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Physics Students' Experiences of the Disciplinary Discourse Encountered in Lectures in English and Swedish

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Abstract

This thesis is an investigation of undergraduate physics students' descriptions of their learning experiences with respect to the lectures they attend. The work examines three connected areas; the effects of the *language of instruction* on learning in Swedish university physics lectures, students' experience of the *equations* presented to them in physics lectures and the way in which learning in university science may be characterized as entering a *disciplinary discourse*.

Twenty-two undergraduate physics students at two Swedish universities attended lectures in both English and Swedish as part of their regular undergraduate programme. These lectures were videotaped and students were then interviewed about their learning experiences using selected excerpts of the video in a process of stimulated recall.

From a language perspective, it was found that there were important differences when Swedish students are taught physics in English and that students were on the whole unaware of the significance these differences for their learning. When taught in English the students asked and answered fewer questions and reported being less able to follow the lecture and take notes at the same time. Students employed a number of strategies to meet these problems by; asking questions after the lecture, changing their study habits so that they no longer took notes in class, reading sections of work before class or by using the lecture for mechanical note taking and then (perhaps) doing extra work with the notes outside class.

The study also maps out the variation in students' experience of the meaning of physics equations, making a number of observations about the students' focus of attention. The main finding here is that students initially focus on the *mathematical nature* of the equation—the physics and real world meaning is absent. A set of pedagogical 'context questions' which may help both lecturers and students to focus on appropriate components of a given physics equation are suggested.

Finally, the thesis combines the work in the area of language and the understanding of equations by characterizing student learning in university science from the perspective of entering a *disciplinary discourse*. An analytical framework for the analysis of such discourse is presented and applied to the interview data. Pedagogical implications of this approach are discussed.

To my family

Preface

The work presented in this thesis sprang from a chance encounter with a job advertisement in 2001. The Swedish National Research School for Science and Engineering Education was in the process of being started and they were advertising for PhD students. I wondered what it would be like to do a PhD in Sweden, and I toyed with the idea of applying—though not too seriously it must be said. Applicants had been invited to put forward a research proposal. I found myself wondering what sorts of things they would be interested in that I actually knew *anything* about. Although trained as a physics teacher I had been teaching English for Specific Purposes for ten years, mostly at university level, so I reasoned that if I were to apply it would have to be something to do with the language aspect of learning university physics.

The courses I teach at the University of Kalmar are language courses. My students need to develop an ability to use English to describe and explain concepts that they have already learnt. Thus, I was used to teaching English skills through a subject that students were familiar with. But what if I turned this on its head? What if I looked at learning the subject *through the language*? The seeds of a research project had been sown.

My encounters with Swedish students during one-to-one tutorials had convinced me that, for some of them at least, learning their subject in English would present serious problems. These problems I predicted would stem from a surface appreciation of the material presented to them. I hypothesized that listening to lectures in English would present the greatest challenge. With English texts, students could stop, look up a word and then continue, but a lecture just goes on and on—unless of course someone is brave enough to ask a question that is… Little did I know that this off-the-cuff analysis would be just the tip of the iceberg.

In the end I didn't apply for that job—after all I wasn't seriously considering doing a PhD. Or was I? The idea persisted and gradually matured, and here in your hand you have a direct product of that day-dreaming episode back in 2001.

John Airey
Kalmar
April, 2006

List of attached peer reviewed publications and conference presentations

Paper I
Airey, J. (2004). Can you Teach it in English? Aspects of the Language Choice Debate in Swedish Higher Education. In Wilkinson, R. (Ed.), Integrating Content and Language: Meeting the Challenge of a Multilingual Higher Education (pp. 97-108). Maastricht, Netherlands: Maastricht University Press

Paper II
Airey, J., & Linder, C. (2006). Language and the experience of learning university physics in Sweden. European Journal of Physics, 27(3), 553-560.

Paper III
Airey, J., Domert, D., & Linder, C. (2006) Representing disciplinary knowledge? Undergraduate students' experience of the equations presented to them in physics lectures. Extended abstract accepted for presentation at *EARLI SIG-2 2006 biennial meeting*. University of Nottingham. 30 August – 1 September 2006, Nottingham, UK.

Paper IV
Airey, J., & Linder, C. (2006 submitted) Necessary conditions for learning? Modes of representation and the disciplinary discourse of university science. Journal of Research in Science Teaching.

Contents

Abbreviations

The following abbreviations are used in the text:

CLIL	content and language integrated learning
EOL	enacted object of learning
IOL	intended object of learning
L1	first language
L2	second language
LOL	lived object of learning
SPRINT	språk-och innehållsintegrerad inlärning och undervisning (the Swedish equivalent of CLIL)
SSL	shared space of learning
PER	physics education research

1. Introduction to the study

1.1. Introduction

This thesis is an investigation of undergraduate physics students' descriptions of their learning experiences with respect to the lectures they attend. The students in this study attended lectures in Swedish and English, and the intention was to examine the effects of this dual language approach to physics learning. This research interest is the focus of papers I and II. A further aspect of the lectures was the use of equations to represent physics knowledge. This aspect is explored in paper III which deals with students' experience of the equations presented to them in physics lectures.

From this work grew an approach which is underpinned by an internationally emerging area of interest in all disciplines—the characterization of learning as entering a discourse. Within this context, Swedish and English can be viewed as aspects of a wider notion of *disciplinary discourse* which encompasses the representations, tools, and activities of university physics. This is the focus of paper IV.

1.2. The significance of the study

The work presented here makes research contributions in four specific areas:

- The understanding of the way in which the relationship between teaching and learning of undergraduate physics change when the language varies between Swedish and English.
- A contribution to the understanding of student experiences of physics equations.
- The development of an analytical framework for characterizing learning as entering a discourse.
- An approach to dealing with the collection and analysis of large amounts of interview data which bypasses verbatim transcription.

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1.2.1. Language of instruction

Swedish society has an impressive level of general English, with the country consistently being rated at the top end in international surveys of language skills (Falk, 2001a). Much higher levels of English language skill are commonplace in Swedish higher education, where the use of English is widespread. In physics the majority of textbooks and a sizable proportion of the teaching at higher levels takes place in English. Recently there has been much discussion about the effects of the exposure to this amount of English. Do students learn physics as well in a language other than their mother tongue? Is there any educationally critical risk that students taught in English are unable to function to their full potential when discussing physics in Swedish? These are some of the questions presently being asked by a number of different stakeholders in Swedish higher education. At the same time, the government is seen to be actively encouraging the use of English, emphasizing the positive benefits for Sweden in the competitive global marketplace, and as a response to the Bologna Declaration.

One of the reasons for the mixed signals in the higher education sector is the lack of solid research in the area of language of instruction and learning. A thorough literature review carried out for this thesis revealed no studies carried out in Sweden into the content learning outcomes when teaching courses in English at university level. There are, however, a number of Swedish studies at pre-university level and several international studies at university level which have examined the learning outcomes for students taught in a language other than their first language. Such studies have attempted to correlate the language used to teach a course with results on examinations or researcher implemented test results. A common factor for all of these studies is an inability to control for the huge diversity of possible variables, and results have therefore been widely regarded as inconclusive.

Thus, the work presented here goes some of the way to redressing this gap in our knowledge by comparing the learning patterns of students in Swedish university physics programmes when they are taught in English and in Swedish. Instead of trying to measure learning through assessment for different samples of students, the work presented here examines *the experience of learning physics* in English and in Swedish (by capturing both the differences across learning experiences and the situatedness of the individual learning experience). Thus instead of a "Which language is better?" approach, the focus of paper II of this study is on the ways in which the relationship between teaching and learning in one language *differs* from this relationship in another language. As such the work gives guidance to teachers of physics courses delivered in English in Sweden as to specific areas which may be problematic.

1.2.2. Equations

As a discipline, physics is concerned with describing the world by constructing models—the end product of this modelling process often being a mathematical representation, which in physics is colloquially referred to as an *equation*. Despite their importance in the representation of physics knowledge, physics equations have received surprisingly little attention in the literature. Whilst a great many studies explore the situated understanding of *specific* equations and their use in problem solving, (see Hsu, Brewe, Foster, & Harper, 2004) the *general* nature of physics equations and how they are experienced by students remains to a large extent unexplored. One exception is the work of Sherin (2001) who has examined students' ability to construct equations. Sherin explains his results in terms of *symbolic forms*—in essence, a limited generic set of templates and elements for equations, which he suggests students have learnt. In contrast, the work presented here explores students' understanding of the equations presented to them in physics lectures. As such it extends Sherin's work by shifting the focus from *production*—representing ones own knowledge in equations, to *interpretation*—deciphering the disciplinary knowledge that the equation represents. Paper III maps out the variation in students' experience of the meaning of physics equations, making a number of observations about the temporal development. This knowledge is then used to suggest a set of pedagogical 'context questions' which may help both lecturers and students to focus on appropriate components of a given physics equation.

1.2.3. Disciplinary discourse

Analysis of the interview data collected led to the original focus moving to include other representations than language, such as mathematics, graphs and diagrams. This in turn led to the adoption of a discourse perspective on learning. Paper IV presents an analytical framework for characterizing learning in university science as entering a disciplinary discourse. Disciplinary discourse is defined as the complex of *representations, tools* and *activities* of a discipline.

1.2.4. An innovative approach to working with interview data

The usual approach to work with interview data is to first transcribe the recording verbatim. Data analysis then takes the form of working with this transcript. In this study, however, all interviews were recorded digitally, enabling direct access to their various sections. This, together with the structure generated by the stimulated recall approach, led to the following form of data analysis. Each of the digital interview files were "cut" into sections where students discussed similar themes. Each of these sections was given a

filename consisting of the topic discussed, the student's name and a five digit identification code which was in fact the excerpt's time stamp in the original master recording. This facilitated cycling through the data since it was possible to listen to several students talking about similar and related themes, efficiently building up an overall picture of what students were saying as individuals and as a group.

This approach of analysis had two benefits: first analysis could begin within a few days of collecting the data, bypassing the lengthy process of transcription, and second, more of the situatedness of the interview was maintained—transcripts being generally acknowledged as one step further away from the phenomenon under study than the audio recording. Maintaining this situatedness was considered important since in the interviews we were attempting, through stimulated recall, to vividly recapture for the students the essentials of their experience of being in a specific lecture. Student files could also easily be re-related to the whole of the interview due to the timestamp identification code we used which led us directly to the correct position in each master recording.

1.3. The research questions

As explained in the previous section, the work presented in this thesis originally stemmed from an interest in the two languages used to teach undergraduate physics in Sweden—English and Swedish. How did this dual language approach affect student learning? During the course of data collection and analysis this focus changed, first to three "languages"; English, Swedish and Mathematics and then to a more general question about the way in which physics knowledge is represented by physics discourse. Thus, the work reported here is part of a larger, ongoing project where the research questions are:

- How may learning in university physics be characterized in terms of entering a disciplinary discourse?
- How do students describe the way in which they learn to interpret and use this disciplinary discourse?

A theoretical and empirical approach to these questions is presented in paper IV of this thesis. In papers II and III, two aspects of this disciplinary discourse are analyzed in detail in an attempt to answer the following two research questions:

- How do Swedish undergraduate students experience being taught physics in English?

- How do Swedish undergraduate students experience the equations presented to them in physics lectures?

1.4. Description of terms used in the study

The following is a list of terms used in the thesis with descriptions of the way in which they have been used. In each description, all terms in *italics* are further explained in the list.

activities	here, actions which are unique to a specific *discipline*
appresentation	mechanism by which aspects which are not physically present in a given *representation* are 'read into' the *representation*. A necessary condition for a *representation* to gain an appropriate disciplinary meaning
bilingual education	education where two distinct languages are used for general teaching
constructivism	philosophy of learning based on the premise that, by reflecting on our experiences, we construct our own individual understanding of the world
case study research	holistic inquiry that examines a contemporary phenomenon in its natural setting.
context questions	questions asked in order to focus awareness on a particular aspect of a system
diglossia	situation where a society has two languages in functional opposition—an everyday 'low' language and a formal 'high' language
discipline	here, an accepted, separate institutional site in society, with its own particular *ways of knowing the world* and a unique *order of discourse*
disciplinary discourse	the complex of *representations*, *tools* and *activities* of a *discipline*

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discourse	ways of referring to or constructing knowledge about a particular topic of practice: a cluster of ideas, images and practices, which provide ways of talking about, forms of knowledge and conduct associated with, a particular topic, social activity or institutional site in society
Discourse	(with a capital 'D') an accepted association among ways of using language, of thinking, feeling, believing, valuing, and of acting that can be used to identify oneself as a member of a particular group
discourse imitation	using *discourse* in line with the disciplinary *order of discourse* but without experiencing the associated disciplinary *way of knowing*
discursive fluency	the ability to use a particular *mode* of *disciplinary discourse* in a legitimate way (that is in line with the disciplinary *order of discourse*) with respect to a certain disciplinary *way of knowing*
domain	a particular sector of society e.g. tertiary education, the workplace, the judiciary, the home, etc.
domain loss	situation where certain societal domains become dominated by a *second language*
*enacted object of learnin*g	what is actually taught as observed by the researcher
epistemology	student or teacher beliefs about what constitutes knowledge and thus, by association, what constitutes learning
experience	used in the phenomenographic sense, i.e. how we conceptualize, understand, perceive, apprehend etc, various phenomena in and aspects of the world around us

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facets	the various attributes of a *way of knowing* which are necessary for constituting the complete *experience* of that way of knowing
first language (L1)	the language a person learns first. Correspondingly, the person is called a native speaker of the language. Usually a child learns the basics of their first language from their family
immersion	teaching where a *second language* is the sole means of communication, the student's first language is never used
intended object of learning	what the teacher intends to teach
language of instruction	the language used to teach a subject
lived object of learning	here, students' *experience* of the content of a lecture
mode	one among many forms of communication used in a discipline. Examples from university science are speech, writing, diagrams graphs, equations, etc. A *discipline* often has a highly developed, specific *order of discourse* for each mode
naturalistic generalization	in this form of generalization a description of a situation resonates with a person's experience and tacit knowledge, allowing them to make legitimate generalizations without necessarily putting them into words
order of discourse	a structured set of conventions associated with *semiotic activity* (including use of language) in a given social space
purposeful repetition	studying the same material over a period of time using a number of different approaches or focuses with the intention of experiencing *variation*
repetition	studying the same material in the same way over an extended period of time

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representation	*semiotic signs*, objects that have been designed to convey the *ways of knowing* of science
second language (L2)	any language other than the first language (L1) typically used for geographical, social, or political reasons
semiotic activity	communication using *semiotic signs*
semiotic sign	An entity consisting of a form fused with a meaning (a signifier fused with a signified)
shared space of learning	the common ground between teacher and student with respect to the *intended object of learning*
stimulated recall	an interview method in which video clips of a situation are used to allow the interviewee to relate some of the feelings experienced in the original situation
symbolic forms	a limited, generic set of templates and elements that students are thought to use to understand equations
tool	specialized, disciplinary specific, physical objects that members of a discipline draw on to create disciplinary *ways of knowing*
variation	theory which holds that aspects of a system are only noticed when they vary. Thus variation may be seen as a basic prerequisite for making learning possible
way of knowing	the coherent system of concepts, ideas, theories, etc. that have been created to account for observed phenomena in a *discipline*

1.5. Overview of the thesis

This chapter has presented the significance of the study, the research questions and descriptions of the specialist terms used in this thesis. Chapter 2 presents a literature review dealing with three specific areas; physics educational research, research into learning in a second language and research that deals with learning in terms of entering a discourse. In chapter 3 the methodology of the study is presented. Chapter 4 presents the results of the study which are then discussed in chapter 5. Chapter 6 suggests topics for future work, whilst chapter 7 gives a Swedish summary of the thesis. The interview protocols used in the three sections of the study can be found in the appendices.

2. Literature Review

2.1. Introduction

The aim of this chapter is to provide general background in order to situate the work presented in the thesis and to give an overview of specific relevant research. As described in the introduction, initially, the focus of this work was the effects of the language of instruction on learning in Swedish university physics courses. However, during data collection for the first pilot study it became clear that language was not a fully representative unit of analysis or description for university physics learning. Other representations such as equations, graphs and diagrams were essential for a satisfying representation of the rich interview data. This led to the initial language study being broadened to focus on *physics discourse*. To this end the literature review has been divided into three sections. First, a general overview of research in physics education is given, this is followed by a presentation of relevant research into learning in a second language. The final section deals with discourse as a unit of analysis, presenting the necessary background for the notion of disciplinary discourse which is the focus of paper IV. As such, the aim is to prepare the way for the next chapter which describes the choice of methodology and outlines the analytical construct of *disciplinary discourse*.

2.2. Physics educational research

2.2.1. Introduction

This thesis is an example of physics education research (PER) in higher education. This (relatively young) branch of educational research focuses on obtaining a better understanding of the teaching and learning of physics, and as such produces knowledge that is qualitatively different than the knowledge created by traditional physics research (Aalst, 2000). In physics research, accurate measurements lead to quantitative results. Often the larger the sample the greater the accuracy. In PER we are more usually concerned with qualitative results.

Physics has been traditionally viewed as a difficult subject to study, particularly at the university level. Recently there has been a great deal of concern in the physics community about falling enrollment in physics courses,

the drop out rate, and the quality of the education given to undergraduates. (American Association of Physics Teachers, 1996). This has led to a huge amount of interest in improving the situation. A comprehensive bibliography of work done in science education research shows approximately three times as much work done in physics compared with the nearest subject (chemistry) (Duit, 2004).

2.2.2. Situating this licentiate in PER

The early work in PER in higher education grew out of university physics rather than science education. This work thus tended to be atheoretical and to attempt to treat PER data as physics data. The main focus for many years was on students' difficulties with understanding parts of the introductory curriculum. Here a great many papers were written, published and presented at conferences (see Duit, 2004; McDermott & Redish, 1999 and; Thacker, 2003 for listings of PER in various areas). As an understanding of learning problems related to the content of the curriculum grew so the focus of the research work began to diversify and explore what teachers could do to help students overcome many of the most persistent learning problems that the PER had uncovered (an excellent overview can be found in Redish, 2003). The situations being explored tended to be what is known as 'service courses'—introductory courses for students taken as a requirement for another areas such as biology.

   At this time in PER development the more general area of science education was also becoming increasingly interested in the mismatch between the ideas that students already held and brought with them into physics classes and those of the discipline. These student ideas were given labels such as pre-conceptions, misconceptions and alternate conceptions. In both communities there was a great deal of discussion on how to change or replace them (for example, Clement, 1982; Driver & Erickson, 1983; Finegold & Gorsky, 1991; McCloskey, 1983). In university physics the student understanding work also led to development of new teaching methods, focusing on the way in which classroom components were put together (e.g. Crouch, Fagen, Callan, & Mazur, 2004; Crouch & Mazur, 2001; Laws, 1996; Meltzer & Manivannan, 2002). The work also gave rise to a powerful model of learning for both PER and science education in general – conceptual change (e.g. Hewson, 1981; Hewson, 1982; Posner, Strike, Hewson, & Gertzog, 1982).

   As theory started to take on more significance, new perspectives began to underpin the work on student difficulties. This led to an awareness that there were a range of other factors (e.g. beliefs about learning, and what science is) that influenced learning. Much of this work had already started in science education (e.g. Driver & Bell, 1986; Easley, 1982; Erickson, 1984; Fensham, 1984; Novak & Gowin, 1984; Osborne & Freyberg, 1985; Pope & Gilbert, 1983) and was later adopted by a growing number of PER studies. During

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this phase people like Smith, diSessa, & Roschelle (1993) began arguing, from a constructivist platform, that it would be better to build on the resources that students bring to physics lectures rather than expecting them to unlearn what they already knew.

Theoretical growth in the higher education sector of PER was slow until physicists who had turned to other areas such as ethnography, education, and psychology, for example, diSessa (1993), Redish (1994) and Hammer (1995), began to examine university learning using a constructivist philosophy. This philosophy began to dominate education thinking at that time. At this point conceptual framing based on metacognition (e.g. Linder & Marshall, 1997) and on physics students' attitudes to physics and learning and their approaches to learning started to appear (for example the recent Colorado Learning Attitudes about Science Survey, Adams et al., 2006; and the Maryland Physics Expectations Survey, MPEX, Redish, Steinberg, & Saul, 1998). This licentiate work falls into this broader epistemological area of PER growth with its exploration of students' experiences of learning by drawing on ideas embedded in the discipline's way of knowing.

2.3. Learning in a second language

2.3.1. Language and physics knowledge

Even without the added complication of a second language, language problems in physics lectures may be particularly acute due to the experienced complexity and abstractness inherent in learning a science such as physics. As Östman (1998) points out, scientific language is abstract and represents special communicative traditions and assumptions. And, on a similar theme, Säljö (2000) argues that difficulties in student learning are in fact difficulties in handling and understanding highly specialized forms of communication which are not found to any great extent in everyday situations. Moreover, it has been claimed that language is much more than a simple representation of disciplinary knowledge, it is actively engaged in bringing such knowledge into being (Halliday & Martin, 1993). Learning a subject like physics therefore depends on learning the language in which the knowledge of the discipline is construed (Lemke, 1990). Thus it can be argued that the relationship between a student's first language and physics learning is by no means straightforward. But what about the effects on physics learning when students are taught in a *second* language?

