced teachers, in the present author's experience. One common response is "For me there is almost nothing new in this, I already know most of it and try to teach according to it". This kind of response is in my opinion encouraging since it gives the findings pragmatic validity and, hopefully, the teacher could gain some new ideas or thoughts even if "most was already known". Another response is that the teacher is provoked by the suggestions and makes comments like, "It is easy to come up with good lists of how teaching should be done, but my working conditions prevent me from realizing most of this".

This response is also encouraging in that the teacher finds the suggestions appropriate, but it is less encouraging that the educational setting does not give the teacher the scope to apply the suggestions.

Pintrich comments on how practitioners should make use of research findings with these words.

> *Architects may have some general design principles that guide their work, but there are clearly very different instantiations of these principles as there are many different types and forms of buildings that are built. In the same manner, teachers and instructional, curriculum, and technology designers need to adapt these principles to fit their goals and the affordances and constraints of the local instructional context and culture* (Pintrich, 2003, p. 672).

7.3 Implications for research

Early on in my research in chemical education I realized that I had entered a vivid and rapidly developing research field in which much knowledge and many research methods were available. Some research judged to be especially relevant has been presented above in the section *Theory and research related to this thesis*, and ideas for refining the research tools used, and for further investigations, are presented below.

7.3.1. Past and future refinements of research tools.

For two of the methods, the attitude questionnaire and check sheets for questions asked, different versions were used (Table 7). In both cases the first version was changed to improve the instrument. For the attitude questionnaire the format was changed from a traditional Likert format to a “two-sided” Likert format. The reasons for this change are discussed in article IV (pages 3-4), but in essence the two-sided format avoids possibilities for ambiguity; both sides of the scale are defined. In addition, the analytical method was changed since the method first used, calculation of means for all questions for each student, did not exploit the full potential of the data. This was indicated already in the first article where this evaluation method was used (article I, page 354). In later uses of the questionnaire PCA was used for analysis since PCA gives a model for attitude, originating from the data (Eriksson et al., 2001). The advantages of this approach are discussed further in article IV (pages 4-5).

For the check sheets (used by the laboratory assistants to mark questions asked by the students) a change was made from a three-dimensional format (practical/theoretical, detailed/contextual, and spontaneous/reflective) to a two-dimensional format (practical/theoretical and spontaneous/reflective), for two reasons. Firstly, it was cumbersome for the laboratory assistants to undertake a three-dimensional categorisation at the same time as supervising the laboratory work. Secondly, the two dimensions detailed/contextual and spontaneous/reflective to some extent overlapped. Spontaneous questions were commonly about details, such as

“Can I use this stopper?” and spontaneous questions that were contextual rarely occurred; they tended to be reflective.

These changes in the two instruments can be seen as refinements of research tools. In the future further refinements could be made. For the check sheets used to classify questions asked during laboratory work it could be possible to reduce the number of dimensions to one; theory/practice. This single dimension could be sufficient in certain instances, such as course development where a coarse measure of focus is needed. Regarding the attitude instrument, PCA has indicated that some items are not very important in the model, hence new versions of these items have been added to the instrument (items 32-34). The new items show more importance in the model (higher loadings) and the old versions of the items could be excluded. It is also noteworthy that another attitude instrument has recently been developed by Dalgety et al. (2003) which could be used, together with our instrument, as a basis for further development of attitude instruments.

7.3.2. Final comments

Universities in Sweden are facing demands from society and politicians to provide a university education for a larger proportion of the population. For example, the government has set a goal that 50 % should have started a university education by the age of 25. Changing circumstances in working life have also caused people to enter and re-enter university at different (older) ages. These changes in society and universities have increased the diversity of our students in terms of age, experience and knowledge. Facing new groups of students, it is becoming increasingly important to consider their attitudes and motivation (and to make appropriate modifications to our learning situations) if we are to fulfil our commission to provide high quality learning environments and high quality learning. The goal for higher education is expressed in the Swedish higher education act by these words “*provide the students with a capability of independent and critical judgment, an ability independently to solve problems and an ability to follow the development of knowledge, all within the field covered by the education”* (Swedish Higher Education Act, 1992).

My interpretation of this goal is that students are expected to develop the ability to use their knowledge to tackle relevant tasks and problems, as indicated by the words *capability, independently, critical judgement, solve problems, and follow the development of knowledge*.

Such use of knowledge is found in the higher facets of the “hierarchies” of both the Bloom and SOLO taxonomies (see Tables 3 and 4 for brief descriptions of these taxonomies). I doubt that anyone involved in higher education, or policy-making for higher education, would object to the statement “We want our students to reach these higher facets of Bloom and SOLO taxonomies”. However, when it comes to *how* students could reach these higher goals and *how* we should organize the learning situations to attain these goals I have found less agreement. This is not to say that disagreement is necessarily bad; we have different perspectives, and emphasise different important aspects of learning. From the perspective of my research I would say that our students’ attitudes towards learning (chemistry) and their motivation are key components for attaining the desirable “higher goals”.