Halliday (1993) has shown how switching from one language to another (English to Chinese) whilst totally changing the discourse of a science text, has very little effect on the *meaning* that the text represents. Drawing on this result, Airey and Linder (2005) have suggested that in university physics

English and Swedish may be viewed as parallel—that is they can be seen as offering similar possibilities for learning. Naturally this is not the same thing as saying that students *experience* teaching in English and Swedish in the same way, only that the inherent potential of say, oral English to represent physics disciplinary knowledge would be similar to that of oral Swedish.

Some clues as to the way in which Swedish students may experience being taught physics in English can be found in studies of *bilingual education*.

2.3.2. Background to teaching in a second language

Teaching some subjects in a student's second language—bilingual education as it is often termed—is carried out for a number of different practical and political reasons throughout the world. In post-colonial countries bilingual education has traditionally involved teaching the language of a minority ruling class to a majority that has one or more indigenous or 'home' languages. In contrast, in the USA bilingual education has involved teaching the majority language to immigrant minorities. Yet another aspect of bilingual education can be seen in Canada for example, where some English-speaking families are electing to have their children taught in the language of a minority (French). Research into this form of teaching has been carried out by such diverse disciplines as education, linguistics, sociolinguistics, psycholinguistics, psychology, anthropology and sociology (Marsh, Hau, & Kong, 2000). In each situation different motivations and power relations lie behind the provision of bilingual education, thus it is not surprising that what is interpreted as a successful bilingual intervention is also very different from project to project. Often the research done in bilingual education has focused primarily on goals such as second-language development and cultural integration of students, the effects on the learning of *subject matter* which is taught through a second language have therefore been treated as of secondary importance.

2.3.3. The Swedish debate

Some of the reasons for using English as the language of instruction in Swedish higher education have been listed by Airey (2003:47):

- In a number of disciplines, the publication of academic papers takes place almost exclusively in English. Teaching in English is therefore seen as necessary in order to prepare students for an academic career.
- In many disciplines the majority of textbooks used are written in English and therefore the step to teaching in English may not be seen as a large one.

- The use of English develops the language skills and confidence of Swedish lecturers and can be seen as promoting movement and exchange of ideas in the academic world.
- Using English as the language of instruction allows the use of visiting researchers in undergraduate and postgraduate teaching.
- Teaching in English allows European Union and exchange students to follow courses at Swedish universities.
- Swedish students can be prepared for their own studies abroad.
- A sound knowledge of English has become a strong asset in the job market.

As pointed out in the previous section, the reasons for using a second language to teach a university subject will, to a large extent, determine the way in which the success of such teaching is judged. From Airey's listing we can see that a desire to internationalize Swedish universities is the main motivation for teaching in English. This analysis is supported by a number of statements by major stakeholders in Swedish higher education.

In 2001 the Swedish government published the white paper, *Den öppna högskolan*, detailing its intentions for the university sector. Here, the following statement was made regarding teaching in English at Swedish universities:

> Swedish universities and university colleges have at present a significant number of courses and degree programmes where the language of instruction is English. Sweden is at the forefront in this area compared to other EU countries. In recent years the range of courses and degree programmes offered in English has increased dramatically. A questionnaire administered by this commission shows the demand for teaching through the medium of English is steadily growing and that the choice of courses of this type seems likely to increase in the future. The government sees this as both a proper and positive development. Utbildningsdepartementet (2001:15) (*translation JA*)

The majority of Swedish higher education establishments are now in the process of creating new courses—and in many cases whole programmes—taught exclusively in English as a response to the *Bologna declaration* for harmonizing European higher education. The thinking behind this declaration is that European students should be able to move freely throughout Europe reading courses at universities in whichever country they choose. Although there is no direct discussion of the language of instruction in this declaration, the default position in Sweden appears to be that such courses will be taught in English.

It would, however, be incorrect to think that the movement towards what Falk (2001a:22) calls the anglicizing of Swedish universities is occurring without criticism. For example, Gunnarsson (1999:16) warns that the Swedish academic community runs the risk of submitting to diglossia—a division

of functions between languages—where English is the academic 'high' language and Swedish is the everyday 'low' language[1].

Further in-depth criticism of the dominance of English came in the report of the Parliamentary Committee for the Swedish Language, *Mål i mun* (Utbildningsdepartementet, 2002). A section of this report deals with the way in which certain subject areas in society become impossible to discuss in Swedish – so called *domain losses*[2] to English. Losing domains to English is portrayed as causing democratic problems, since it effectively denies large sections of society access to these areas. *Mål i mun* acknowledges the need for English in certain domains, but emphasizes that Swedish should also be present in these areas. This is also the position of the Nordic Council of Ministers:

> English is both essential and welcomed in Nordic universities. Students, lecturers and researchers must be able to understand academic English and use it regularly. However this use of English must not be allowed to result in the Nordic languages disappearing from universities. We should be aiming for parallel use rather than monolingualism. Höglin (2002:28)(*translation JA*)

A major problem seen by the authors of *Mål i mun* with regard to university teaching in English, is the *extra demand* on students when required to learn subject matter through a language other than Swedish.

> Finally we would like to stress that it is well known that extra pressure is involved in students not being able to use their first language. We know very little about the consequences of the widespread use of English in certain disciplines. Research should therefore be carried out into the effects for learning, understanding, the teaching situation, etc., when Swedish students receive their education through the medium of English and how such teaching can be successfully achieved. Utbildningsdepartementet (2002:97) (*translation JA*)

Similarly, Karin Carlson, in her article *Tvåspråkiga naturvetare* voices the concerns held by many in Swedish higher education:

> At present there has been no systematic research into the way in which student learning is affected by the language used, but my gut feeling and that of many of my colleagues is that students gain less robust knowledge and poorer understanding if the language used is not their mother tongue. Carlson (2002:15)(*translation JA*)

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[1] The term diglossia (Ferguson, 1959) describes a situation where a society has two languages in functional opposition – a 'low' language used in everyday encounters and a 'high' language, learned largely by formal education and used for most written and formal purposes.
[2] Fishman (1967) first presented the idea of domains dictating language. Examples of domains are the family, school, the workplace, etc.

This 'gut feeling' experienced by Carlson and her colleagues has led to a radical rethinking of teaching at the University of Uppsala. In a project named DiaNa (Dialogue for Natural Scientists), the academic departments of chemistry, biology and earth science now put a heavy emphasis on Swedish communication training in their courses (Uppsala universitet, 2001). Carlson and her colleagues also reduced the percentage of courses offered in English to third and fourth year biology students from circa 70% to circa 40%. All students now read at least one advanced course in Swedish. Whilst sympathising with the general thrust of the DiaNa project, Airey (2004) points out that any educational changes made without solid research grounding risk outcomes other than those originally intended.

2.3.4. Research into teaching in a second language

As pointed out in *Mål i Mun* (Utbildningsdepartementet, 2002), research into the effects of teaching through the medium of English at Swedish universities is limited. However, teaching in a second language is better-documented in the compulsory school system and internationally. The first contemporary studies in this area come from the experience of the Canadian bilingual immersion programmes. A large number of Canadian longitudinal studies since the late 50's have shown that pupils with English L1 can achieve a high level of fluency in French, with no noticeable effect on performance in other subjects. These immersion pupils achieve similar results on French comprehension tests as native speakers, and their written and spoken language is also highly developed, with only a few lapses of grammar and collocation. (See for example Genesee, 1987; Swain & Lapkin, 1982).

In Europe, similar attempts, termed content and language integrated learning (CLIL) have been documented by Baetens Beardsmore (1993) and the European Commission Directorate General for Education and Culture (2001; 2006). Early Swedish attempts in CLIL have been reported by pioneers such as Åseskog (1982), and continued by Knight (1990), Washburn (1997), Hall (1998), Falk (2001b) and Nixon (2000; 2001). The Swedish term for such studies is språk-och innehållsintegrerad inlärning och undervisning (SPRINT). The main interest of the SPRINT programmes is improving student's L2 language skills (English). In this respect, a recurrent feature of the SPRINT studies is that students and teachers agree that the resulting level of *English language skills* is higher than in a comparable monolingual class. Although encouraging, this evidence is unreliable, since the researchers were asking people involved in a particular pilot study—and therefore naturally positive to it—to express their opinions. In the two studies that actually attempted to *measure* differences in English ability (Knight 1990; Washburn 1997) no measurable difference could be shown. Despite the many variables

affecting the measured learning outcomes, this is still somewhat surprising given the level of self-selection associated with this type of schooling[3].

As regards *subject knowledge*, Washburn (1997:261) claims that the students in her study did 'as well as could be expected'. An interesting observation is that at the start of the study, Washburn's experiment class averaged just as good or better grades than the control class. At the end of the study, students who had received teaching in English had significantly lower grades in chemistry than those who had been taught in Swedish. The experiment class also had lower (but not significantly lower) grades in physics than the control class, despite having higher grades than the control class before the experiment (Hyltenstam, 2004). The evidence for claims of minimal effects on content learning in Swedish bilingual education programmes is therefore at best inconclusive. Some of the teachers in bilingual studies acknowledge this criticism and admit that they are forced to cover less material. The reasons these teachers are still positive to teaching in English can be divided into two groups; either they welcome being forced to concentrate on the central issues of the subject, or they point out that the aims of their course are more than a simple transfer of subject knowledge. This latter group feel that the gains in English outweigh what they feel are the marginal negative effects on subject knowledge.

Further, it appears that English-medium education affects the *Swedish* of the students taught. Alvtörn (2002) found that students who study in bilingual education classes have poorer written Swedish than students in 'normal' schools. Interestingly, the types of mistakes made by these students were similar to those made by highly competent users of Swedish as a second language. The results show no effect as far as amount written, sentence length and complexity are concerned, but do show statistically significant differences in the number of mistakes with prepositions, vocabulary, idiom and style.

There are a number of studies from the lower levels of schooling which suggest that there may in fact be some direct benefits of bilingual education. In the most sophisticated of these, Willig (1985) carried out a meta-analysis of US bilingual programmes, concluding that participation in bilingual education programmes consistently produced results that favoured bilingual education. However, Met & Lorenz, (1997) and Duff (1997) claim that limitations in L2 may inhibit student's ability to explore abstract concepts in non-language subjects.

Thus, despite the well-documented and generally accepted positive effects of many bilingual education programmes, Marsh Hau & Kong (2000; 2002) working in Hong Kong, found large *negative* effects of high school teaching in a second language on non-language subjects. They note that the focus of

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[3] We can assume that a typical pupil in bilingual education is above average when it comes to grades, motivation, and language skills/interest.

earlier bilingual studies has been on achievement in languages with *"a re-markable disregard for achievement in non-language subjects"*(Marsh et al., 2000:339). Moreover they point out that the majority of research that exists on bilingual immersion programmes deals with early-immersion where pupils are taught in the L2 from the start of formal schooling. The effects of late-immersion are less well-documented, particularly when it comes to learning outcomes in non-language subjects. Thus, Marsh and his colleagues suggest that results found at a lower level of schooling may not transfer un-problematically to a higher level of education. These results for the Hong Kong situation were confirmed by Yip, Tsang, & Cheung (2003) who found that English–medium students, despite having initially higher ability in science performed more poorly on tests than their peers who were taught in Chinese. The L2 students were found to be particularly weak in problems that assessed understanding of abstract concepts, their ability to discriminate between scientific terms and their application of scientific knowledge in new situations. Both Marsh et al. (2000; 2002) and Yip et al. (2003) account for their results in terms of the increasing demands placed on language as a constructor of knowledge as suggested by Halliday & Martin (1993). With this in mind, the remainder of this survey will be confined to research into *content learning outcomes* at *university level*.

The majority of Scandinavian studies that have been carried out in higher education have either been surveys of the extent to which a second language is used in educational situations or have focused on the language learning effects of such teaching, for example (Falk, 2001a; Gunnarsson & Öhman, 1997; Hellekjaer & Westergaard, 2002; Melander, 2005; Teleman, 1992; Tella, Räsänen, & Vähäpassi, 1999; Wilson, 2002). Surprisingly, there has been very little research into the relationship between *content learning* and the *teaching language* at university level. In Sweden no studies have been carried out into the effects of lectures in a foreign language. Two recent studies did however examine the understanding of written text, both concluding that the ability to judge broad relevance is greatly reduced when text is in English (Karlgren & Hansen, 2003; Söderlundh, 2004).

Further afield, researchers in New Zealand have found negative correlations between second-language learning and performance in undergraduate mathematics, with students disadvantaged by 10% when taught in a second language (Barton & Neville-Barton, 2003, 2004; Neville-Barton & Barton, 2005). These negative effects were found to be at their worst in the final undergraduate year. Similar relationships have been confirmed to some extent by Gerber, Engelbrecht, Harding & Rogan (2005) in their study of speakers of Afrikaans learning undergraduate mathematics in English in South Africa. Research in the Netherlands has also shown negative effects for Dutch engineering students' learning when they are taught in English (Klaassen, 2001; Vinke, 1995). In contrast to the other tertiary level studies reported here, Klaassen's work suggests that the negative effects might be

temporary and limited to the first year of study in a second language. Interestingly one of the replies to Klaassen's student questionnaire suggests a possible reason for this transient negative effect:

> My achievements in the English-medium programme are entirely my own credit and are unrelated to the performance of the lecturers in this programme. (Klaassen, 2001:182)

Commenting on this work, Airey & Linder (2006) suggest that the students in Klaassen's study may have learned to compensate for lack of understanding in lectures by doing extra work outside class.

The studies reported above are undoubtedly interesting for those faced with deciding which language to use in a given lecture situation. However, there are many reasons that can be seen as legitimate for giving undergraduate courses in English and therefore such lecturing seems guaranteed to both continue and expand. From this perspective, studies pointing out possible negative learning outcomes of such lecturing compared with first-language lecturing are not particularly useful. Without knowledge about *what* students may find difficult in second language lectures and *how* student learning patterns change as the lecture language changes, the picture will continue to be unclear. Meanwhile lecturers faced with giving courses in their students' second language remain unsure as to any specific negative effects of such lecturing and are thus unable to modify their strategies in order to minimize such effects.

The situation has been well summarized by Flowerdew (1994). In a survey of international research relevant for academic lectures given to second-language listeners in all disciplines, he points out that whilst there is much research relevant to second-language lecture studies, the majority of the work raises more questions than it answers:

> One thing that is clear from this review is that a lot more research is needed before we have a clear idea of what constitutes a successful second-language lecture. A lot more information is needed – in terms of how a lecture is comprehended, in terms of what a lecture is made up of, and in terms of how the variable features of a lecture may be manipulated to ensure optimum comprehension – before meaningful statements can be made about many aspects of lectures which will have concrete effects on pedagogy. Flowerdew (1994:25)

Klaassen (2001) suggests following up her work with stimulated recall sessions to find out what students are actually *doing* in lectures this is the approach adopted by Airey & Linder (2006) (paper II in this thesis).

2.3.5. Summary of learning in a second language

In summary then, there are a number of studies which show positive or neutral effects of teaching in a second language on the learning of disciplinary knowledge. However on closer examination, these results appear only to apply to specific situations with respect to age of introduction, selectivity and the relative status of the student's L1 and L2. Late immersion (after grade 7) appears to be associated with large negative effects on subject knowledge, and this is borne out in the few studies that have been carried out at university level. The reasons for these negative effects appears to be related to the demands placed on language due to increasing levels of abstract knowledge at higher levels of education.

2.4. Learning and discourse

2.4.1. Introduction

As early as the seventies Postman and Weingartner (1971:103) pointed out that "A discipline is a way of knowing, and whatever is known is inseparable from its symbols (mostly words) in which the knowing is codified". One way of collectively referring to this "system of symbols" is to use the term *discourse*.

The argument that the ways of knowing that constitute a discipline are inseparable from their discursive representations has led to the suggestion that a significant part of learning may be regarded as "discovering" the meaning of the discourse employed by a discipline through participation (Kuhn, 1962/1996; Northedge, 2002, 2003; Östman, 1998). For example, Kuhn makes the following claim about physics discourse:

> If, for example the student of Newtonian dynamics ever discovers the meaning of terms like 'force', 'mass', 'space', and 'time', he does so less from the incomplete though sometimes helpful definitions in his text than by observing and participating in the application of these concepts to problem-solution Kuhn (1962/1996:46-47)

Northedge (2002:257) further argues that "We encounter [words] embedded within discourse, and come to apprehend their meaning in the process of participating in the discourse which generates them". Learning may then be characterized as coming to experience disciplinary ways of knowing as they are represented by the disciplinary discourse through participation.

2.4.2. Problems with teaching and learning discourse

Gee (1990) stresses that discourses are not mastered by overt instruction, suggesting that two types of teaching are required; teaching$_a$ and teaching$_l$. Teaching$_a$ refers to apprenticing students into a discourse, whereas teaching$_l$ "leads to learning by a process of explanation and analysis that breaks down learning into its analytical bits and develops meta-knowledge of the structure of a given domain of knowledge" (Gee, 1990:154). Gee further suggests that good teachers are good at both teaching$_a$ and teaching$_l$.

It has been shown, however that many dimensions of disciplinary ways of knowing are often taken for granted by university lecturers in their teaching (Pace & Middendorf, 2004; Tobias, 1986, 1992-1993). In this respect, Northedge (2002:256) believes university lecturers often do not fully appreciate "…the sociocultural groundings of meaning. Their thoughts are so deeply rooted in specialist discourse that they are unaware that meanings they take for granted are simply not construable from outside the discourse". In a similar vein, Geisler (1994) claims:

> Texts, like other objects of expert knowledge, appear to afford and sustain both expert and naïve representations: the expert representation available to insiders to the academic professions and the naïve representation available to those outside. Geisler (1994:xi-xii)

Thus a number of authors have made the case that problems in student learning are largely a function of difficulties in handling and understanding highly specialized forms of communication that are not found to any great extent in everyday situations, for example, Driver & Ericksson (1983), Solomon (1983) and Säljö (2000). Englund (1998) suggests analyzing the causes of problems in student understanding of a specific discourse with a view to changing institutionalized communicative patterns, thus making the discourse more accessible. However the other side of this coin is expressed by Wickman & Östman (2002) who have viewed learning as a form of discourse change. Learning is thus increasingly being characterized in terms of *entering a discourse* (Florence & Yore, 2004; Lemke, 1990, 1995, 1998; Northedge, 2002, 2003; Roth, McGinn, & Bowen, 1996; Swales, 1990; Säljö, 1999; Wickman & Östman, 2002).

2.4.3. Multimodal discourse

Following Fairclough (1995) the New London Group (2000:20) argue that each semiotic domain has its own specific order of discourse that is "a structured set of conventions associated with semiotic activity (including use of language) in a given social space". Here we can see that language has now been relegated to one amongst many *semiotic activities*. This change in emphasis is a direct result of the work of another member of the New London

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Group, Kress. Together with van Leeuwen, Kress had earlier mapped out a visual grammar for reading images (Kress & van Leeuwen, 1996). The further development of this work led to the notion of *multimodality* (Kress & van Leeuwen, 2001) here language is viewed as being one of many *modes*. In this respect, Lemke (1998:7) claims that scientists handle problems that would otherwise be impossible to solve by orchestrating movement between a wide range of discursive resources (modes):

> We can partly talk our way through a scientific event or problem in purely verbal conceptual terms, and then we can partly make sense of what is happening by combining our discourse with the drawing and interpretation of visual diagrams and graphs and other representations, and we can integrate both of these with mathematical formulas and algebraic derivations as well as quantitative calculations, and finally we can integrate all of these with actual experimental procedures and operations. In terms of which, on site and in the doing of the experiment, we can make sense directly through action and observation, later interpreted and represented in words, images, and formulas.

From an educational point of view, Kress, Jewitt, Ogborn & Tsatsarelis (2001) depict the discourse of a discipline as being made up of a number of *modes*, where spoken and written language are examples of two such modes. Each of these modes is seen as having different *affordances* or, to put this in more tangible terms, *different possibilities for representing disciplinary ways of knowing* This multimodal approach to disciplinary learning is developed in Paper IV.

2.4.4. Summary of learning and discourse

Several researchers have suggested that learning can be seen as *entering a discourse*, however, most of these researchers see discourse as synonomous with *language*. For the study reported here, it was important to include other representations such as diagrams, graphs and equations. In this respect a number of researchers do include extra linguistic 'stuff' in their analyses of discourse, however it was felt that the multimodal approach adopted by Kress et al. (2001) provided the most complete description of the data collected from university physics lectures.

2.5. Literature review summary

This literature review has dealt with three areas which are significant for this study; PER, learning in a second language and learning and discourse.

The historical development of PER was described as moving from an initial atheoretical focus on student problems with learning particular physics content and how to solve these; through an appreciation of the value of gen-

eralizing theory over this "recipe-book" approach; to an appreciation of the multiple parameters which can affect student learning and hence the value of multiple theoretical approaches to capture the various aspects of this complexity.

The research into teaching in a second language was summarized, pointing out the way in which political and linguistic aims appear to have led to a methodological "blindspot" with respect to research into content learning outcomes. The paucity of international studies at university level was also highlighted, along with the fact that no research has been carried out into content learning outcomes in Sweden at the university level. More importantly it was also noted that there are a number of compelling reasons for taking a bilingual approach to university physics. Thus, studies which suggest possible negative learning outcomes of such lecturing compared with first-language lecturing—taking a "black box" approach to learning by looking at "output" in terms of assessment are not particularly useful. Only studies which can point out *specific differences* in the experience of learning physics between one language and another and which identify changes in *student approaches* have the potential to yield results which may be of use to the university physics community.

Finally, a brief description of the approach which views learning as entering a discourse was presented. This multimodal approach is further developed in the next chapter.

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3. Methodology and method

3.1. Introduction

This chapter examines methodological issues with respect to the intended study and describes the way in which decisions about the experimental methods were initially taken and how these were further developed during the three phases of the study. An extended analytical framework for the construct of disciplinary discourse is presented.

3.2. Case study research

This study is an example of *case study research*. The analytical approach used is based upon looking for patterns and key events using iterative cycles through the data. The goal of such analysis is to move towards the crystallization of a rich description and explanation of the data. The kind of generalization anticipated in this work is what Stake & Trumbull (1982) refer to as *naturalistic generalization* in this type of generalization the thick description offered resonates with readers' tacit knowledge, helping people make connections and associations for themselves.

3.3. The initial research problem: Studying experience

At the outset of this work it was decided to study the *experience of attending physics lectures* in relation to the language of instruction. There were two reasons for this choice: First, this form of teaching—the lecture—is widespread in the university world, having reached what Waggoner (1984:7) calls "paradigmatic stature". In fact, Benson (1994:181) goes as far as to claim that university learning can be seen as initiation into a specific culture, where the "central ritual" of this culture is the lecture. There has also been a great deal of criticism of this characteristically academic university tradition (Bligh, 1998; Ramsden, 1992). The second reason for choosing to study lectures was much more pragmatic—the empirical content of lectures is generally both accessible and analytically documentable.

3.2.1. Designing the study

The idea that the language of instruction used in a lecture may have a bearing on the learning of physics is an easy concept to grasp. A much more thorny issue is how to frame a study so that it produces results that are useful, meaningful and of recognizably high quality. As explained in the preface to this thesis, the initial approach to the research problem was based on the author's own real-life experience of tutoring Swedish undergraduates. Thereafter, a preliminary literature review identified a number of quantitative bilingual studies which could perhaps be adapted to suit the emerging research questions of this study. Thus, the original idea was to carry out a quantitative study with research and control groups. However at this stage two important issues came to the fore, related to *project design* and *relevance*.

3.2.2. Project design and relevance

The first of these issues—project design—pertains to the real-life problems of designating research and control groups. What exactly would kept constant in a controlled study and how would that be achieved? The earlier attempts to find statistical correlations between language choice and academic performance all suffered from this same methodological weakness—whilst the researchers themselves often claimed to have found statistically significant relationships, most of the conclusions of these studies had been questioned (Hyltenstam, 2004; Marsh et al., 2000). In short, the most common element of this type of study was the very *similarity* between research and control groups. Working in the Netherlands with engineering students who were lectured in English, Klaassen (2001) concluded that by far the most important factor in university learning was not the language of instruction, but rather the pedagogical content knowledge of the teacher. However, such studies failed to dampen the feeling amongst experienced practitioners that the language of instruction *did* play an important role in learning. It seemed clear that if there was a "language effect" it would be difficult to isolate from other much stronger effects related to the teacher, and student effects such as, prior knowledge, epistemology, academic self-concept, gender and social and educational background. Though technically possible, such a study would require very large samples and highly sophisticated data collection and manipulation in order to have any chance of success.

The second, and actually more pertinent issue was one of relevance. Let us say, for the sake of argument, that a quantitative study *could* be carried out and that such a study produced conclusive results—say students scored 10% lower on physics exams when taught in English rather than in Swedish. What use would this result be to physics lecturers? Perhaps there might be some movement to teach fewer physics courses in English, but physics would continue to be taught in English for all the reasons listed in the litera-

ture review (Airey, 2003). (Perhaps lecturers could lower their pass-marks for courses taught in English by 10% …?).

Since physics would continue to be taught in English a "Which language is better?" approach seemed somewhat irrelevant. What would be useful, however, was an investigation of the way in which *student learning* differed between the two situations, aimed at informing teacher practice. Thus it became clear that an appropriate approach to the research questions would be *qualitative* rather than quantitative. This state of affairs is discussed by McDermott and Redish (1999:757):

> In traditional physics experiments, the goal is to obtain quantitative results with the uncertainty in the measurements well specified and as small as possible. However, a meaningful interpretation of numerical results requires a sound qualitative understanding of the underlying physics. In studies involving students, the value of quantitative results also depends on our understanding of qualitative issues, which usually are much less well understood than in the case of physical systems. To be able to determine the depth of students' knowledge and the nature of their difficulties, it is necessary to probe the reasoning that lies behind the answers. The analysis of numerical data alone may lead to incorrect interpretations. Detailed investigations with a small number of students can be very useful for identifying conceptual or reasoning difficulties that might be missed in large-scale testing.

3.2.3. Early theoretical framing: The shared space of learning

Instead of attempting to equate learning with assessment, it was decided to examine students' *experiences of learning*[4]. By experiences is meant capturing both the differences across learning experiences and the situatedness of the individual learning experience. The product of the initial discussion of data collection methods can be seen in figure 1.

The plan was to find two parallel physics courses, one taught in English and the other taught in Swedish, which had a number of students in common. One lecture from each of these courses would be videotaped. Prior to this filming, each lecturer would be interviewed as to their aims for their lecture. From this interview it was hoped to distinctly identify the intended object of learning (IOL). The video footage could also be analyzed to determine enacted object of learning (EOL). Finally, the students would be interviewed in an attempt to map out the lived object of learning (LOL)(Marton & Morris, 2002). It was expected that comparing the three constructs, IOL, EOL and LOL would lead to a discussion as to the extent to which a space of learning was shared between teacher and students This shared space of learning (SSL) has been discussed by Tsui (2004b).

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[4] Centred around student experiences and actions in lectures, and links between the language of instruction and student ability to *understand, describe and explain* physics concepts.
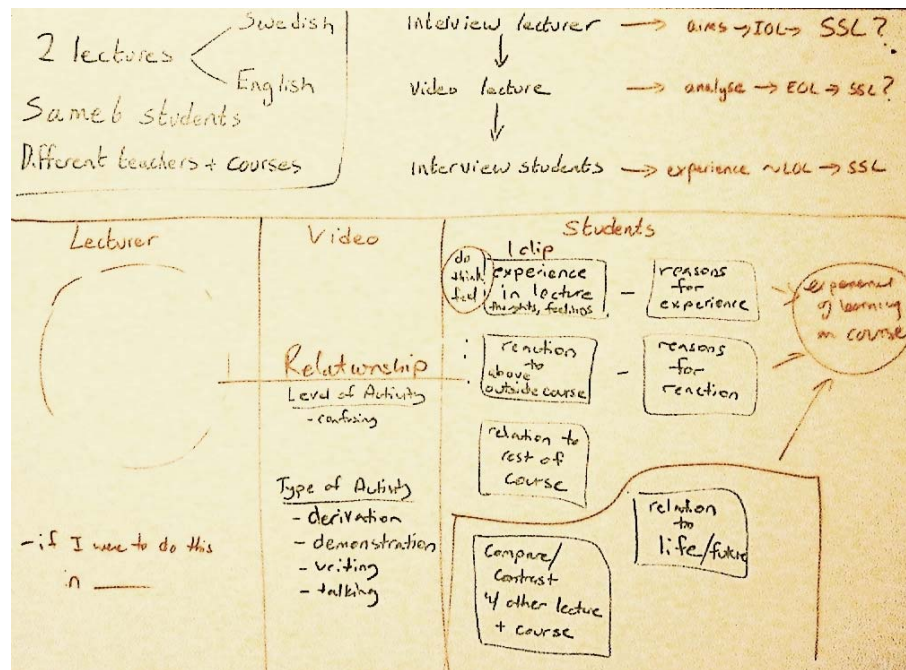
Figure 1. Brainstorming the focus of the first study

The connections between IOL, EOL, LOL and SSL have been discussed by Airey & Linder (2004) in terms of a number of overlapping spaces—the teacher's intended space of learning and the students' presumed space of learning. This relationship between the various objects and spaces of learning can be seen diagrammatically for one student in figures 2-10.

In figure 2. the teacher selects an object of learning from a disciplinary knowledge structure. This object of learning is then analyzed for its critical features (figure 3.).
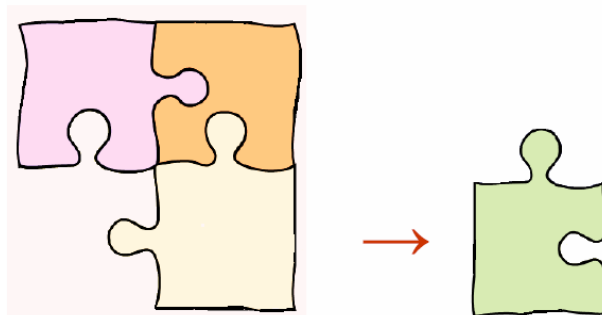
Figure 2. The teacher selects the intended object of learning from a coherent disciplinary knowledge structure

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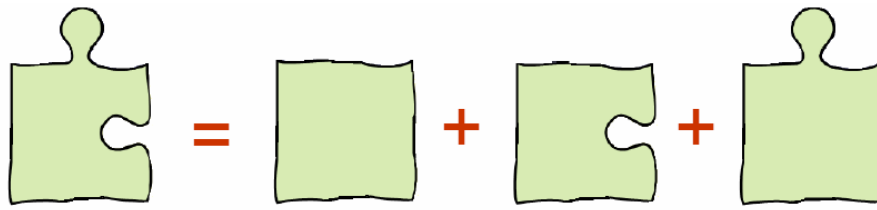
Figure 3. The teacher analyzes the object of learning for its critical features

The relationship between the teacher's intended space of learning and the student's presumed space of learning is shown in figure 4. Naturally, there is some degree of misalignment between these two spaces. Where the two spaces overlap, a space of learning is shared. It is this space that the teacher can gainfully exploit for the teaching of an object of learning. Figure 5. shows the enacted object of learning as seen by the teacher (against the teacher's intended space of learning).
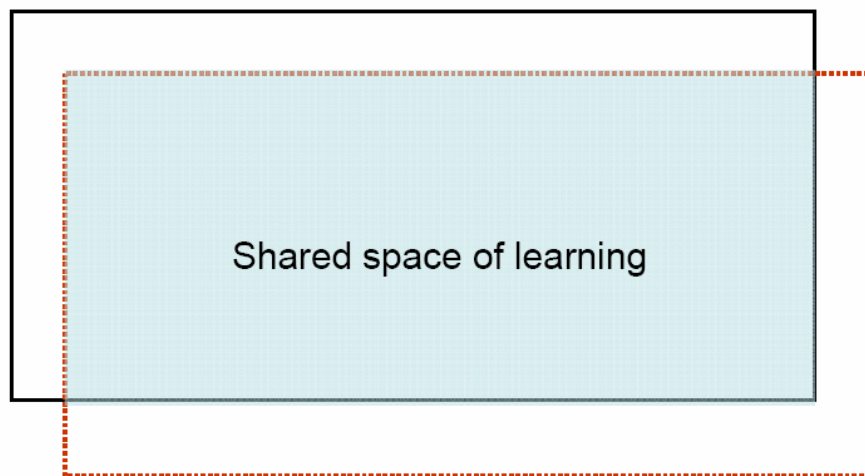
Figure 4. The shared space of learning—where teacher's intended space of learning (solid box) and student's presumed space of learning (broken box) overlap.
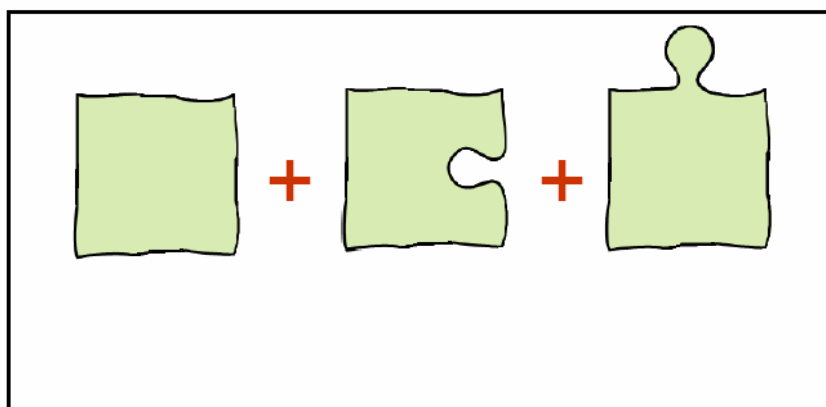
Figure 5. The enacted object of learning. Critical features of the object of learning varied against the teacher's intended space of learning

If we now adopt a student perspective, the interesting question is what it is possible for a student to experience from the enacted object of learning. Only those aspects which were framed within the shared space of learning have the possibility of being experienced by the student (figure 6.).
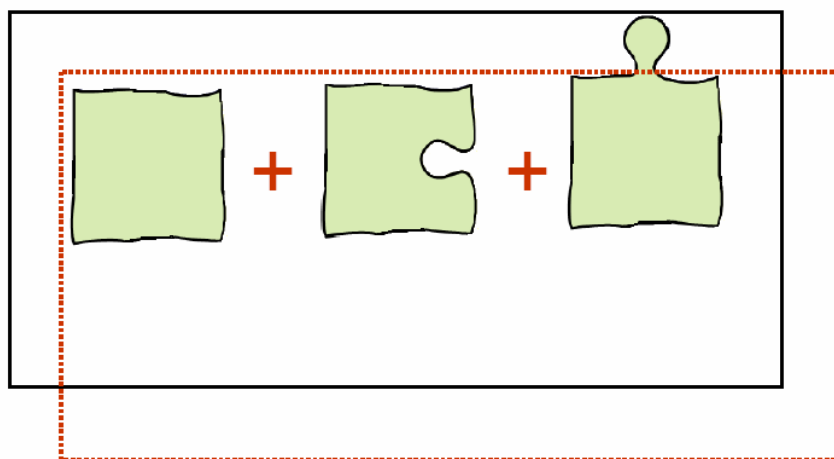
Figure 6. The student's presumed space of learning superimposed on the teacher's intended space of learning.

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Any aspects of the object of learning which are outside the shared space of learning will either be ignored or misinterpreted (figures7-8).
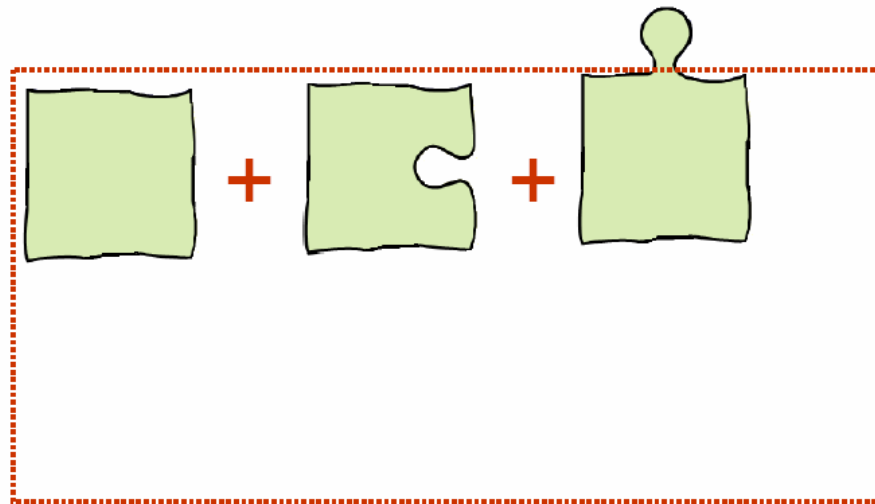
Figure 7. The object of learning from the student's perspective
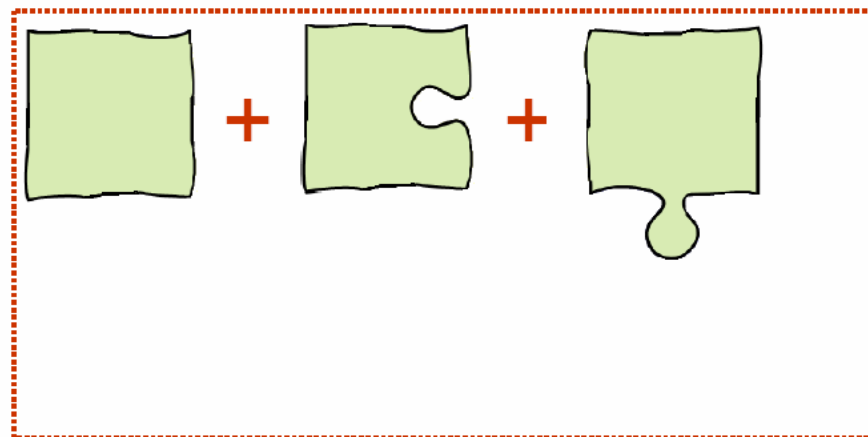
Figure 8. What the student experiences.

In the example given in figure 9. the student only has the possibility to experience a distorted object of learning. This lived object of learning is incompatible with wider disciplinary knowledge structures (figure 10.).
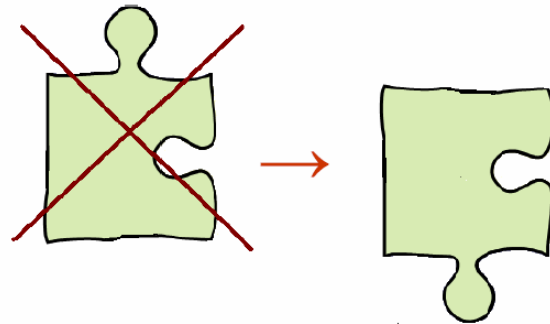
Figure 9. The lived object of learning
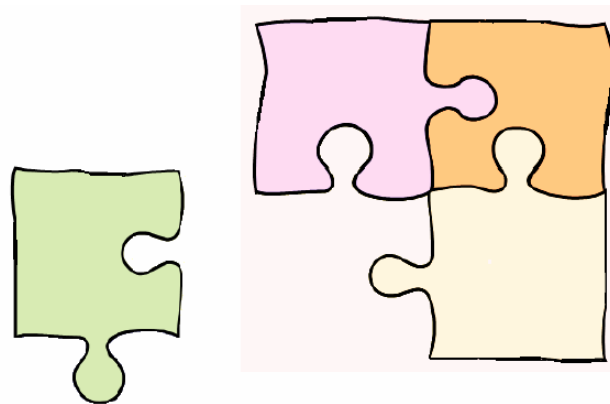
Figure 10. The lived object of learning is incompatible with disciplinary knowledge

3.2.3. Language and the shared space of learning

Even in native speaker interactions there will always be an element of dislocation between the teacher's intended space of learning and each student's presumed space of learning. Here the speed of delivery can be important. In lectures in the students' L1 there is usually ample time to: first compensate for the mismatch between the two spaces of learning, then to experience variation in the critical features of the object of

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learning and to thus construct the object of learning for oneself. In many cases, students still have enough time to also attempt to combine this construction with disciplinary knowledge structures. When the language of instruction changes students may be forced to spend more time focusing on decoding the language before this process can occur. See Flowerdew (1994:22-24) for an overview of research into the speed of delivery in second language lectures.

For the purposes of this study it was important to understand the way in which language could affect the shared space of learning. Tsui (2004a; 2004b) sees the role of a teacher as opening up a shared space of learning and goes on to describe how this space can be semantically widened or thickened. Language is the means of opening up this space.[5]

> In classrooms where the medium of instruction is not the students' mother tongue (i.e., a language in which the students are less competent), the failure to widen the shared space of learning may be caused by lack of linguistic resources (particularly on the part of the students, although sometimes it can be on the part of the teacher). (Tsui, 2004b:182)

3.3. Interviews and stimulated recall

3.3.1. Stimulated recall

Having decided to adopt the shared space of learning as an analytical framework, the next question was how to operationalize the planned study. For the lived object of learning to be appropriately described, the students would need to be able to describe their thinking in lectures. The student interview would thus be an extremely important source of data for this task. Here it was decided that an appropriate approach would be to use *stimulated recall*. This technique uses video footage to attempt to recreate the central atmosphere of the original learning situation, thus allowing students to better describe and reflect on their learning experiences in the specific situations that they are shown (Bloom, 1953; Calderhead, 1981; Haglund, 2003). There are a number of approaches to the use of stimulated recall, and since at this stage it was not known what aspects of a lecture might be important it was decided to focus on as many *different types* of activity as possible. Thus, it was decided to edit the two hours of video footage from a typical lecture session down to four short clips which together lasted less than ten minutes. Each clip would deal with a separate aspect of the lecture.