To give an example of another important component, which was not prominent in my research, I would mention examination and assessment, which affect what students learn and how they can use their knowledge (Bergendahl, 2004).

Future research on students' attitude positions (and how they affect the outcome of learning situations other than laboratory activities), examinations and assessments could add to our knowledge of how our students can reach higher educational goals. Projects focusing on the "other side of the coin" – how attitudes are developed and affected by learning environments and assessment – would also be most interesting. From my experience this kind of research would benefit from the involvement of science education researchers working in *cooperation* with teachers and the learners.

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Possible:
Bruno who encouraged me and enabled me to set sail at the start of the voyage.

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Christina and Mikael who have been sharing the ups and downs during the journey, sometimes as crew and sometimes as spectators. Christina, I will try to remember the wise words you said, and I will never forget our laughter when we were exhausted. Mikael, you are right, two brains are better than one. Two brains can even re-invent the SOLO taxonomy

Going in the right direction:
Johan and Lisbeth, it’s useful to have guides in the boat.

Navigate:
Henry and Norman, people that have navigated the waterways before are good company in the boat. If they also know the language of ~~the~~ natives they are even more useful.

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Appendix B.
Explanations of some educational research terms

This list of explanations is not designed to be a comprehensive thesaurus of terms used in science education research, neither would the explanations necessarily be accepted by all researchers. In many cases a full description of a word could constitute a thesis in its own rights since the terms are under debate and their meaning is not always clear-cut. The explanations given represent (part of) my own understanding and for those of you who want a fuller description see psychology, social science or education dictionaries. A cursory search on the internet will also give useful (but sometimes confusing) information. Bearing these precautions in mind, I hope that the list could be helpful for teachers interested in reading the thesis, since even an incomplete explanation is better than nothing.

Action research	Research methodology that involves action, or change, and research at the same time. For example, a group of teachers/researchers, together with their students, may investigate their course in a cyclic process in which changes are based on findings in previous runs of the same course.
Attitude	The word attitude in research is used in very much the same way as attitude in everyday life. An example of a scientific definition of attitude is, "*Attitude is a psychological tendency that is expressed by evaluating a particular entity with some degree of favor or disfavor*". The notion "I like laboratory work" is an attitude both from a research perspective and also in the everyday use of the word attitude.
Cognitive	Human thinking. For example cognitive development describes how thinking develops and cognitive focus could be used to describe what someone is thinking (most) of.
Constructivism	Constructivism is a philosophy of learning founded on the idea that by reflecting on our experiences we construct our own understanding of the world we live in. In other words, knowledge is constructed in the learners' mind and not directly transferred from the teacher. In science education this is a widespread perspective.
Epistemology	Epistemology was originally a branch of philosophy in which knowledge was studied. In educational psychology epistemology treats issues such as how knowledge is constructed, evaluated, where it resides, and how knowing occurs.
Likert format (in questionnaires)	A technique to measure attitudes originally developed by R. Likert in 1932. A written statement is given and the person is asked to respond on a scale from strongly agree to strongly disagree; usually five response categories are used.

LoPos and HiPos	Abbreviations of lower/higher attitude position, respectively, describing the way students view chemistry studies. HiPos show a more relativistic and LoPos a more dualistic view. LoPos and HiPos are not descriptions of good and bad students.
Metacognition	The process of thinking about one's own thinking. I am engaging in metacognition if I notice that I learn more by solving problems together with others than by solving problems alone.
Overload (mental overload)	Term used to describe the situation where working memory (described below) is used “above” its capacity. It can also be described as a situation where too much information and too many thoughts have to be handled simultaneously.
Post-lab	Exercise following a laboratory activity, usually designed to promote understanding of “what happened” or a clearer understanding of theory connected to the laboratory activity.
Pre-lab	Exercise preceding a laboratory activity, usually designed to promote understanding of “what to do” or a clearer understanding of theory connected to the laboratory activity.
Triangulation	Technique of using several (at least two) different methods to investigate something that is interesting but not easily described or measured, e.g. the learning outcome of a laboratory activity where examination results, students’ self evaluations, and interviews could all give relevant, but incomplete, information. By using all three methods in conjunction more complete information can be gained about the learning outcome.
Working memory and Long-term memory	Working memory is where our conscious cognitive (thinking) processes occur. Working memory can only handle a few elements at the same time. In cases where too many thinking elements are required simultaneously, the term overload is used. Long-term memory, on the other hand, can store immense amounts of information that can be brought to the working memory when needed. For example, if you tried to calculate the total annual cost of your food you would use information such as mathematical rules and memories of monthly payments from your food account, and lunch prices, stored in your long term memory and then do the thinking and calculation in your working memory.