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[5] See Hull (1985); Watkins et al (1991); Kokkotas et al (1995); Adamson & Lai (1997); Gropengiesser (1999); Halliday & Matthiessen (1999); Anderberg (1999); Clark & Rutherford (2000); Kilic (2003); Roth & Duit (2003).

3.3.2. Creating interview protocols

For the lecturer interviews the goals were twofold:

- To identify the intended object of learning
- To gain an overview of the structure and various types of activity of the planned lecture

An example of the protocol used to interview the lecturers can be seen in appendix A.

For student interviews, it was important to focus on the language aspect of student experience. In this respect it was decided to carry out the interviews in *both* Swedish and English. Students were thus recorded talking about the same physics content in both languages and for both lectures. Examples of the three student interview protocols can be found in the appendices.

Initial analysis of the interview data collected led to the original language focus moving to include representations other than language, such as mathematics, graphs and diagrams. This focus was broadened still further during the analysis stage to an analytical framework where learning in university physics could be treated as *entering a disciplinary discourse*.

3.4. Learning as entering a discourse

3.4.1. Disciplinary discourse: an analytical framework

If we take the point of view that there are useful insights to be gained by characterizing learning as entering a discourse, then for the purposes of the analysis presented in this thesis we first need to define what is meant by such discourse. Tsui (2004b:167) recently defined discourse for the purposes of contemporary educational research work as "a process in which meanings are negotiated and disambiguated, as well as a process in which common grounds are established and widened". This definition fully matches our own view of disciplinary discourse; however, there is a risk that using such a definition can become unintentionally limiting. This is because the definition does not *specifically* challenge the traditional view that disciplinary discourse is synonymous with the specialized *language* used within a discipline. Such a language-based interpretation of Tsui's definition proves to be limiting when attempting to capture the conditions necessary for learning university science, since it takes for granted or ignores other important representations (such as diagrams, graphs and mathematics).

The interest in exploring a broader notion of discourse grew out of an interest in the two main languages, English and Swedish, used in the teaching and learning of university physics in Sweden: If we characterize learning as

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entering a discourse, then what is the nature of the discourse that students are expected to enter into when *two* languages are involved? When, during the early stages of the study, the value of including representations other than language in the analytical framework emerged, Hall's (1997) view of discourse became a central pillar in the developing analytical framework. Here, discourse is viewed as a concept describing "…ways of referring to or constructing knowledge about a particular topic of practice: a cluster (or formation) of ideas, images and practices, which provide ways of talking about, forms of knowledge and conduct associated with, a particular topic, social activity or institutional site in society". This facilitated a further extension by drawing on Kress, Jewitt, Ogborn & Tsatsarelis (2001) to depict the discourse of a discipline as being made up of a number of *modes*, where spoken and written language are examples of two such modes. Each of these modes is seen as having different *affordances* or, to put it in another way, *different possibilities for representing disciplinary ways of knowing*:

> Several issues open out from this starting-point: if there are a number of distinct modes in operation at the same time (in our description and analysis we focus on speech, image, gesture, action with models, writing, etc.), then the first question is: "Do they offer differing possibilities for representing?" For ourselves we put that question in these terms: "What are the *affordances* of each mode used in the science classroom; what are the potentials and limitations for representing of each mode?"; and, "Are the modes specialized to function in particular ways. Is speech say, best for this, and image best for that?" (Kress et al., 2001:1)

For the analytic needs of this study a notion which termed *disciplinary discourse* was consequently developed to characterize this collection of modes. It is this disciplinary discourse that students are expected to enter into and make their own. In this spirit, disciplinary discourse is now defined as *the complex of representations, tools and activities of a discipline*.

3.4.2. Representations

By representations is meant semiotic signs that have been designed to convey the ways of knowing of science. This stems from the notion that in university science such a system of semiotic signs is made up of far more than simply the representational modes of oral and written language. Other modes such as images (e.g. graphs and diagrams), mathematics and gesture also play a central role in this system (Kress & van Leeuwen, 2001; Roth, Tobin, & Shaw, 1997; Roth & Welzel, 2001) and should therefore be included in our framework.

3.4.3. Tools

Every discipline has its own specialized tools that its members draw on to create disciplinary ways of knowing, and indeed the scientific community excels itself in this respect. Thus, learning to use the tools of science can be regarded as an integral part of being able to *do* science. But there is another perhaps less obvious characteristic of tools. From a cultural-historical perspective it is possible to see a tool in terms of a *condensation of meaning*. Thus, for example, Wartofsky (1979) has argued that it is possible for a tool, in certain circumstances, to mediate the knowing that went into its production. In other words, appropriate interaction with a tool can lead to more than a simple, situated understanding of how to *do* a piece of science, and thus students may also gain access to some of the ways of knowing the world implicit in a given tool's development. Hence, the tools of a discipline— though not explicitly designed to mediate scientific ways of knowing—must be included as a separate mode in any characterization of the system of mediating signs of that discipline.

3.4.4. Activities

Similar to tools, the things that are done in the name of scientific activity need to be assimilated and learned by apprentices of the discipline. And, as with tools, these activities can be characterized in terms of condensations of meaning. Thus the ways of knowing that underpin the activities may be opened to students through participation and observation. (See for example Crawford, Kelly, & Brown, 2000; Kuhn, 1962/1996; Roth & Lawless, 2002; Wells, 2000). This idea is the *leitmotif* of student laboratory work. Thus activities has been included as a further mode of disciplinary discourse.

3.4.5. Disciplinary discourse

In this framework, then, the modes of disciplinary discourse include not only the words, symbols, gestures, diagrams, formulas, etc. used by a discipline; but also the artifacts, pieces of apparatus, measuring devices, etc. and the actions, practices and methods residing within the discipline. We can therefore argue that the disciplinary discourse of university science serves a dual purpose; it is first and foremost the physical application of the ways of knowing of the scientific community—quite simply it is how we *do* science, and it is also the sole means we have of sharing and evaluating this knowing.

3.4.6. Languages and modes

An important question for this thesis was: *How do English and Swedish relate to the system of modes of disciplinary discourse?* Halliday (1993) has

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shown how switching from one language to another (English to Chinese) whilst totally changing the discourse of a science text, has very little effect on the meaning that the text represents. It is therefore suggested that in university physics discourse (the focus of our study) the modes that go together to make up English and Swedish may be viewed as *parallel*. This is because the modes that constitute English and Swedish instruction offer similar possibilities for learning. Naturally it is not being suggested that students experience English and Swedish modes in the same way. Rather that, given a student who was equally fluent in both Swedish and English, the potential of say, oral English to represent physics ways of knowing would be similar to that of oral Swedish. Note again here that in this characterization, neither English nor Swedish can be viewed as being fully representative of the ways of knowing of university science. Modes other than spoken and written language, such as mathematics, image, gesture and the tools and activities of science are also major components of disciplinary discourse.

3.4.7. "Big D" Discourse

In a number of respects the notion of disciplinary discourse is similar to Gee's (2005:20) "big D" Discourses. Gee uses Discourse (with a capital letter) to designate the combination of discourse—that is language-in-use with other, non-language "stuff". The difference between disciplinary discourse and Discourse, is that disciplinary discourse carries a much more focused meaning—being defined as the complex of representations, tools and activities of a discipline. Gee's Discourse is a much wider concept which includes the *whole context* within which disciplinary discourse may be used. Indeed, in contrast to the view presented here where disciplinary discourse is seen as *representing* a particular way of knowing, Moje, Collazo, Carrillo & Marx (2001:470) in the following quote appear to suggest that Discourse *is* a particular way of knowing: "Any stretch of language (discourse) is always embedded in a particular way of knowing (Discourse)…". Thus Discourse can be characterized as including such things as students' epistemology, group dynamics, gender, social status, etc[6]. These aspects, whilst certainly important in student learning, are purposefully not part of the constitution of disciplinary discourse. The reason for excluding such important aspects is that this work is interested in analyzing *basic necessary conditions* for learning disciplinary ways of knowing with respect to the discourse perspective laid out earlier. By basic necessary conditions is meant conditions without which learning disciplinary ways of knowing may become impossible, regardless of any other factors.

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[6] For a good illustration of Discourse see Kittleson & Southerland (2004) who use the concept to analyze engineering students' group knowledge construction.

3.4.8. Appresentation and facets of a way of knowing

If each of the modes of disciplinary discourse has different possibilities for representing disciplinary ways of knowing, then we can say that each mode has certain potentials for revealing particular *facets* of a given way of knowing. By facets is meant the various attributes of a way of knowing which are necessary for constituting the complete experience of that way of knowing. An example of these facets of a way of knowing can be seen in the teaching and learning of Ohm's law. A student may experience Ohm's law in a number of different ways through, say: hands-on activities (with batteries, wires and bulbs), a circuit diagram, oral descriptions from the teacher, written descriptions in a textbook, the mathematical formula **V=IR**, a table of voltages and currents for a given circuit or a simple line graph of these voltages and currents. In each of these situations certain facets of Ohm's law are brought to the fore, whilst others remain in the background (or are simply not present). Thus each disciplinary way of knowing may only be partially represented by a particular mode of disciplinary discourse. As Marton & Booth (1997) point out, the experience of a disciplinary way of knowing depends on the phenomenological concept of *appresentation:*

> When we have a perceptual or sensuous experience of something, which is to say we see, hear or smell it, we can talk about the mode in which it presents itself, that is, the way in which it appears to one or more of our senses. But in addition to what is "presented" to us—that is what we see, hear, smell—we experience other things as well. If we look at a tabletop from above, for instance, we hardly experience it as a two-dimensional surface floating in the air, in spite of the fact that what we see is, strictly speaking, a two-dimensional surface separated in some mysterious way from the ground. But in looking down on a tabletop we experience the legs that support it as well, because the experience is not of a two-dimensional surface, but of a table… That which is not seen, is not even visible is appresented … We wish to apply the concept of appresentation to experiences of abstract entities as well as concrete ones. If we think of the gravitational constant, g, for instance, then the highly abstract formulation made by Newton of how bodies affect one another at a distance is appresented, given that we have acquired sufficient education in and experience of classical physics (Marton & Booth, 1997:99-100).

Thus one mode of disciplinary discourse opens up the possibility to experience a particular number of facets of a disciplinary way of knowing, but, in order to appropriately experience this way of knowing, the other facets of the way of knowing need to be appresent. It is therefore argued that students of the discipline may be unable to fully experience a disciplinary way of knowing until two criteria are met: First, at some stage they must have experienced each of the various facets of the way of knowing. This it is argued entails *multimodal representation*. Second, they need to be able to experience these facets simultaneously—that is, when one group of facets is pre-

sented to them through a particular mode of disciplinary discourse, the other facets need to be appresent. It is suggested that this second criterion can only be met after students have familiarized themselves with the disciplinary discourse to such an extent that experiencing the various facets simultaneously becomes second nature, or to put it another way, when they have become *discursively fluent* in a number of modes.

3.4.9. Discursive fluency

Following Fairclough (1995) the New London Group (2000:20) argue that each semiotic domain has its own specific *order of discourse* that is "a structured set of conventions associated with semiotic activity (including use of language) in a given social space". Building on this, with an interest in the individual modes of disciplinary discourse, the notion of *discursive fluency* was to constituted to characterize the ability to use *a particular mode* of disciplinary discourse in a legitimate way (that is in line with the disciplinary "order of discourse") with respect to a certain disciplinary way of knowing. Thus, in this characterization, if a person is said to be discursively fluent in a particular mode they have familiarized themselves with the ways in which the discipline generally uses that mode when representing a particular way of knowing. Taber (2002:73) suggests this familiarization is needed because: "…the logical structure needed to develop the new ideas may exceed the processing capabilities of the student. Although each step in an explanation may itself be manageable, the overall structure may 'swamp' the student and seem much too complicated". Thus, it is suggested that a degree of discursive fluency may be necessary before the facets of a disciplinary way of knowing that are made available by a given mode of disciplinary discourse can be appropriately experienced.

In this respect there is always the possibility that discursive fluency may not necessarily lead to an appropriate experience of the related facets of the disciplinary way of knowing—students might simply learn to *imitate* the "order of discourse" of a discipline. However, if students are imitating the "order of discourse" they will encounter difficulty when they are required to use disciplinary discourse in a creative way in unfamiliar situations. This *discourse imitation* argument is further developed in the results section.

3.5. Summary

This chapter has presented the reasoning behind the study and the way in which decisions were taken about the design of data collection using video and interviews. The early theoretical framing of the study with respect to a shared space of learning was discussed along with the way this developed into an approach which views learning as entering a disciplinary discourse.

A presentation of this disciplinary discourse analytical framework was given. This framework is further developed in chapter four of this thesis in parallel with the analysis of the interview data.

4. Results

4.1. Introduction

For this study data was collected from five courses; first, two parallel courses in Karlstad—electromagnetism (in English) and mathematical methods for physicists (in Swedish). This was followed by data collection from two parallel courses in Kalmar—classical mechanics (in English) and oscillations and waves (in Swedish). Finally data was collected twice from a single course in Karlstad—quantum physics which was taught in both Swedish and English by the same teacher.

4.2. Data collection

As set out in the introduction to this section a total of six physics lectures with different lecturers were videotaped. Each student in the study was present at two of these lectures. Prior to filming, the lecturers had been interviewed about; their aims for the lecture and how it fitted into the "whole", their experiences of the group as learners and any areas where they expected students to have problems with the material to be covered.

Guided by these interviews, and the interest in sampling as many modes of disciplinary discourse as possible the resulting video footage was edited down to four segments for each lecture. These four segments always included a part of the teaching sequence where lecturer presented a diagram and where a mathematical representation was discussed. The total running time of these four segments was between seven and ten minutes. Other clips used included; teacher explanations of problem solving strategies, presentation of graphs and tables, computer animations, lecturer demonstrations, and sections of lectures where the teacher or a student asked and/or answered questions.

In the first study, five students at the University of Karlstad were interviewed as to their experiences on a course in electromagnetism taught in English and a course on mathematical methods for physicists taught in Swedish. In the second study, three students were interviewed on their experiences in a course of classical mechanics in English and a course on oscil-

lations and waves in Swedish. Finally, fourteen students were interviewed on their experiences on a course in quantum mechanics. In this final course the presence of exchange students meant that the same teacher taught the same students in both English and Swedish. All told, twenty-two volunteer students were then interviewed using a semi-structured interview protocol. These interviews were open-ended and lasted approximately 1hr 30mins. Students were first asked to talk about their experiences of learning physics through different representations such as diagrams, text, oral descriptions and mathematics. The interviews continued by exploring student expectations of; the two lectures they participated in, the two courses of which these lectures formed a part and their entire degree program to date. Further themes dealt with such issues as student experiences of other "input" such as laboratory work and problem-solving sessions, their use of the course text, and so on. The amount of work-time students put in outside class and their work-time with other students was also explored. The 2x4 edited segments of video footage were then used to create a *stimulated recall* environment as described in the previous chapter (Bloom, 1953; Calderhead, 1981).

4.3. Working with interview recordings

All interviews were recorded digitally, enabling direct access to their various sections. This, together with the structure generated by the stimulated recall approach, led to the following form of data analysis. Each of the digital interview files were "cut" into sections where students discussed similar themes. Each of these sections was given a filename consisting of the topic discussed, the student's name and a five digit identification code which was in fact the excerpt's time stamp in the original master recording. This allowed easy cycling through the data, listening to several students talking about similar and related themes in order to efficiently build up an overall picture of what students were saying as individuals and as a group.

This method of analysis had two benefits: first, analysis could be begun within a few days of collecting the data, bypassing the lengthy process of transcription, and second, more of the situatedness of the interview was maintained—transcripts being generally acknowledged as one step further away from the phenomenon under study than the audio recording[7]. Maintaining this situatedness was considered important since in the interviews we were attempting, through stimulated recall, to vividly recapture for the students the essentials of their experience of being in a specific lecture. Student

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[7] The audio recording is of course one step further away from the interview itself, which is in turn several steps away from the actual learning experience in the lecture. See Säljö (1997) and Kvale (1996) for discussions of the limitations of interview studies as a source of information about classroom learning.

files could also easily be re-related to the whole of the interview due to the timestamp identification code used which led directly to the correct position in each master recording. A description of a software solution similar to the way of working described here is given in (Pea, in press).

4.4. Results in language terms (paper II)

4.4.1. Language is seen as unimportant

The most striking aspect of the combined findings of the three studies is that when asked directly, students say they felt that there was very little difference in their learning when taught in English rather than in Swedish. This is something that is common for all students at both universities. This result is similar to those of Neville-Barton and Barton (2005) who find that the second-language mathematics students in their study self-report levels of understanding similar to those of first-language students. The overwhelming majority of students interviewed in the studies feel the lecturer should use the language he or she is most comfortable with—i.e. since the students are well-versed in English from high school they do not see their own competence in English as problematic. Students suggest that the limiting factor for their learning is the lecturer's ability to mediate physics knowledge in the chosen language. However, despite all students initially maintaining that language was not an important factor for their learning, both the analysis of the videoed lecture material and the students' own accounts of their learning experiences during stimulated recall indicate a number of problems related to learning in English rather than Swedish.

4.4.2. Asking questions

It was observed that the willingness to ask and answer questions was greatly reduced in English-medium lectures. This was also reported by the students themselves. That the traditional reluctance to ask questions is exacerbated when lectures are in English is all the more worrying when we take into account the fact that lecturers see a strong correlation between asking questions and student understanding. When observing this particular lecturer's sessions it was found that a number of students, though quiet in the lecture, came forward at the end of each session to ask questions.

4.4.3. Answering questions

The students in the study describe how they tend to answer fewer questions when lectures are given in English. This reduction in asking and answering questions is an important finding. If lecturer/student interaction is reduced in

this way (in extreme cases effectively limiting lectures to a monologue) then we would expect what is widely characterized as the shared space of learning (Tsui, 2004b) to be correspondingly reduced.

4.4.4. Focusing on note taking

When lectures are given in English, those students who take notes report spending a large proportion of their time concentrating on the process of writing rather than understanding lecture content:

Student: You're not as used to listening to someone speak English as Swedish. … You know speaking Swedish you can just er. You can listen and you can write what he's saying and you don't have to, you know, make such a big effort out of it. But if it's in English you've maybe got to focus a bit more on what he's saying and maybe the general message of the physics or maths gets lost a bit more… (Airey & Linder, 2006:556)

4.4.5. Work outside class

For students who take notes, their success in understanding the content of a lecture given in English appears to critically depend on the work done outside class after the lecture (or sometimes before the lecture, see section 4.4.6.).

This should not be interpreted as a suggestion that when the students attended lectures in Swedish they did not need to do work outside class. Rather, as shown in section 4.4.4., the students in the three studies indicated that when they took notes in a lecture given in Swedish they were better able to simultaneously follow the thread of that lecture than they were when taking notes in a lecture given in English. Consequently, when the students took notes in a lecture given in English, they found they typically had to do more work outside class than when the lectures were given in Swedish.

4.4.6. Reading before the lecture

In some cases students had read through the relevant chapters before the English language lecture and, without exception, these students were those who claimed higher levels of understanding during the lecture. This reading done before class would probably have the same positive effect on the understanding of lectures given in Swedish; however, the students in the study only mentioned reading before class as a strategy they adopted when they were lectured in English.

4.4.7. Multi-representational support

In one of the videoed lecturers, the lecturer followed one textbook very closely, working through each of its sections on the board. Often there was little difference between the pages of the book and what was written on the board. This could be interpreted as a rather boring and unproductive lecturing strategy, however, this 'walking students through the landscape' was appreciated by all the students interviewed. So one useful lecturing strategy could be to follow a book or a set of lecture notes that students have already had access to – students can then simply annotate the text whilst concentrating on what is being said. Similarly, one student talked about the need for written support for oral descriptions:

Student:	It's easier in a lecture when you have a…when they write things down on the board. That's actually something with English, that its difficult to sit and spontaneously make notes 'cause you've got enough on your plate trying to first understand the English and then understand the physics. If they only talk it's difficult to translate and make notes, you end up with a bit of a mixture, a bit of Swedish and a bit of English. I think it's easier – actually I think it's always easier when the teacher writes a lot on the board…
Interviewer:	So the lecturer has to, if it's taught in English, has to write down a lot otherwise it becomes very difficult?
Student:	Yep […] I personally find it difficult to take things in when I only hear it and don't get written notes.

(Airey & Linder, 2006:558)

Here we can see that when lecturing in a second language, writing extensively on the board appears to help students. We can speculate that other forms of support such as handouts, overhead slides, demonstrations, computer simulations, etc. would also help.

4.4.8. Summary of results in language terms

The main result of this study is that there appear to be differences in the ways Swedish physics students experience lectures in Swedish and English—and that students are on the whole unaware of these differences.

When taught in English the students in the study asked and answered fewer questions and reported being less able to follow the lecture and take notes at the same time. Students employed a number of strategies to meet these problems by; asking questions after the lecture, changing their study habits so that they no longer took notes in class, reading sections of work before class or—in the worst case—by simply using the lecture for mechanical note taking and then (perhaps?) putting in more work to make sense of these notes later.

4.5. Results in terms of students' experience of equations (paper III)

4.5.1. What students focus on when presented with an equation

Analysis of the interview data indicated that the variation in students' experience of equations could be mapped out as shown in Table 1. A layered structure of increasing complexity was found. At level A, students can identify the equation by name. At level B students can read out the symbols of the equation, e.g. $V = f\lambda$ (vee equals eff lambda). Level C involves students substituting terms for symbols e.g. velocity equals frequency times wavelength. At level D students show evidence of *understanding* the parts of the equation. Level D is differentiated from level C since it is far from clear whether saying 'frequency', for example, carries any disciplinary meaning. As diSessa (1993) and others have pointed out, a student can easily learn to express an equation in linguistic terms repeating it as a *slogan* without actually understanding *what* the slogan means. Level E relates to being able to appreciate the meaning of the equation *as a whole*. Each of the observed levels has one or more focuses as shown in table 1. Each of the observed levels may have a related mathematics, physics and real world interpretations (shaded cells in table 1). Taken together, each cell may be seen as contributing in a specific way to a more complete understanding of the equation.

Table 1. Students' experience of the disciplinary knowledge of a physics equation. The shaded areas correspond to the range of student focus at the various levels A-E.

	Category	Description	Focus		
			Maths	Physics	World
A	Equation having a name/label	A name is attributed to the equation	▓	▓	
B	Symbolic recognition of parts	The *symbols* of the equation can be read out	▓	▓	
C	Linguistic recognition of parts	The symbols in C can be appropriately identified as physics or mathematics terms.	▓	▓	
D	Understanding of the parts	Student shows evidence of *understanding* the physics, mathematics or real world meaning of parts of the equation	▓	▓	▓
E	Understanding of the whole	The equation as a whole is related to appropriate mathematics/physics/real-world situations	▓	▓	▓

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4.5.2. Results – what do students focus on first?

What was interesting from an educational point of view was the *order* in which students appeared to focus on these different components of under-standing. All students seemed to initially concentrate on the *mathematical nature* of a new equation. For a number of students this ability to handle an equation mathematically was equated with understanding. This was particularly obvious when students claimed to understand mathematically simple physics equations, but could not say what the terms in the equation represented. Other students claimed to use their mathematical knowledge to access the physics of the equation:

Student: Often I recognize the mathematical terms before I understand the physics. And then I apply the mathematics and try to do some problem-solving and then it all—not all but much of it—falls into place.

And here another student on the same theme:

Student: If I can see the mathematical connections with all the terms and variables then I can usually go back and see the physical part. So I go that way. First I go to the math and then I try to understand [the physics].

In some cases, this finding could be explained in terms of students using symbolic forms (Sherin, 2001; Tuminaro, 2004; Tuminaro & Redish, 2003) to decipher the meaning represented by the equation. A number of students appeared to 'stop' at this level, equating ability to use the equation to solve physics problems as understanding. Only a smaller number of students claimed to be looking for real-world applications as a means to 'understand' the equation.

4.6. Results in discourse terms (paper IV)

The analysis now presented illustrates the use of the discourse analytical framework described in chapter three and how the results were obtained. Since the students in the interviews are commenting on their experience of learning in lectures (where the sole purpose of the lecture is to communicate the ways of knowing of the discipline) the data best illustrates those modes of disciplinary discourse that have been characterized as *representations*.

4.6.1. Discursive fluency through repetition

The students in the study describe their learning of disciplinary discourse through a process of *repetition*; working with a large number of problem sets and reading and re-reading lecture notes and prescribed textbooks.

With the growth of constructivist ideas about students constructing meaning for themselves, the behaviorist idea of repetition as an important dynamic in learning became widely unfashionable. However, recently there has been renewed interest in repetition. Marton & Trigwell (2000) for example put forward the idea that *variation* rather than repetition should be focused on when giving consideration to making learning possible. It is the variation in the object of learning (that *can* occur through repetition) which allows a student access to a disciplinary way of knowing. Thus in Marton & Trigwell's framework, repetition which offers no new variation in the object of learning should be viewed as playing no meaningful role in learning. This idea of variation has also been developed by Linder & Marshall (2003) who put forward the idea of *purposeful repetition.* In their argument learning may involve using the *same material* over a period of time if this is done with the *intention* of experiencing variation. Thus, despite repeating exactly the same task, critical variation in an object of learning can be achieved if the student's *focus* changes from one iteration of repetition to the next. From this perspective it is possible to interpret some dynamics of repetition in terms of searching for variation. As will be described later, this variation approach is central to the theoretical framework when accounting for the way in which students experience the ways of knowing of a discipline. However it was found that characterizing learning through variation alone did not fully describe the empirical data. It is therefore argued that there is another, complementary way of viewing student repetition, namely as an attempt to achieve *discursive fluency*. By discursive fluency is meant a process through which handling a mode of disciplinary discourse becomes almost second-nature[8].

This interpretation mat be illustrated by referring to a well-known and widely respected example of variation. Marton, Runesson & Tsui (2004) illustrate the central role variation plays in learning by referring to Moxley's (1979) experimental study on motor learning. In Moxley's study children were asked to practice hitting a target with a ball. One group of children practiced throwing the ball from the same position all the time, whilst the other group practiced from a number of different places. When the two groups were compared in their ability to hit the target from a position that

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[8] Note that each of the modes of disciplinary discourse has a productive and a receptive version e.g. reading and writing, speaking and listening, etc. The term discursive fluency is not limited to production and can refer equally well to familiarization with a receptive version of a mode.

was new to both groups, the group which had had experience of several positions was found to be better at hitting the target.

An interpretation of the ball throwing example feasibly includes more than variation alone. This is because the children in Moxley's study *practiced* throwing. Put simply, the experience of variation would not seem to be sufficient for them to learn to hit the target, what was also needed was a repetitive, temporal aspect. Repetition over time led to improved performance. Similarly, the students' descriptions in the study also pointed to a repetitive, temporal aspect being involved in the learning of physics. In the same way that oral fluency in a foreign language is a product of repeated practice, the students in the study attain *discursive fluency* in the various modes of disciplinary discourse through a process that includes repetition—what Kuhn (1962/1996:47) has likened to "finger exercises" on the piano.

4.6.2. Discursive fluency and disciplinary ways of knowing

In this characterization, then, gradual familiarization with the way meaning about a particular way of knowing is constituted in a particular mode leads to increased discursive fluency in that mode. It is further suggested that discursive fluency is a necessary condition for experiencing the associated facets of a way of knowing that the disciplinary discourse represents. In the following quotes students suggest that they use their discursive fluency (here in the mathematical mode) in order to experience facets of the ways of knowing of the physics discipline.

Student: Often I recognize the mathematical terms before I understand the physics. And then I apply the mathematics and try to do some problem-solving and then it all—not all but much of it—falls into place.

And here another student on the same theme:

Student: If I can see the mathematical connections with all the terms and variables then I can usually go back and see the physical part. So I go that way. First I go to the math and then I try to understand [the physics]. (Airey & Linder, 2006 in review)

These statements may be interpreted in terms of students using their discursive fluency in the mathematical mode as a stepping stone to experiencing some of the facets of a disciplinary way of knowing. In this characterization, these facets of the way of knowing that are provided by the mathematical mode help these students to structure input in other modes and hence experience further facets of the disciplinary way of knowing. These facets could be described as acting like a "seed crystal" around which other representations can be collected and "decoded". Following the framework such decoding can itself only occur when students have become discursively fluent in these

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other modes of disciplinary discourse. This notion is corroborated by the observation that when discursive fluency is not present students seem unable to experience the associated facets of a disciplinary way of knowing.

4.6.3. When students are not discursively fluent

An illustrative example of a lack of discursive fluency is given below (visual mode). In this section of a lecture the lecturer drew a diagram of a transformer on the board (fig.1) and gave the following oral and written description. (Airey & Linder, 2006 in review)

Lecturer: And now we will look at section 7.2.2 which is about transformers. A transformer is just a device for transforming—that means changing the value of—either currents or voltages. [underlined text written on the board]
And concretely it looks like this.
[starting to draw fig. 1] You have a metallic core which has some permeability, μ. And as you will see it will be interesting to take ferromagnets—that means that μ is large. And we take two coils which are wound on this core, one is to the left and another one to the right. And let's assume that there is a current I_1 in the coil to the left and there are N_1 turns in this coil, and here we have N_2 turns and the current I_2

Figure 11. Diagram of a transformer drawn by the lecturer on the whiteboard

The following is the transcript of an interview with a student after having seen this short video clip during stimulated recall:

Interviewer: This is him starting this thing about transformers—what, what did you think about this particular part?
Student: Ummmh. Yeah, I don't know what this is. I didn't know what he was writing…
Interviewer: Okay, he's drawing some kind of diagram, but you don't really know what that is that he's drawing or…?

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Student: No.
Interviewer: Okay, so…
Student: —And I think it's, it's, quite often like that in the lectures—that he's drawing something on the whiteboard and he assumes that we know this from before.
Interviewer: So er, you—you've got, er, no idea what this transformer thing is?
Student: [laughing] No.
Interviewer: What do you think makes this difficult to understand, then … just for you?
Student: [sighs] errm … errm—at first I think he should tell us what this is!

The interpretation here is that this student has not experienced the facets of the way of knowing described by this diagram (visual mode) and appeals for help. Paradoxically, as can be seen from the teacher's description of the transformer, the teacher provided a clear description of what the diagram represents, both orally and on the board. It is suggested that the interviewed student has not become discursively fluent in this visual mode, i.e., the student has not become appropriately proficient in seeing and handling this particular representation. Had the student instead answered that "The teacher drew a diagram of a transformer with a core and two coils" then we could have inferred that this student was discursively fluent in this mode—note, however, that this is not the same as saying that the student would then *know what a transformer is*. If the student has never *seen* a transformer, nor understood *why* changing voltages, currents and associated electric fields could be of any interest, then discursive fluency—in this case simply knowing that this is a standard representation of a transformer—will not give the student access to the disciplinary way of knowing.

    This student transcript nicely illustrates Northedge's (2002) claim that some meanings cannot be construed from outside the discourse. All the other students in this part of the study appeared to relate the diagram to a shared way of knowing of the discipline. As discussed in chapter three, in phenomenological terms, the way of knowing was *appresent* for them. Logically, however, there must also have been some stage when the diagram did not carry this disciplinary way of knowing even for these students. At some stage in the past, these students learned to "see" something *beyond* the diagram, but now they (and the lecturer) take this meaning for granted—in the terms of this framework they have entered the discourse of the discipline. Thus it is believed students need to achieve discursive fluency within a particular mode before they are able to experience the associated facets of a disciplinary way of knowing.

4.6.4. Necessary but not sufficient, discourse imitation

If we accept that discursive fluency is necessary for experiencing facets of a disciplinary way of knowing, the next question is whether this discursive

fluency is a sufficient condition for experiencing these facets. Put simply, does familiarization with a representation automatically lead to a student experiencing the associated facets of a disciplinary way of knowing? This study suggests that discursive fluency is a *necessary but not sufficient condition*, that is students may learn to use disciplinary discourse appropriately, but still not experience the associated facets of a way of knowing. This ability to use disciplinary discourse without experiencing the associated ways of knowing has in fact been documented by a number of researchers. For example, diSessa (1993) reports the following:

> One of the most striking findings from the interviewing studies on which this work is based is that MIT undergraduates, when asked to comment about their high school physics, almost universally declared they "could solve all the problems" (and essentially all had received A's) but still felt they "really didn't understand at all what was going on" … these students' impressions of incomprehension are ironically more correct than their school assessments: They did not understand, even though they could perform (diSessa, 1993:206).

diSessa accounts for this phenomenon as follows:

> Symbolic and verbal propositions are prominent in instruction. It is possible to view these as being learned prior to the broader co-ordinations in intuitive knowledge that are eventually required. This is like the way learning slogans may precede a deeper commitment to a political ideology (diSessa, 1993:152).

It is suggested that these "slogans" are a common part of learning. In the analytical framework the term *discourse imitation* is used to describe discursive fluency without a corresponding experience of the associated facets of a disciplinary way of knowing. This notion of discourse imitation is by no means new, being a theme which dates back to the ancient Greek and Roman rhetoricians and a commonly discussed factor in the teaching of academic writing (D. Clark, 1951; Mintock, 1995; Rider, 1990). Below are examples of discourse imitation—instances where students are fluent in one or more modes of disciplinary discourse of the university physics community, but where they have apparently not experienced the corresponding facets of the way of knowing which the segment of discourse represents (Airey & Linder, 2006 in review).

Interviewer:	You've seen these equations before..?
Student:	Yeah I've seen them before er… but I really don't know exactly what they mean [laughs].
Interviewer:	Can you tell me what this means to you? [pointing to the formula $\nabla \times E = 0$]
Student:	Um, I think the E is er the intensity of er an electric field. And then the curl of E… [quietly to herself] mmh equals zero…

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> Erm, I think this is erm a conservative vector field—and I know how to calculate it but I don't know what it means.

This student is discursively fluent in the mathematical and oral modes with respect to this particular way of knowing. Here we can see strong supporting evidence for diSessa's (1993) slogans in the words "conservative vector field". The student appears to have heard or read this expression many times, but it is clear that the student has not experienced the way of knowing it represents. In the terms of the framework developed here this is discourse imitation. Moreover, the student can *calculate* answers using this formula—in fact this student had been one of the more successful participants on the degree course up to that point and self-reports finding mathematics easy. However, it is evident that in this case the student does not know *what* it is that has been calculated.

4.6.5. Translation between modes

The students in the study suggest that discursive fluency in some of the representative modes of physics discourse may be insufficient to constitute an appropriate disciplinary experience of physics ways of knowing. Here is a student talking about learning quantum mechanics:

Student:	You can calculate using a mathematical formula in physics but you don't understand what's happening. You want to translate into plain Swedish—what's happening in physics through the math—but that's not always easy. Especially not now because now you can't really see a picture of it or understand really what it is that's happening in quantum physics.
Interviewer:	Mmm, that's interesting. Do you think there are some things that can only really be described with math in this subject?
Student:	Yeah, I think so.
Interviewer:	There aren't really adequate Swedish words to describe what's going on?
Student:	Yeah—and no English ones either. It's only math, only math can describe it properly. And just that—that there aren't really any words for this—gives you a feeling that it doesn't really exist—you can't really 'see' it—it doesn't really exist you can only calculate it.

(Airey & Linder, 2006 in review)

This student's suggestion that only mathematics can describe quantum physics is further confirmation that different modes of disciplinary discourse play different roles in offering access to physics ways of knowing. Moreover, different disciplinary ways of knowing appear to be best represented through different combinations and "proportions" of modes. Perhaps, as this student suggests, the disciplinary way of knowing the world which we call quantum

mechanics is best represented through a higher "proportion" of mathematics in relation to oral and written language than say Newtonian mechanics.

This student is obviously struggling to understand quantum mechanics and consequently is attempting to translate the meaning in the mathematical mode to meaning in the oral and visual modes. Following Stern, Aprea, & Ebner (2003) such re-representation of meaning is a natural part of learning and such translation between modes can reveal further facets of a disciplinary way of knowing that students were previously unaware of. This interpretation can be seen to be supported by the following dialogue taken from an interview with another student on the subject of learning mechanics:

Student: It's different for me to… maybe I think I understand and then I should calculate and then I cannot do it—so maybe I haven't understood er, maybe I just **think** I understand but I, I don't actually because it's hard to calculate.

Here one can see how the student recognizes in moving from the written and oral modes of disciplinary discourse—reading about and listening to descriptions of a way of knowing—to the mathematical mode—"calculating"—that there is a mismatch between their own way of knowing and that of the discipline.

Similarly, since each mode has different possibilities for meaning-making it therefore seems reasonable to argue, following Marton & Tsui (2004), that from a variation point of view a *multimodal* approach to teaching will enhance the possibility of appropriate learning. For example, here we have a student describing the usefulness of multimodality in her own learning:

Student: I usually write down more or less everything the teacher writes on the board.
Interviewer: Even though it's there in the book?
Student: Yeah. At least with the theory.
              I think it's more comfortable to write down derivations and so on— if you write it down it goes in another, one more way so to speak.
Interviewer: Aha, so the doing in some way…?
Student: Yes I think so.
(Airey & Linder, 2006 in review)

This student's use of a multimodal approach is an example of Linder & Marshall's (2003) notion of *purposeful repetition* which was briefly described earlier, that is the student's translation between modes can be seen as an attempt to experience critical variation in the object of learning.

4.6.6. Critical constellations of modes

From the point of view of disciplinary discourse, we can say that *no one mode in itself can be fully representative of a disciplinary way of knowing*

the world, and therefore it is impossible to experience disciplinary ways of knowing through input from one mode alone.[9] That is not to say that mono-modal discourse may not be useful within the scientific community. Once students have experienced the ways of knowing of a discipline, (or as it has been characterized here, "entered the discourse" of the discipline) a few short phrases, or an equation, or a simple diagram can allow them to share meaning with others—those facets of a way of knowing which are not present in the immediate representation are automatically appresent. For example, as pointed out earlier, for the majority of students in the lesson with transformers the diagram that the lecturer drew on the board *meant something appropriate*—simply drawing this diagram evoked a whole dimension of shared meaning. One way of characterizing this is to use Wittgenstein's (1958) idea of students and lecturer *playing the same language game*. This kind of mutually accepted system can only occur if both student and lecturer have fully experienced the ways of knowing of some part of the discipline. And, as is have argued here, such ways of knowing may perhaps only be fully experienced through certain types of disciplinary discourse.

Each way of knowing in, for example physics, may in fact, only be constituted by a certain critical constellation of modes. Once a way of knowing has been experienced, it can be activated in other modes, but the initial possibility to experience may only be available by experiencing critical variation in a particular constellation of modes.

Based on these findings and following the ideas of variation and purposeful repetition, it is argued that: *first*, multimodal teaching has the distinct potential to achieve better learning outcomes than teaching with a reduced number of modes. And, *second*, it is of utmost importance that research be carried out into *which* constellation of modes opens up the possibility for experiencing each of the particular ways of knowing of physics. Without this knowledge lecturers will have little possibility of systematically building their teaching around a "variation approach" (Marton & Tsui, 2004) and then it is argued that there is a risk that their teaching may in fact not offer the specific constellation of modes needed make a particular way of knowing accessible to students.

At this point it is perhaps appropriate for us to once again remind the reader of the intentions of this work. It is not suggested that providing students with access to a certain combination of modes is sufficient in itself to guarantee learning—far from it. A great deal of research has pointed to the importance of other factors that need to be considered in descriptions of learning science, such as gender and power relations (Conefrey, 1997; Sey-

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[9] I do not mean to suggest here that a course text or a lecture is of necessity mono-modal in nature. The majority of physics texts and lectures are multimodal, using for example mathematical notation, diagrams, graphs and pictures along with the written or spoken mode of English or Swedish.

mour & Hewitt, 1997; Thomas, 1990), student epistemology (Hammer, 1995), culture (Brown, 2004), group dynamics, (Bianchini, 1997), etc. Thus much of the interview data could be gainfully interpreted from any or all of these perspectives. However, what is being suggested here is that, irrespective of these other factors, certain disciplinary ways of knowing may be *impossible to appropriately constitute* without discursive fluency in a critical combination of modes. However, even when discursive fluency in a critical constellation of modes is achieved, discourse imitation may still continue for any number of reasons which are related to the particular context (See Gee's (2005) concept of Discourse which was described in chapter three).

4.6.7. "Discoursing" in university science

From the multimodal viewpoint, simple *exposure* to disciplinary discourse is not enough for students to experience disciplinary ways of knowing, students need practice in *using* disciplinary discourse to make meaning for themselves. Northedge (2002) has suggested that teachers ought to scaffold student meaning making. Students should be expected to initially make "fuzzy" meaning—that is their discourse will initially be a *poor imitation* of disciplinary discourse, but, with appropriate guidance, gradually this will spiral towards something closer to the discourse of the discipline (they achieve discursive fluency). Examples of such scaffolding of multimodal student discourse can be seen in Stern, Aprea, & Ebner (2003) and Kozma, Chin, Russell, & Marx (2000). From the interviews with teachers and students and the research group's experience of university physics one can find evidence that the supporting of students' own meaning making within disciplinary discourse is not a typically a common practice in university science. In university science, such scaffolding of student *use* of disciplinary discourse appears to be limited to guidance in using the tools and carrying out the activities of science in laboratory work, along with some mathematical guidance in formal problem-solving sessions (although in the latter situation it is not uncommon that students are reduced to passive observers whilst the lecturer "models" the mathematical mode of disciplinary discourse).