Appendix A. Attitydenkät.

CHEER Chemical Education Research and Development

Namn | Program

Detta frågeformulär behandlar din inställning till lärande. Du hittar nedan en rad motstående påståenden med fem rutor emellan. Genom att kryssa en av rutorna anger du vad du anser om påståendena.

Ett exempel

Jag måste ha bakgrunds musik när jag studerar.	☐	☐	☐	☐	☐	Jag står inte ut med något bakgrundsljud när jag studerar

Om du kryssar rutan längst till vänster betyder det att du samtycker med påståendet till vänster. Kryssar du ruta två betyder det att du håller med men inte lika starkt som om du kryssat ruta ett. Ett kryss i mitten betyder att du inte tycker något speciellt när det gäller påståendena. De två rutorna till höger betyder att du håller med om påståendet på den sidan.

Det finns inga riktiga eller felaktiga svar utan det är vad du tycker som räknas! Dina svar skall användas för att vi ska kunna göra våra kurser bättre för studenterna.

S=samtycker **SD**=samtycker delvis **N**=Neutral

		S	SD	N	SD	S	
1	För att klara en kurs ska det räcka med att jag lär mig det läraren har föreläst om.	☐	☐	☐	☐	☐	För att klara en kurs räcker det inte att bara lära sig det läraren föreläst om.
2	Jag anser att en bra föreläsare ger inblick i flera olika sätt att betrakta ett fenomen/kunskapsområde.	☐	☐	☐	☐	☐	En bra föreläsare ger studenterna den mest accepterade förklaringen av ett fenomen/kunskapsområde.
3	Jag tycker att föreläsare ska undvika att ta med sådant i kursen som de vet är svårt för studenterna.	☐	☐	☐	☐	☐	Jag tycker att föreläsare bör ta med svåra saker i kursen för att ge studenterna utmaningar.
4	Jag tror inte på att bara lära mig vad läraren lär ut. Jag försöker själv bedöma vad som är viktigt.	☐	☐	☐	☐	☐	Jag lär mig det som läraren säger. Funderar jag för mycket kan det sluta med att jag "kör".
5	Jag anser att det är lärarens uppgift att förse mig med den kunskap jag behöver.	☐	☐	☐	☐	☐	Lärarens uppgift är inte att lära mig allt jag behöver kunna, utan att stimulera mitt eget tänkande.
6	Om jag läser något som inte stämmer med det som läraren beskrivit håller jag mig till det läraren sagt.	☐	☐	☐	☐	☐	Om jag läser något som inte stämmer med det som läraren beskrivit vill jag diskutera det med läraren.

7	Jag tycker att det är bra att jobba tillsammans med andra studenter. Genom att höra deras synpunkter kan jag lära mig mera.	☐ ☐ ☐ ☐ ☐	Jag föredrar att jobba ensam eftersom jag då undviker att plocka upp felaktiga ideer från andra studenter.
8	Det är slöseri med tid att jobba med problem där det inte går att komma fram till ett entydigt svar.	☐ ☐ ☐ ☐ ☐	Det är väl använd tid att jobba med problem även om det inte går att komma fram till ett entydigt svar.
9	Jag gillar att ta mig an ett problem där läraren inte exakt har visat hur det skall lösas.	☐ ☐ ☐ ☐ ☐	Jag gillar att läraren har visat hur man ska gå tillväga för att lösa en viss typ av problem.
10	Tentamensfrågor ska till största delen bestå av frågor där man ska analysera och diskutera olika frågeställningar och problem.	☐ ☐ ☐ ☐ ☐	Tentamensfrågor ska till största delen bestå av frågor som kan besvaras med relativt korta svar.
11	På tentamen vill jag helst ha frågor av den typ som behandlats under kursen.	☐ ☐ ☐ ☐ ☐	På tentamen får det gärna förekomma frågor som ej direkt behandlats under kursen.
12	Jag anser att det är kvaliteten på mina tentamenssvar som skall räknas, inte hur mycket jag skrivit.	☐ ☐ ☐ ☐ ☐	På tentamen förväntar jag mig hög poäng om jag fått med så mycket som möjligt.
13	Jag vill ha ett graderat betyg på kursen som grundar sig på mitt tentamenresultat.	☐ ☐ ☐ ☐ ☐	Jag skulle uppskatta att, förutom betyget, få ett utlåtande om mina kunskaper på kursen.
14	Jag föredrar tentamensfrågor som ger mig möjlighet att visa att jag har egna förslag till lösningar.	☐ ☐ ☐ ☐ ☐	Jag föredrar tentamensfrågor som kan lösas med den metodik vi tränat på under kursen.
15	I kemi är det viktigast att man lär sig fakta och hur man använder formler.	☐ ☐ ☐ ☐ ☐	I kemi är det viktigast att man lär sig förstå samband och mönster bland fakta och formler.
16	En laboration skall komma först efter det att all teori som den skall belysa är genomgången.	☐ ☐ ☐ ☐ ☐	En laboration kan genomföras utan att nödvändig teori gåtts igenom.
17	En laboration skall vara upplagd så att jag får bra data som verifierar den teori som avses.	☐ ☐ ☐ ☐ ☐	En laboration skall vara upplagd så att jag får verklighetstrogna data även om de kräver en hel del arbete att tolka.
18	En laborationsinstruktion bör inte innehålla hjälpfrågor. Jag vill själv komma på poängen med laborationen.	☐ ☐ ☐ ☐ ☐	En laborationsinstruktion ska innehålla frågor som hjälper mig att förstå poängen med laborationen.