Lemke (1990) believes that students should be given the chance to *"talk science"*, whilst Tobias (1986) has suggested that learning would be enhanced if science students were encouraged to *"kick the ideas around'"* as they are in the social sciences and humanities. From the perspective of this the work presented here these assertions may be reformulated by suggesting that students need to be given the opportunity to *"discourse"* in science, in order to gain the necessary fluency. That is students need opportunities to engage with the various modes of disciplinary discourse with respect to each separate disciplinary way of knowing the world.

The students in this study repeatedly reported that a large proportion of their learning occurs when "discoursing" in science, that is engaging in shar-

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ing meaning using the various modes of disciplinary discourse with other students, this is similar to the findings of Svensson & Högfors (1988). This "discoursing" occurs in *ad hoc* problem-solving study groups, rather than when interacting with university lecturers. It is therefore suggested that the knowledge of the lecturer as a competent user of disciplinary discourse is often under-exploited in university science.

4.6.8. Expecting discourse imitation

Part of the analysis has brought to the fore the notion that a natural step on the way to entering a disciplinary discourse includes at least some element of *discourse imitation*, that is students appear to initially achieve discursive fluency without appropriately experiencing the associated disciplinary ways of knowing the world. If this is indeed the case then lecturers need to be reflective about student learning not only when students answer questions "incorrectly", but even when students give the expected "correct" answer. Lecturers need to be sure as they can be that their students are playing the same "language game" (Wittgenstein, 1958) as the rest of the discipline. This in turn suggests what many in university science education argue, namely that the traditional method of examining science courses through problem-solving and calculation may lead to students passing examinations without experiencing the appropriate ways of knowing of the discipline. Furthermore, since disciplinary discourse is multimodal, examinations using mainly the mathematical mode may encourage discourse imitation, particularly at introductory levels. Why should a student pay attention to all those other modes if the perception is that only the mathematical mode is formally graded? Wickman & Östman (2002) discuss how Wittgenstein's language games can be operationalized, using the idea of *lingering gaps* in conversation. An experienced teacher, using classroom evaluation techniques will notice these gaps and see them as a cue for further probing of student understanding (Angelo & Cross, 1993; Gipps, 2002).

4.7. Summary

This chapter has presented the combined results of the three studies in terms of language, equations and discourse. These results are summarized and discussed in chapter five.

5. Discussion

The results presented in this thesis can be seen to fall into three broad sections; language of instruction, equations and discourse. In this chapter, the results for each of the areas are summarized and implications of the findings are discussed. A discussion of the digital method of data analysis that was developed for the study is also given in this chapter.

5.1. Language of instruction

The language related research question for this thesis was

- How do Swedish undergraduate students experience being taught physics in English?

The results reported here provide a good illustrative case study of second-language lecturing to Swedish physics undergraduates. The main conclusion of this study is that there appear to be differences in the ways Swedish physics students experience lectures in Swedish and English—and that students are on the whole unaware of these differences.

When taught in English the students in the study asked and answered fewer questions and reported being less able to follow the lecture and take notes at the same time. Students employed a number of strategies to meet these experienced differences by; asking questions after the lecture, changing their study habits so that they no longer took notes in class, reading sections of work before class or—in the worst case—by simply using the lecture for mechanical note taking and then (perhaps?) putting in more work to make sense of these notes later.

5.2.1. Implications and recommendations

Some experienced lecturers might suggest that they could have anticipated the results reported here, however, the fact remains that with the increased movement of students throughout Europe envisaged in the Bologna declaration we need to base our pedagogical decisions on empirical work rather than gut feeling. Moreover, the finding that students initially see the lecture language as unimportant simply highlights the fact that empirical findings

can be counterintuitive. In this spirit the following are some tentative recommendations drawn from the results of this study and the experience of the researchers involved.

When lecturing in the students' second language it is suggested that students will be helped if lecturers:

- *Discuss the fact that there are differences when lectures are in a second language*. A common response from students in the study was to thank the researchers for the opportunity to discuss these issues. Students need to be aware that specific problems can occur in second-language lectures and that there are strategies (see below) that can minimize these problems.

- *Create more opportunities for students to ask and answer questions.* Three reasons for the lack of teacher/student interaction in lectures appear to be; student uncertainty about whether they have understood the question correctly, fear of revealing lack of understanding to the lecturer and a fear of speaking English. Using short, small-group discussions within a lecture to come up with answers to questions and to generate new questions may be one way of dealing with this problem. These small 'buzz groups' allow students to check their understanding in a less threatening forum than the whole class. Moreover, the resulting student interaction with the lecturer becomes less threatening since it takes place on a *group* level rather than an individual level. Each group can also choose one person to express their ideas. Those students with a particular aversion to speaking English will still avoid speaking in class but at least they participate in vicarious interaction with the lecturer (Bligh, 1998).

- *Allow time at the end the lecture for students to ask questions and encourage students to use this opportunity*. Being available for informal questions at the end of the lecture allows students to come forward and discuss problems in a less threatening environment. In this respect it is probably a good idea to finish lectures early so that both students and lecturer do not need to be somewhere else. If possible students should be allowed to ask questions in their first language.

- *Be reflective when introducing new material in lectures.* A typical approach to new subject matter is to introduce the topic in a lecture. The research presented here suggests that lectures may not always be the best way to introduce students to a topic, since students may have difficulty following and taking notes at the same time. If lec-

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tures are used to introduce a topic it may be prudent to simultaneously give out lecture notes that students can annotate.

- *Ask and expect students to read material before the lecture.* A good strategy is to ask students to read about a subject *before* lectures, the lectures can then be used for confirmation and clarification of what students have already seen. Choose a book or use a set of lecture notes which are then followed closely in class.

- *Give as much multi-representational support as possible.* Lecturers should support their oral descriptions with a number of other types of representation such as overhead slides, handouts, demonstrations, computer simulations, etc. However it is important that each representation reinforces the main themes of the lecture—using multiple representations without a clear reason will simply confuse students. Similarly, planning a logical structure and layout to any input on the board will also be useful.

5.2.2. Good approaches to lecturing are the same in any language

The recommendations listed above could be said to apply equally well to lectures in the students' first language. It is suggested that changing the lecturing language merely accentuates communication problems that are already present in first-language lectures. In her study of Dutch engineering students Klaassen (2001) found that effective lecturing behaviour had a much greater effect on how students experienced lectures than the language used. Those teachers who were rated as more effective lecturers in Klaassen's study may have already used some of the strategies listed in 5.2.1. to help students to cope with the shift in language.

5.2.3. Relevance for other teaching situations

The extent to which these results can be generalized to other types of student within Sweden and to other countries where the English language ability of both students and lecturers varies is an open question. We can, however, speculate that since Sweden is widely believed to be one of the countries in Europe with the highest levels of second-language English ability, that the problems described would perhaps be even more pronounced in countries with generally lower levels of English language competence.

This study set out to inform physics lecturers about what might be problematic when their students are taught in a second language. We believe we have succeeded in this task and that physics lecturers will be able to transpose these results to other specific lecturing situations, devising their own strategies to mitigate any possible problems. Although there will always be

questions about the generalizability of this kind of study, the very fact that problems *can* be experienced by students should be enough to prompt lecturers to rethink their strategies when presenting physics in a second language.

5.3. Equations

The research question related to equations was:

- How do Swedish undergraduate students experience the equations presented to them in physics lectures?

The results suggest that when students are presented with an equation, they initially focus on the mathematical complexity. They appear to ask themselves the question "Can I handle this mathematically?" For some students, if the answer is, "Yes" then they feel that they understand the equation. It is suggested that this feeling may hinder students from noticing the physics and real-world relevance of the equation. Other students appear to equate understanding with ability to solve physics problems. Here again, the real-world applications of the equation may go unnoticed. Drawing on these results led to the production of a generic list of 'context questions'.

5.3.2. Context questions

Epistemological Status	What is the status of this equation? Is it a law, axiom, pseudo law, or just some sort of mathematical 'fix' used to tidy things up or express them in a form that is recognizable and 'solvable'? Is it empirically derived or theoretically derived?
Name	Does this equation have a name? How do physicists refer to this equation?
Mathematical structure	What type of equation is this? What do I need to do mathematically to use this equation? What measurements/values do I need to have to be able to use this equation?
Dimensions and units	What are the dimensions of the terms in the equation? What are the units that the various terms are measured in?
Range of validity	When and where can I use this equation? What are the limits to the area of use? What happens when we approach those limits or exceed them?

Approximations & idealizations	What approximations are 'built into' this equation? What is it that makes this a *mapping* of the real world rather than a perfect description? What consequences do the approximations and idealizations have for being able to use the equation from a mathematical point of view. What consequences do the idealizations and approximations have for the predictions of the equation in the real world?
Origin	Where did this equation come from? What real-world problem was it originally designed to solve?
Use	What area of physics does this equation belong to? What things in the real world does this equation adequately describe?
Meaning	What does this equation mean? What does it tell us about the real world?

We believe these context questions may be a useful tool for both lecturers and students to focus attention on appropriate components of a given physics equation, thereby broadening and increasing the awareness of the disciplinary knowledge that is represented by the equations.

5.4. Discourse

The research questions with respect to discourse were:

- How may learning in university physics be characterized in terms of entering a disciplinary discourse?
- How do students describe the way in which they learn to interpret and use this disciplinary discourse?

The results presented in this thesis represent a starting point in the work of characterizing learning in a university science such as physics as entering a disciplinary discourse. As part of the analysis a number of emerging relationships between the notion of disciplinary discourse and the experience of the ways of knowing university science were suggested. What follows is a summary of the findings and these relationships.

5.4.1. Summary and discussion of results

- *The disciplinary discourse of university science is of necessity multimodal.* It was observed that in university physics, disciplinary knowledge is constituted using a wide range of modes over and above written and oral language, such as mathematics, diagrams, gesture, physical apparatus and activities.

- *A temporal, repetitive element is a necessary part of learning university science.* All the students in the study indicated that repetition over time played a key role in their coming to experience disciplinary ways of knowing.

- *This repetitive element is the means by which students become discursively fluent.* In the analysis it was proposed that students use repetition in order to familiarize themselves with the way meaning about a particular way of knowing is constituted in a particular mode. This familiarization was characterized as *discursive fluency*.

- *Discursive fluency in a mode is a necessary but not sufficient condition for experiencing facets of a disciplinary way of knowing.* It is proposed that students need to become discursively fluent in a particular mode of disciplinary discourse before the facets of the way of knowing the world that are described by that mode can become available to them. However, the data strongly suggests that discursive fluency does not automatically lead to a student experience of the related facets of a disciplinary way of knowing. Some of the examples quoted in the results chapter illustrate how students can be fluent in a particular mode of disciplinary discourse but clearly not experience the associated facets of the disciplinary way of knowing the world. The dataset contains many more such examples. It is therefore proposed that discursive fluency is a necessary, but not sufficient condition for experiencing a disciplinary way of knowing. This ability to use disciplinary discourse without experiencing the associated way of knowing is characterized as discourse imitation.

- *An element of discourse imitation may be a natural stage on the way to experiencing a disciplinary way of knowing.* Since the study identifies a number of students who are discursively fluent in a mode (modes) of disciplinary discourse but who show no appropriate experience of the corresponding way of knowing the world, it is

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believed that this state of affairs may be wide-spread in university science education.

- *Only certain constellations of modes of disciplinary discourse may be able to afford access to disciplinary ways of knowing.* By appealing to the phenomenographic[10] idea that variation underpins all learning, it is proposed that learning how to appropriately represent the ways of knowing the world that constitute a discipline requires a wide range of modes, with each way of knowing requiring differing proportions of these modes. Moreover, by referring to the phenomenological concept of appresentation, it is further proposed that in order for students to have the possibility to fully experience disciplinary ways of knowing the world they need to become discursively fluent in a critical combination of modes of disciplinary discourse.

- *Translation between modes can help students notice discrepancies between their way of knowing and that of the discipline.* If each disciplinary way of knowing the world can best be learnt through a critical combination of modes, then a student who has not appropriately experienced a disciplinary way of knowing may have the possibility for such an appropriate experience opened up for them by translation between modes.

5.4.2. Pedagogical implications

Based on these outcomes the following pedagogical implications are suggested:

- *Students need opportunities to use the representations, tools and activities of the discipline as an integral part of their science education.* Since the disciplinary discourse of university science is multimodal in nature and since it has been suggested that students need to acquire discursive fluency in a critical constellation of modes; it may be argued that students need to be able to practice using these modes within their degree courses.

- *To improve the possibilities for learning, lecturers need to come to better understand the specific constellations of modes necessary for a full representation of each individual disciplinary way of know-*

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[10] Phenomenography is the study of the qualitative variation in ways of experiencing the world around us—how we conceptualize, understand, perceive, apprehend etc, various phenomena in and aspects of the world around us. (Marton, 1986; Marton & Booth, 1997).

ing. It is argued that if university science lecturers do not come to better understand which modes are necessary for an appropriate experience of a disciplinary way of knowing; it will be difficult to adequately constitute learning experiences which provide the necessary variation in critical constellations of modes of disciplinary discourse.

- *The assessment criteria for university science courses should reflect the multimodal nature of disciplinary knowledge.* It is now well established that assessment plays an important role in influencing *what* students learn (for example, see the review in Scoulier & Prosser (1994), and discussions by Newble & Jaeger (1983), Fransson (1977), Marton & Säljö (1976) and Hakstian (1971). For an example from university physics education see Peters (1982)). If disciplinary ways of knowing are best experienced through a critical constellation of modes, then designing of assessment which takes into account these modes may promote better desired learning and minimize discourse imitation.

- *The specialist knowledge of lecturers as experts in using disciplinary discourse may often be under-exploited in university science lectures.* Many science lectures appear to at best reconstitute the representations, tools and activities of science in language terms, or at worst even take them for granted. Following Northedge (2002) it is proposed that the lecturer, as a person competent in disciplinary discourse should rather act as a guide in this respect, not only modeling disciplinary discourse but also actively engaging students in their attempts to make meaning with such discourse for themselves. Ironically, at the moment this role seems to be filled by fellow students, who are themselves struggling to learn the discourse of the discipline.

5.4.3. Summary

Much of the research carried out in university science education focuses on new ways of understanding old problems. This work suggests that viewing learning as entering a disciplinary discourse with an emphasis on elements of repetition, discursive fluency and critical constellations of modes, opens up another useful dimension in the characterization of learning in university science which may be helpful to teachers and students alike.

5.5. Data analysis

One of the technical contributions made by this study was the development of the digital method for processing and analyzing interview data. Whilst this method of data analysis used was appropriate for extraction of broad themes and patterns, the method seems less suited to detailed discourse analysis. It appears that this method of data analysis is particularly suited to studies which aim to find general patterns and themes such as phenomenography and grounded theory. The method may also be of use in giving the researcher an overall 'feel' for the data, allowing identification of key sections of the data (as is the case in this study) which may then be transcribed and submitted to other more conventional forms of discourse analysis.

6. Future research

The work presented in this thesis has focused on two main issues:

- Extraction of broad themes to do with the language of instruction and student experience of equations.
- Development and application of the disciplinary discourse analytical framework.

As such, much of the work that was originally planned for this project remains to be done.

First, the data collection was constructed so as to afford a comparison of each student discussing the same physics concepts in Swedish and in English. Thus, a traditional discourse analysis of these excerpts would be interesting, as this would allow comparisons to be made between the language of instruction and student ability to describe and explain physics concepts in both languages. Of particular interest in this respect are the 14 students who were taught by the *same teacher* in both English and Swedish, since this effectively controls for teacher effects[11]. Clearly the digital analysis method presented in this thesis is less suited to this kind of detailed discourse analysis (see discussion in section 5.5.). Hence key episodes of the data will need to be transcribed.

Linked to this approach, the intrinsic design of the study generated three related categories of data: lecturers descriptions of what they plan to teach, the videos of the actual lectures and students descriptions of their experience of these lectures. This data lends itself to a comparison of the three objects of learning—intended, enacted and lived (Marton & Booth, 1997). Such a comparison could either be framed within the context of a shared space of learning (Tsui, 2004b) or pedagogical resonance (Trigwell & Shale, 2004).

The work presented here on student experience of equations is still at a preliminary stage, but the initial results seem extremely encouraging. The full phenomenographic study of students experience of equations promises to make a valuable contribution to our understanding of the teaching and learning of university physics. Here, it is expected that the extended abstract—paper III—will be developed into a full paper. Further work in this area will be carried out by other members of the Uppsala PER team.

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[11] These effects have been found to be particularly strong earlier studies

Theoretically, the analytical constructs developed in paper IV need to be tested and developed. As pointed out in the results section, the data gathered for this study mainly illustrates the *representations* aspect of disciplinary discourse. It would therefore be of interest to apply the framework in a context where the *tools* and *activities* aspects of disciplinary discourse come to the fore. Thus, although beyond the scope of the PhD, a study of student laboratories would be a natural extension of this work. In such environments a disciplinary discourse approach would have a distinct potential for extending our understanding of student learning. This is because the approach allows for the treatment of a wide range of disciplinary semiotic activity within the same analytical framework.

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7. Sammanfattning på svenska

7.1. Bakgrund

Undervisningen på svenska universitet och högskolor präglas av en utbredd användning av engelska–särskilt i naturvetenskapliga ämnen där merparten av kurslitteraturen oftast är engelskspråkig och allt mer undervisning sker på engelska. Denna engelskspråkiga dominans lär knappast minska de närmaste åren då högskolor och universitet i all hast förbereds för att möta de internationaliseringskrav som den pågående harmoniseringen av högskoleutbildning i Europa (den s.k. Bolognaprocessen) ställer. Användandet av engelska har många positiva sidor. Studenterna får t.ex. tillgång till de senaste läroböckerna, de tar del av lektioner från utländska gästforskare och de kan tidigt bekanta sig med detta mycket viktiga internationella forskningsspråk. Men vad händer med kunskapsinhämtningen när studenterna inte får tillgång till undervisning på sitt modersmål?

Det finns för närvarande ingen svensk undersökning av hur ämnesinlärning på högskolenivå påverkas av valet av undervisningsspråk, och den internationella forskningen som finns inom detta område väcker mer frågor än svar. Ett antal internationella och svenska studier har dokumenterat utbredningen av *användandet* av engelska och en hel del studier har avhandlat effekterna för *språkinlärning* av ämnesundervisning på engelska. Däremot är forskning som berör kopplingen mellan *ämnesinlärning* och *språkval* mycket begränsad och har mestadels innefattat försök att finna statistiska korrelationer mellan undervisningsspråk och ämnesprestation på nationella prov och dylikt. Resultaten av dessa studier har varit svårtolkade då det mest slående draget oftast har varit likheterna mellan forsknings- och kontrollgrupper. Dock finns det några internationella studier från Hong Kong, Sydafrika, Nya Zeeland och Nederländerna som pekar på att det kan finnas negativa konsekvenser för ämnesinlärning när undervisning inte sker på studenternas modersmål.

7.2. Syfte

Syftet med avhandlingen är att undersöka undervisning i fysik på högskolenivå. Det arbete som redovisas här har sitt ursprung i ett intresse för de två språk som används i undervisning av högskolefysik–engelska och svenska.

Hur påverkas fysikinlärningen när lektionerna ges på två språk? Under den tid då data samlades och analyserades utvidgades först forskningsfrågan till att omfatta tre "språk": engelska, svenska och matematik och därefter till en mer övergripande fråga om hur fysikkunskaper representeras av *fysikämnets diskurs.*

Därmed är denna avhandling en del i ett vidare projekt där frågeställningarna är:

- I vilken mån kan lärandet i högskolefysik beskrivas och förklaras som ett närmande till en *ämnesdiskurs*?
- Hur beskriver studenterna det sätt som de lär sig att tolka och deltaga i en sådan ämnesdiskurs?

En teoretisk och en empirisk undersökning av dessa frågor behandlas i artikel IV. I artikel II och artikel III analyseras två olika aspekter av denna ämnesdiskurs för att belysa följande frågor:

- Hur upplever svenska studenter lektioner i fysik som ges på engelska?
- Hur upplever studenter de ekvationer som presenteras på fysiklektioner?

7.3. Metod

I ett försök att undvika några av de problem som drabbat tidigare undersökningar har denna studie dokumenterat studenters *erfarenheter och inlärningsmönster* när de undervisas på svenska respektive engelska. Detta uppnåddes genom videoinspelning av lektioner och intervjuer med studenter på tre kurser vid Karlstads Universitet och två kurser vid Högskolan i Kalmar. Varje student var närvarande vid två lektioner, en på engelska och en på svenska. Vid intervjuerna tillämpades en teknik där valda delar av videoinspelningar av lektionerna visades upp för studenterna och studenterna fick berätta hur de gjorde, vad de tänkte just då och hur de upplevde det stoff som avhandlades. Studenternas beskrivningar av sina erfarenheter av undervisningsmaterialet samlades in på både svenska och engelska och därmed fanns möjlighet att: undersöka hur studenter förstår, beskriver och förklarar fysiska fenomen på båda språken och att söka kopplingar mellan dessa kompetenser och undervisningsspråket.

7.4. Resultat

7.4.1. Fysiklektioner på engelska och svenska

Huvudslutsatsen av undersökningen är att det finns ett antal skillnader i sättet som svenska fysikstudenter upplever lektioner när de ges på svenska respektive engelska–och att studenterna för det mesta inte själva uppmärksammade dessa skillnader. När undervisningen skedde på engelska ställde och svarade studenterna i denna studie färre frågor och de berättade även hur de var sämre rustade för att följa lektionens 'röda tråd' medan de samtidigt tog noteringar. Studenterna anpassade sig till dessa förhållanden genom att ställa frågor efter lektionen, förändra sina studievanor så att de inte längre tog noteringar under själva lektionen, läste igenom studiematerialet före lektionen, eller–i sämsta fall–använde lektionen för mekanisk avskrivning som (kanske) bearbetades efter lektionstillfället. Studien utmynnar i ett antal pedagogiska förslag som syftar till att minska negativa effekter av undervisning på engelska.

7.4.2. Ekvationer

Fysik kan ses handla om beskrivandet av världen genom framställning av modeller. Slutresultat av denna modellering blir oftast en matematisk representation som vi kallar en ekvation. Artikel III är en kartläggning av vilken mening studenter uppfattar från de ekvationer som presenteras under fysiklektioner och hur denna förståelse utvecklas över tid.

Studenterna beskriver hur de först fokuserar på den *matematiska* aspekten av en ekvation, och sedan ställer sig frågan "kan jag hantera denna ekvation på en matematisk nivå"? Om svaret på denna fråga är "ja", säger sig en del studenter *förstå* ekvationen. För andra studenter jämställdes förståelse med kunskap om hur man hanterar ekvationen för att *lösa fysikproblem*. Bara en mindre del av de studenter som tillfrågades nämnde att de sökte länkar mellan ekvationen och verkliga företeelser i *världen*. Utvecklandet av förståelse för en ekvation kan därmed sägas följa en bana från matematik, genom fysik till världen. Det finns en risk att studenter kan nöja sig med förståelse i en sfär och därmed inte fokusera på de andra viktiga aspekterna av ekvationen.

Med tanke på denna kunskap om utvecklandet av en förståelse för de ämneskunskaper som en ekvation representerar, framställs ett antal *frågor om kontextualisering*. Det är tänkt att studenter och lärare skall kunna ställa sig dessa frågor för att bättre fokusera på de aspekter av en ekvation som behövs för en mer komplett förståelse av denna.

7.4.3. Fysikämnets diskurs

Under datainsamlingen uppmärksammades att inhämtande av fysikkunskap baseras på mycket mer än bara språk. Kunskapen läggs fram med hjälp av ett

antal s.k. *modes* t.ex. matematik, grafiska framställningar, diagram, tekniska redskap och arbetssätt. I avhandlingen likställs därför begreppet ämnesdiskurs med en kombination av *representationer*, *redskap* och *aktiviteter*.

Alla studenter i studien beskriver hur *repetition* spelar en viktig roll i deras växande förståelse av fysikämnet. I avhandlingen anses denna repetition vara det sätt som studenter använder för att bekanta sig med hur ämneskunskaper brukar presenteras i en viss *mode*. Denna bekantskap är ett nödvändigt men icke tillräckligt villkor för studenter att erfara kunskaperna på samma sätt som de framställs av ämnet. I detta sammanhang verkar det som om en viss del av *imitation av ämnesdiskursen* är en naturlig del av denna bekantskapsprocess.

En viktig slutsats av denna studie skulle kunna vara att endast en viss bestämd *konstellation av modes* finns för att studenterna skall kunna tillägna sig vissa ämneskunskaper. I detta sammanhang kan förflyttning mellan olika *modes* uppmärksamma studenter på att deras sätt att uppfatta kunskapen inte överensstämmer med det sätt som godtas i ämnet.

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Appendices

Appendix A: Lecturer interview protocol

The following protocol was used as a guide when interviewing the lecturers in all three studies before filming their lectures.

Lecturer interview protocol

Introduction
>   Interested in the experience of learning physics

Lecturer background
>   Cultural and linguistic
>   Experience teaching in this language + other langs.

Knowledge of students' background
>   Social and language groups
>   In terms of physics already read etc.
>   What do you think of their level of physics knowledge?

The course
>   Course aims
>   Course activities (lectures, labs, problem solving sessions etc)
>   Materials (documents, web pages, books, compendiums etc)

What do students find difficult in this course?
>   How much work do you want them to do outside class?
>   Expect they will do?
>   Do you feel you have all the students 'with you' in a lecture situation?

Why this language?
>   Do anything special to help students with language?

Lecture specifics
>   Subject matter
>   Specific aims for this lecture

How does this lecture fit into the rest of course?
Types of activity
Things you think might be of interest
What do you think they will find difficult in this lecture?

Your preparation for this lecture in relation to if it had been in your L1/L2
Time
Style of delivery
Sense of being at ease when preparing and teaching

How do you feel about the relative use of English and Swedish in this course? … and in a physics degree as a whole?

AOB

Appendix B: Student interview protocol 1

The following protocol was used as a guide when interviewing the students in the first study. There were two lectures with different teachers; Electromagnetism (in English) and Mathematical methods for physicists (in Swedish). Diagrams and equations have been added where appropriate to illustrate what was being discussed. *Note: equations added to the mathematics for physicists section of this interview have been taken from the course material which was in English. However, the lecture and these equations were originally presented in Swedish. Students in the study viewed the original, Swedish video material.*

Student Interview Protocol

Introduction   About the researcher
This study - interested in student *experiences* of
learning physics - no right or wrong answers help me make
teaching better

Student background
Can you tell me a little about your background
With respect to learning + language
Tell me about your experiences of learning physics up to now
Mathematics? English? Swedish?
What experience do you have learning in Swedish, English
other languages?
How do you feel about learning in English? Swedish?
How do you learn physics in language terms?

Electromagnetism course specifics
In general, how do you feel about this course?
How do you see the aims of this course?
How does this course fit into your long-term goals?

Participation (lectures, labs, problem solving sessions etc)?
Materials used (documents, web pages, books, compendiums etc)?
Do you have/use the text book?
Take notes?   Can I see?

How much do you study outside of class? (before/after)
Do you work with other students? Which lang?
How much do you think the lecturer thinks you should do?

What do you think is the most difficult thing with this course?
Prior knowledge think you needed/lacked?
What do you think about being taught in this language?
How does this affect learning?
Do you do anything special to cope with communication problems ?
How often do you need to look up words?

To what extent can you follow what is going on?
What happens when you can't?
In class, questions? Is it easy to ask questions?
Does the language make a difference?
Other students?   Use textbook

Now we'll look at some clips. Here's the start of the Electromagnetism lecture **(Lecture given in English)**

Clip A   from start to 00:30 → "at the same time" (modifications)

Electrostatic Model	Magnetostatic Model
$\nabla \times \mathbf{E} = 0$ $\nabla \cdot \mathbf{D} = \rho$	$\nabla \cdot \mathbf{B} = 0$ $\nabla \times \mathbf{H} = \mathbf{J}$
$\mathbf{D} = \epsilon\mathbf{E}$	$\mathbf{H} = \dfrac{1}{\mu}\mathbf{B}$

What were you thinking at this stage?
Tell me about what you were doing at this stage. Reason
How did you feel? Language Reason
To what extent did you feel you were 'with the lecturer'? Reason
Can you say how you think this section fits into the rest of the lecture?
the course?

Clip B   1.25 → "apply them to many other problems as well"

Tell me about what you were thinking at this stage. Reason
Tell me about what you were doing at this stage. Notes etc? Reason

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How did you feel? Language Reason
To what extent did you feel you were 'with the lecturer'?
Reason
He calls the equations beautiful – do you understand?
What is the most difficult thing to understand here?
Can you say how you think this section fits into the rest of the
lecture?
the course?

English   It's a long time since I did anything like this – could you de-
scribe how you understand the meaning of this equation for
me?

$$\boxed{\nabla \times \mathbf{E} = 0}$$

What do you understand by curl?

Clip C   SWEDISH 5:00 $\rightarrow$ "easily convince yourself not consistent"

$$\boxed{\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}.}$$

Okej dags för lite svenska…
Vad tänkte du på i denna situation? Varför?
Kan du berätta vad du gjorde just här?
Hur kändes det? Varför?
I vilken mån hängde du med? Varför?
Kändes det att du lärde dig någonting? Varför
Vad är det svåraste med att försöka förstå det här?
Vilka saker hjälpte till med inlärningen? Varför
Kunde du se hur detta hängde ihop med resten av lektionen?
Kursen?

Svenska   Länge sedan jag gjorde det här. Skulle du kunna sammanfatta
vad det är som man har kommit fram till här?
Vad är innebörden av detta?
Han säger att konstanten är minus ett kan du berätta varför?

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Nu har vi pratat lite på svenska, hur kändes det?
Skulle det vara lättare för dig att ställa frågor på svenska?

Clip D   8:00 → "current I$_2$" (transformers) (diagram)
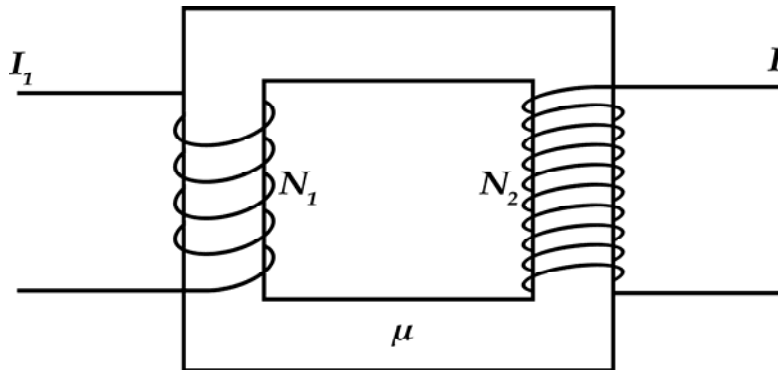
I_1 I_2

N_1 N_2

μ

Tell me about what you were thinking at this stage. Reason
Tell me about what you were doing at this stage. Notes etc?
Reason
How did you feel? Language Reason
To what extent did you feel you were 'with the lecturer'?
Reason
Do you feel you learned something? Reason
Were there any things that helped your learning? Reason
To what extent does the diagram help you understand?
What is the most difficult thing to understand here?
Can you say how you think this section fits into the rest of the
lecture?
the course?

Mathematics for physics course specifics (**Lecture given in Swedish**)

In general, how do your feel about this course?
How do you see the aims of this course?
How does this course fit into your long-term goals?

Participation (lectures, labs, problem solving sessions etc)?

Materials used (documents, web pages, books, compendiums etc)?
Do you have/use the text book?
Take notes?   Can I see?

How much do you study outside of class? (before/after)
Do you work with other students? Which lang?
How much do you think the lecturer thinks you should do?

What do you think is the most difficult thing with this course?
Prior knowledge think you needed/lacked?
What do you think about being taught in this language?
How does this affect learning?
Do you do anything special to cope with communication problems
How often do you need to look up words?

To what extent can you follow what is going on?
What happens when you can't?
In class, questions? Is it easy to ask questions?
Does the language make a difference?
Other students?
Use textbook?

Now we'll look at some clips

Here's the start of the lecture…

Clip A   16:28 → starts to draw a box (lecture start)

Definition 1.2 *(K. Weierstrass) The sequence $(x_n)_n \subset \mathbb{R}$ is called* **convergent** *if there exists $a \in \mathbb{R}$ such that:*
$(\forall)\varepsilon > 0$, there exists $n_\varepsilon \in \mathbb{N}$ such that $(\forall)n \in \mathbb{N}, \ n \geq n_\varepsilon \Rightarrow |x_n - a| < \varepsilon.$

What were you thinking at this stage?
Tell me about what you were doing at this stage. Reason
How did you feel? Language Reason
To what extent did you feel you were 'with the lecturer'? Reason
Can you say how you think this section fits into the rest of the lecture?
the course?

Clip B   Play scene ten → "udda tal… grafen är så" (Diagram)

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1. $f_n : [-\frac{1}{2}, 1] \longrightarrow \mathbb{R}, \ f_n(x) := x^n \ (\forall)n = 1, 2, 3, \ldots$

   Remark: $\displaystyle\lim_{n\to\infty} f_n(x) = \begin{cases} 0 & \text{for } -\frac{1}{2} \leq x < 1 \\ 1 & \text{for } x = 1 \end{cases} := f(x).$

Tell me about what you were thinking at this stage. Reason
 Tell me about what you were doing at this stage. Notes etc?
 Reason
 How did you feel? Language Reason
 To what extent did you feel you were 'with the lecturer'?
 Reason
 Do you feel you learned something? Reason
 Were there any things that helped your learning? Reason
 To what extent does the diagram help you understand?
 What is the most difficult thing to understand here?
 Can you say how you think this section fits into the rest of the
 lecture?
 the course?
 Can you say how you think this section fits into the rest of the
 lecture?
 the course?

Clip C Play scene 11→ "mycket, mycket svår" (coming to the end of
  a derivation)

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Theorem 1.3 *(Weierstrass.)*
*If there exists a sequence of real numbers $(M_n)_{n\geq 1}$, $M_n \geq 0$ for every n, such that the series $\Sigma_{n\geq 1} M_n$ is **convergent** and $|f_n(x)| \leq M_n$ $(\forall) x \in J$, $(\forall) n \geq 1$ then the series $\Sigma_{n\geq 1} f_n$ is **absolute** and **uniform convergent**.*

Okej dags för lite svenska...
Vad tänkte du på i denna situation? Varför?
Kan du berätta vad du gjorde just här?
Hur kändes det? Varför?
I vilken mån hängde du med? Varför?
Kändes det att du lärde dig någonting? Varför
Vad är det svåraste med att försöka förstå det här?
Vilka saker hjälpte till med inlärningen? Varför
Kunde du se hur detta hängde ihop med resten av lektionen?
Kursen?

Svenska   Jag har aldrig gjort det här. Skulle du kunna sammanfatta vad det är som man har kommit fram till här?
Vad är innebörden av detta?

Nu har vi pratat lite på svenska, hur kändes det?

Clip D   22:08 → "här vi sysslar med supremum"

With the previous notations we define the sequence $(a_n)_n$ of elements of $[0, \infty]$ by:
$$a_n := \sup_{x \in J} |f_n(x) - f(x)|.$$

Theorem 1.1 $f_n \xrightarrow{u} f \iff a_n \longrightarrow 0.$

Tell me about what you were thinking at this stage. Reason
Tell me about what you were doing at this stage. Notes etc? Reason
How did you feel? Language Reason
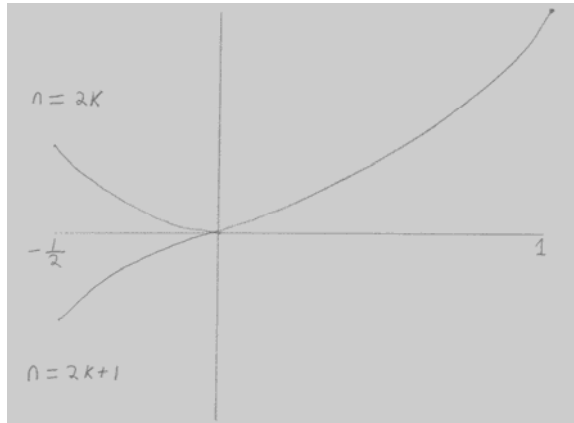To what extent did you feel you were 'with the lecturer'? Reason
Do you feel you learned something? Reason
Were there any things that helped your learning? Reason
What is the most difficult thing to understand here?
Did the question help you to understand?
Do you ask questions?
Is it easier to ask questions in Swedish?
Can you say how you think this section fits into the rest of the lecture?
the course?

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English   As I said I haven't done anything like this – could you describe how you understand the meaning of this derivation for me?

What do you understand by supremum?

Comparison
            How would you compare the two learning language experiences?
            Which do you prefer? Why? Different if courses had been in the other language? Is there anything that is more difficult when learning in English?
            How do you feel about the use of English and Swedish in your courses?
            and in your physics degree as a whole?

Cinema tickets

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Appendix C: Student interview protocol 2

The following protocol was used as a guide when interviewing the students in the second study. There were two lectures with different teachers: Classical Mechanics (in English) and Oscillations and waves (in Swedish). Diagrams and equations have been added to the interview protocol where appropriate to illustrate what was being discussed.

Student Interview Protocol

Introduction   About the researcher

This study—interested in student *experiences* of learning physics - no right or wrong answers
help me make teaching better

Student background

Can you tell me a little about your background with respect to learning + language?
Tell me about your experiences of learning physics up to now. Mathematics? English? Swedish?
What experience do you have learning in Swedish, English, other languages?
How do you feel about learning in English? Swedish?
How do you learn physics in language terms?

Course specifics

In general, how do you feel about this course?
How do you see the aims of this course?
How does this course fit into your long-term goals?

Participation (lectures, labs, problem solving sessions etc)?
Different for mechanics and oscillations?
Materials used (documents, web pages, books, compendiums etc)?
Do you have/use the text book?
Take notes?   Can I see? Different for each class?

How much do you study outside of class? (before/after)
Do you work with other students? Which language?
How much do you think the lecturer thinks you should do?
Different for lecturer 1 and lecturer 2?
What do you think is the most difficult thing in mechanics section course?

Oscillations section?
Prior knowledge think you needed/lacked?
What do you think about being taught in English?
How does this affect learning?
What do you think about being taught in Swedish?
How does this affect learning?

Do you do anything special to cope with communication problems
Other students?   Use textbook
How often do you need to look up words?
To what extent can you follow what is going on?
What happens when you can't?
In class, questions? Is it easy to ask questions?
Does the language make a difference?

Now we'll look at some clips. Here's the start of the mechanics lecture
(Lecture given in English)

Clip A   from start → "the behaviour of these large collections of particles

Rotations in Two Dimensions

Last time; Systems of N particles
Imaginary point—centre of mass →overall motion of the system

c of m

Internal motion (around the c of m)

What were you thinking at this stage?
Tell me about what you were doing at this stage. Reason
How did you feel?
To what extent did you feel you were 'with the lecturer'? Reason
Can you say how you think this section fits into the rest of the lecture?
the course?

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Clip B   (02:51) pen throw demonstration → "overall mass of system"

Tell me about what you were thinking at this stage. Reason
Tell me about what you were doing at this stage. Notes etc?
Reason
How did you feel?
To what extent did you feel you were 'with the lecturer'?
Reason
What do you think the lecturer wanted to illustrate by throwing the pen?
Can you say how you think this section fits into the rest of the lecture?
 the course?

Clip C   continue from clip B → "angle defined WRT say the x-axis"

Tell me about what you were thinking at this stage. Reason
Tell me about what you were doing at this stage. Notes etc?
Reason
How did you feel?
To what extent did you feel you were 'with the lecturer'?
Reason
Why do you think it was difficult to get people to answer?
Can you say how you think this section fits into the rest of the lecture?
the course?

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Clip D   SWEDISH (klipp sex) → "try to exploit as much as possible"

One-dimensional motion	Two-dimensional motion
x position of the particle	Angle θ how far the body has rotated
Velocity $v = dx/dt$	Angular velocity $\omega = d\theta/dt$
Acceleration $a = dv/dt = d^2x/dt^2$	Angular acceleration $d\omega/dt = d^2\theta/dt^2$
Force	Torque $\tau = xF_y - yF_x$
Momentum	Angular momentum $L = xP_y - yP_x$

Okej dags för lite svenska…
Vad tänkte du på i denna situation? Varför?
Kan du berätta vad du gjorde just här?
Hur kändes det? Varför?
I vilken mån hängde du med? Varför?
Kändes det att du lärde dig någonting? Varför
Vad är det svåraste med att försöka förstå det här?
Vilka saker hjälpte till med inlärningen? Varför
Kunde du se hur detta hängde ihop med resten av lektionen?
Kursen?
Visa upp tabellen

Svenska   Det här var den tabell han tog fram. Skulle du kunna samman-
fatta vad det är som man har kommit fram till här?
Vad är innebörden av denna jämförelse?
Vad betyder denna ekvation för dig?

Nu har vi pratat lite på svenska, hur kändes det?
Skulle det vara lättare för dig att ställa frågor på svenska?