19	Jag tror att jag bäst lär mig den teori som laborationen skall illustrera om jag själv planerar och genomför experiment.	☐	☐	☐	☐	☐	Jag tror att jag bäst lär mig den teori som laborationen skall illustrera om det finns utförliga anvisningar som visar hur experimentet skall läggas upp och genomföras.
20	En laborationsinstruktion skall vara försedd med förtryckta formler och tabeller så att jag samlar data på ett rationellt sätt.	☐	☐	☐	☐	☐	En labinstruktion skall ge mig en uppgift att lösa, jag vill själv konstruera mina tabeller och söka de formler som behövs.
21	När jag gör ett experiment vill jag att läraren hjälper mig så att det blir rätt direkt.	☐	☐	☐	☐	☐	När jag gör ett experiment vill jag helst pröva själv utan att läraren kommenterar mitt arbete.
22	De experiment som jag utför i kemi avspeglar inte vad kemister gör i sitt arbete.	☐	☐	☐	☐	☐	De experiment som jag utför i kemi avspeglar vad kemister gör i sitt arbete.
23	Jag kan använda kemiska metoder inom andra delar av naturvetenskapen tex biologi, geovetenskap etc.	☐	☐	☐	☐	☐	Jag kan inte använda kemiska metoder inom andra delar av naturvetenskapen tex biologi, geovetenskap etc.
24	Jag tycker att laborationer är något av det viktigaste inom kemistudierna.	☐	☐	☐	☐	☐	Jag tycker att laborationerna är ett mindre viktigt inslag i kemistudierna.
25	Kemiska experiment är oftast ointressanta.	☐	☐	☐	☐	☐	Kemiska experiment är oftast intressanta.
26	När jag jobbar i labbet gör jag något som känns viktigt.	☐	☐	☐	☐	☐	När jag jobbar i labbet känns det inte att jag gör något viktigt.
27	Jag klarar inte av att utföra kemiska experiment på ett riktigt sätt.	☐	☐	☐	☐	☐	Jag klarar av att utföra kemiska experiment på ett riktigt sätt.
28	Kemikunskaper är värdefulla för att kunna lösa viktiga problem inom tex miljö eller medicin.	☐	☐	☐	☐	☐	Kemikunskaper behövs knappast för att kunna lösa viktiga problem inom tex miljö eller medicin.
29	Jag tror inte att jag kommer att få någon större nytta av det jag lärt mig i kemi i mitt framtida yrke.	☐	☐	☐	☐	☐	Jag tror att jag kommer att få stor nytta av det jag lärt mig i kemi i mitt framtida yrke.
30	Det är viktigt att få utföra laborationer på riktiga prover tex malmprover eller livsmedel även om det är mera tidskrävande och komplicerat.	☐	☐	☐	☐	☐	Att utföra laborationer på riktiga prover blir för tidskrävande och komplicerat för att vara värt besväret.
31	Det är viktigt att kunna presentera sina experimentella data på ett tydligt och lättbegripligt sätt.	☐	☐	☐	☐	☐	Det är inte speciellt viktigt att kunna presentera experimentella data. Det viktiga är att jag gjort rätt och förstått.

32 Jag uppskattar att någon som verkligen vet förklarar ett problem	☐	☐	☐	☐	☐	Jag uppskattar att höra andras synpunkter som tänkbara förklaringar på ett problem
33 Inom andra naturvetenskaper är kunskaper i kemi mindre viktiga	☐	☐	☐	☐	☐	Inom andra naturvetenskaper är kunskaper i kemi väldigt viktiga
34 Jag kan tänka mig att se vad som händer när jag gör ett experiment innan jag lärt mig tillhörande teori	☐	☐	☐	☐	☐	Jag vill kunna teorin för vad som skall hända innan jag gör ett experiment