Clip E   → "That's exactly the theory of levers

$\Delta w = F_t\, r\Delta\theta = \tau\Delta\theta$

$\tau = F_t\, r$ ①

$F_t = F\sin\alpha$

$\tau = F\sin\alpha\, r$

$\tau = F r_o$ ②

Tell me about what you were thinking at this stage. Reason
Tell me about what you were doing at this stage. Notes etc?
Reason
How did you feel? Language Reason
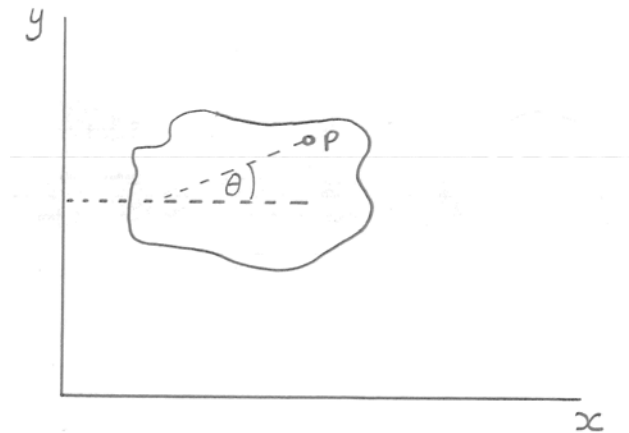To what extent did you feel you were 'with the lecturer'?
Reason
Do you feel you learned something? Reason
Were there any things that helped your learning? Reason
To what extent does the diagram help you understand?
What is the most difficult thing to understand here?
Can you say how you think this section fits into the rest of the
lecture?
the course?

English   It's a long time since I did this – could you describe how you
understand the meaning of these two equations ① and ② for
me?
What do you understand by torque?

Oscillations Lecture

Now we'll look at some clips from the oscillations course

Here's the start of the lecture…

Clip A → "energi svänger mellan potentiell och kinetisk energi

$$\boxed{\text{Energi} = U + K = \tfrac{1}{2}\,\kappa A^2 = \text{konstant}}$$

What were you thinking at this stage?
Tell me about what you were doing at this stage. Reason
How did you feel? Language Reason
To what extent did you feel you were 'with the lecturer'? Reason
Can you say how you think this section fits into the rest of the lecture?
the course?
Can you tell me what you understand by this equation?

Clip B   Play scene nine → "Skilja mellan olika fall"

I svag dämpning
II kraftig dämpning
III kritisk dämpning
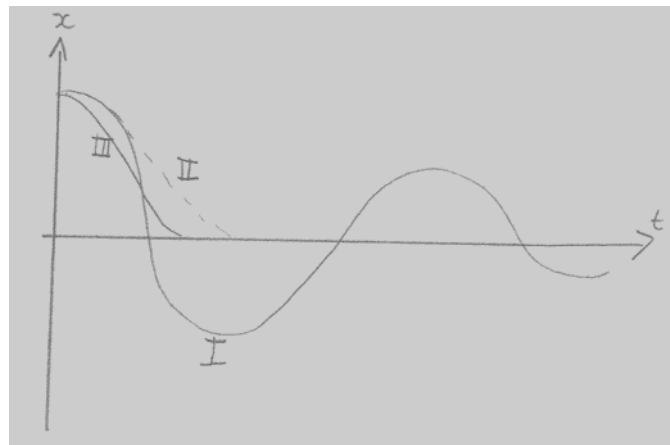
Tell me about what you were thinking at this stage. Reason

Tell me about what you were doing at this stage. Notes etc?
Reason
How did you feel?
To what extent did you feel you were 'with the lecturer'?
Reason
Do you feel you learned something? Reason
Were there any things that helped your learning? Reason
To what extent does the diagram help you understand?
What is the most difficult thing to understand here?
Can you say how you think this section fits into the rest of the
lecture?
the course?
Can you say how you think this section fits into the rest of the
lecture?
the course?
What do these diagrams show you?

Clip C   Play scene 10 → "hyfsa till … från matematik kursen"

Dämpad svängning   Describe in English
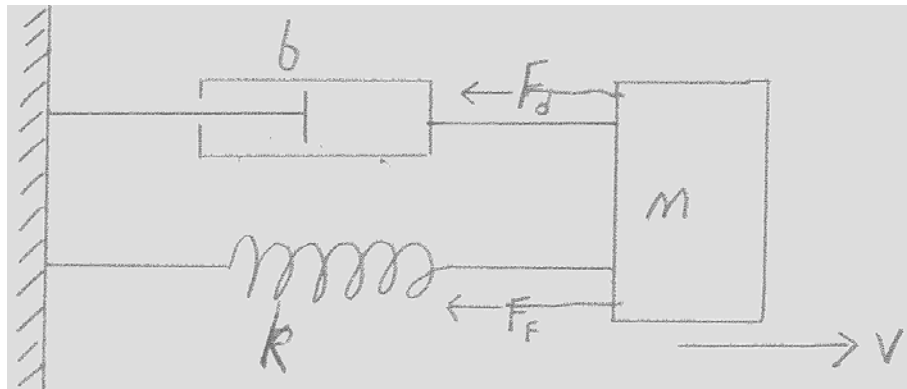
Can you describe this diagram for me?

SWEDISH!!! Okej dags för lite svenska…
Vad tänkte du på i denna situation? Varför?
Kan du berätta vad du gjorde just här?
Hur kändes det? Varför?
I vilken mån hängde du med? Varför?
Kändes det att du lärde dig någonting? Varför

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Vad är det svåraste med att försöka förstå det här?
Vilka saker hjälpte till med inlärningen? Varför
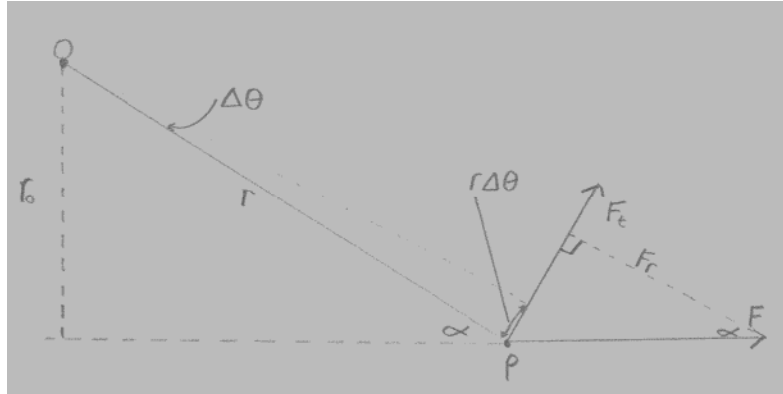Kunde du se hur detta hängde ihop med resten av lektionen?
Kursen?

Svenska   Kan du beskriva vad vi har här i denna bild?
Kan du förklara vad denna ekvation betyder för dig?
Varför tror du han gör så här?
Nu har vi pratat lite på svenska, hur kändes det?

Clip D   scene 12 computer animation → "dämpas ut, det tar en stund"
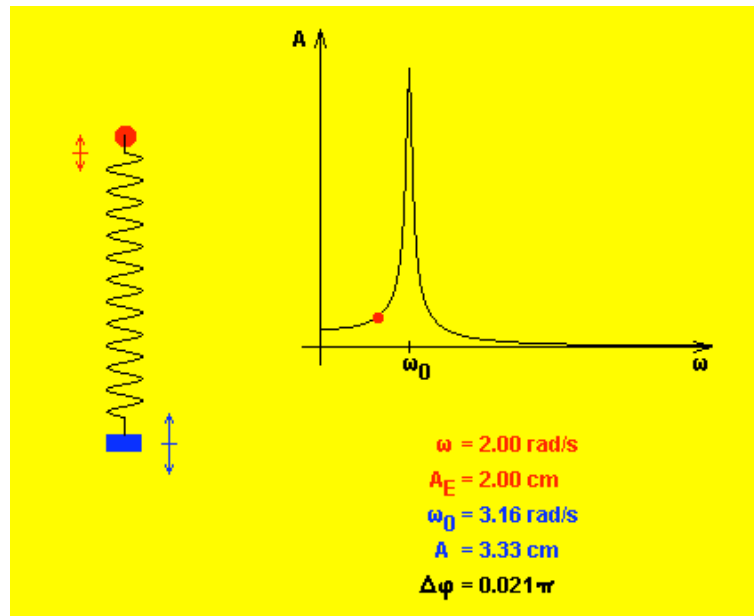
Tell me about what you were thinking at this stage. Reason
Tell me about what you were doing at this stage. Notes etc?
Reason
How did you feel? Language Reason
To what extent did you feel you were 'with the lecturer'?
Reason
Do you feel you learned something? Reason
Were there any things that helped your learning? Reason
What is the most difficult thing to understand here?
Did the demonstration help you to understand?
Can you say how you think this section fits into the rest of the
lecture?
the course?

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Clip E   scene 13 solution to equation → End

$$X_H(t) = A_o e^{-\gamma t} \cos(\omega_o t + \delta) \quad \text{Homogena ekvationen}$$

$$X_P(t) = B\cos(\omega_d + \varphi) \quad \text{Partikulär lösning}$$

$$X(t) = X_H(t) + X_P(t) \quad \text{Allmänna lösningen}$$

homogena   partikulär

fysik   transienta   stationär

Tell me about what you were thinking at this stage. Reason
Tell me about what you were doing at this stage. Notes etc?
Reason
How did you feel? Language Reason
To what extent did you feel you were 'with the lecturer'?
Reason
Do you feel you learned something? Reason
Were there any things that helped your learning? Reason
What is the most difficult thing to understand here?

English   Could you describe how you understand the meaning of this
             equation for me?

             What do you understand by the two sections?

Comparison
             How would you compare the two learning experiences? Lan-
             guage.
             Which do you prefer? Why? Different if been in the other
             language?
             Is there anything that is more difficult when learning in Eng-
             lish?
             How do you feel about the use of English and Swedish in
             your courses?
             …..and in your physics degree as a whole?

Cinema tickets

Appendix D: Student interview protocol 3

The following protocol was used as a guide when interviewing the students in the second study. Here there was only one lecturer in quantum physics who gave a morning lecture (in English) and an afternoon lecture (in Swedish). The interviewed students were present at both lectures.

Student Interview Protocol

Introduction

> Interviewer. This study - interested in student *experiences* of learning physics - no right or wrong answers help us make teaching better

Student background

> Your background
> Tell me about your experiences of learning physics up to now
> Mathematics? English? Swedish?
> Have you learned subjects in English before?
> How do you feel about learning in English? Swedish?
> How do you learn physics in language terms?

Course specifics

> In general, how do you feel about this course?
> How do you see the aims of this course?
> How does this course fit into your long-term goals?
> Your participation (lectures, labs, problem solving sessions etc)?
> Materials used (documents, web pages, books, compendiums etc)?
> Do you have/use the text book?
> Take notes – which language?
> Different for class?
>
> How much do you study outside of class? (before/after)
> Do you work with other students? Which language?
> How much do you think the lecturer thinks you should do?
> What do you think is the most difficult thing in the lecturer's course?
> What do you think about the mathematics in this course?
> Prior knowledge???
> What do you think about being taught in English?
> How does this affect learning?
> What do you think about being taught in Swedish?

How does this affect learning?
How often do you need to look up words?

To what extent can you follow what is going on in lectures?
What happens when you can't?
In class, do you ask questions? Is it easy to ask questions?
Does the language make a difference?

Now we'll look at some clips. Here's the start of the morning
lecture

Morning (Lecture in English)

Clip A   de Broglie   from start → 0:58 (frame freezes 5 secs)

$\lambda = h / P$ $f = E / h$ $k = 2\pi / \lambda$

$\omega = 2\pi f$ $k = P / \hbar$ $\omega = E / \hbar$

What were you thinking at this stage?
Tell me about what you were doing at this stage. Reason
How did you feel? Language Reason
To what extent did you feel you were 'with the lecturer'?
Reason
Can you say how you think this section fits into the rest of the
lecture?
the course?

Show equations on paper

Can you describe what these equations mean to you?
What do the symbols stand for?

Clip B   Probability   continue → end 2:26

$\Psi(x,t)$
$P(x,t) = \psi^*(x,t) \, \psi(x,t) = |\psi(x,t)|^2$

Tell me about what you were thinking at this stage. Reason
To what extent did you feel you were 'with the lecturer'?
Reason
What do you think the lecturer was trying to say here?
What does this equation mean to you?

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Nu ska vi prata lite Svenska

Läraren har precis visat en lösning för klassiska vågor t.ex ljus.

Sedan fortsätter hon så här…

Clip C   Schrödinger   SWEDISH continue from 2:39

$$-\frac{\hbar^2}{2m}\frac{\partial^2 \Psi(x,t)}{\partial x^2} + V(x,t)\Psi(x,t) = i\hbar\frac{\partial \Psi(x,t)}{\partial t}$$

Okej dags för lite svenska…
Vad tänkte du på i denna situation? Varför?
Kan du berätta vad du gjorde just här?
Hur kändes det? Varför?
I vilken mån hängde du med? Varför?
Kändes det att du lärde dig någonting? Varför
Vad är det svåraste med att försöka förstå det här?
Vilka saker hjälpte till med inlärningen? Varför
Kunde du se hur detta hängde ihop med resten av lektionen?
Kursen?

Svenska   Här ser du denna ekvation
Vad betyder denna ekvation för dig?
Vad betyder de olika termer?
Var tror du ekvationen kommer ifrån?
När kan man använda den?

Clip D   Randvillkor   to end (English to Swedish ability)

Här pratar läraren om olika villkor som vågfunktionen bör uppfylla.
Skulle du kunna *sammanfatta* vad hon försöker säger här?
Var kommer dessa villkor ifrån?

Afternoon (lecture in Swedish)

In the afternoon the teacher described a problem solving strategy for quantum problems

Clip E   Problem solving strategy

- krafter?
- potentiell energi V
- V(x)?
- Schrödinger ekv.
- stoppa in V(x)
- lösa den
- gränsvillkor
- $\Psi_n(x)$ Vilka är riktiga vågfunktioner?
- normera $\Psi(x)$ $\int_{-\infty}^{\infty} |\Psi(x)|^2 dx = 1$

Could you describe these steps?

Clip F   Diagrams
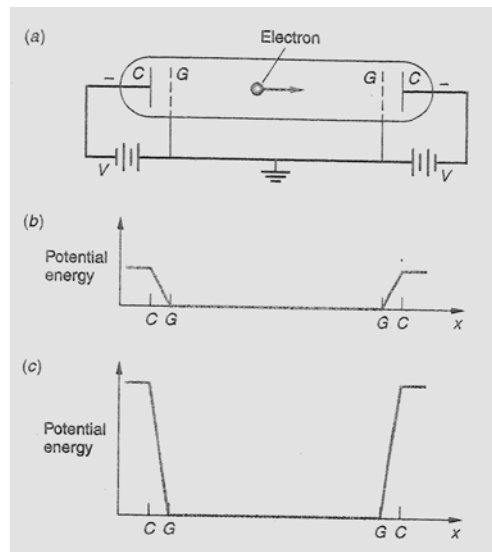
126

Tell me about what you were thinking at this stage. Reason
To what extent did you feel you were 'with the lecturer'?
Reason
What do you think the lecturer was trying to say here?

Clip G

i brunnen $V(x) = 0$
utanför brunnen $V(x) = \infty$ $\psi(x) \equiv 0$

$$-\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2} + V(x)\psi(x) = E$$

$$-\frac{\hbar^2}{2m}\frac{d^2\psi}{dx^2} = E\psi(x)$$

$$\frac{d^2\psi}{dx^2} = -\underbrace{\frac{2mE}{\hbar^2}}_{k^2}\psi(x)$$

$$\psi(x) \neq A\cos kx$$

$$\psi(x) = A\sin kx$$

Gränsvillkor

$$x = 0 \Rightarrow \psi(0) = 0$$
$$x = L \Rightarrow \psi(L) = A\sin(kL) = 0$$
$$k_n L = n\pi \Rightarrow k_n = \frac{n\pi}{\lambda_n} = \frac{n\pi}{L} \quad \lambda_n = \frac{2L}{n}$$
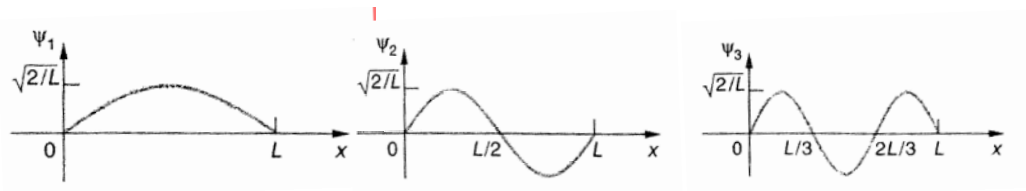
Nu tar vi lite svenska
Sedan gjorde hon så här
Skulle du kunna beskriva tankegångerna här
Vad ser du?
Kan du försöka beskriva vad du tror detta visar

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Clip H   Schrödinger II

$$-\frac{\hbar^2}{2m}\frac{\partial^2 \Psi(x,t)}{\partial x^2} + V(x,t)\Psi(x,t) = i\hbar\frac{\partial \Psi(x,t)}{\partial t}$$

English description
Here we have an equation
What does this equation mean to you?
What are the terms here?
Where do you think this comes from?
When can you use this equation?

Comparison

Interested in the three different languages used in your learning of physics
How do you think about mathematics when you're learning physics?
What does mathematics do?

English and Swedish

How would you compare the two learning experiences? Language.
Which do you prefer? Why? Different if been just in English or Swedish?
Is there anything that is more difficult when learning in English?
How do you feel about the use of English and Swedish in your courses?
…..and in your physics degree as a whole?

Cinema tickets

The Papers

Paper I
Airey, J. (2004). Can you Teach it in English? Aspects of the Language Choice
Debate in Swedish Higher Education. In Wilkinson, R. (Ed.), Integrating
Content and Language: Meeting the Challenge of a Multilingual Higher
Education (pp. 97-108). Maastricht, Netherlands: Maastricht University Press

Paper II
Airey, J., & Linder, C. (2006). Language and the experience of learning
university physics in Sweden. European Journal of Physics, 27(3), 553-560.

Paper III
Airey, J., Domert, D., & Linder, C. (2006) Representing disciplinary
knowledge? Undergraduate students' experience of the equations presented to
them in physics lectures. Extended abstract accepted for presentation at *EARLI
SIG-2 2006 biennial meeting*. University of Nottingham. 30 August – 1
September 2006, Nottingham, UK.

Paper IV
Airey, J., & Linder, C. (2006 submitted) Necessary conditions for learning?
Modes of representation and the disciplinary discourse of university science.
Journal of Research in Science Teaching.

Paper I

Integrating Content and Language:

Meeting the challenge of a

multilingual higher education

Proceedings of the ICL Conference, October 23-25 2003

Edited by
Robert Wilkinson
Maastricht University, Netherlands

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Can you teach it in English?
Aspects of the language choice debate in Swedish Higher Education

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1. Introduction

In May 2004 the biggest ever enlargement of the European Union is set to take place with ten new countries being accepted into membership. This unprecedented expansion seems certain to bring with it logistical problems regarding language. At present there are eleven official languages in the EU and over forty so-called minority languages (Erhrenberg-Sundin, 1998). These numbers are now set to rise dramatically with the admission of the new member states. The European Commission and Council of Ministers will continue to manage with English, French and German, but the European Parliament is busily preparing for a situation with 20 official languages, where the number of possible language combinations will be over 500 (Black, 2002).

Questions have been asked about the costs of linguistic enlargement. With eleven languages the current cost has been estimated at two euros per person per year but this cost will certainly rise with the addition of new languages. This is seen as the price to be paid for 'unity within diversity' – a principle that lies at the heart of the EU enterprise (European Commission, 2001). In November 2002, in what was seen as a 'dummy run' for the new EU, observers from the candidate countries were present in the EU parliament in Strasbourg. Despite simultaneous translation available in a record 23 languages, several of the observers used (American-accented) English. The message is clear: English already has the *de facto* status of a common language of communication, and expansion will simply accentuate this trend.

In Sweden a number of observers have noted a recent change in political attitudes to the Swedish language. Whereas the period 1960-1990 has been characterised as 'society protecting the minority languages', the period after 1990 has been characterised as 'society protecting Swedish' – Swedes have started to worry about the standing of their language. The threat to Swedish has been portrayed as coming from two quarters: immigration and the global

spread of English (Hyltenstam, 1999; Teleman, 1992; Teleman and Westman, 1997).

The perceived threat to Swedish from immigration has led to repeated calls for Swedish language tests for immigrants, most recently from a major political party (Folkpartiet) in the 2002 election. The threat from immigrant languages is seen as taking two forms; either the new minority languages will somehow 'pollute' Swedish and lead to a mixed form – as is 'evidenced' by the language used in the suburbs of the major cities – or these languages will 'force out' Swedish onto the sidelines. Research shows, however, that the idea of a dominant language being threatened by the languages of minorities has no basis in fact (Hyltenstam, 2004).

The threat to Swedish from English is not as easily dismissed. The ability of one language to 'win over' domains from another is seen as depending on status (Hyltenstam and Stroud, 1991), and the status of English is high and continues to rise. There are predictions that out of the 5000 or so world languages, only a few hundred will survive to the end of this century. Although Swedish is at present a strong language, 'prevention is better than cure', especially since the process of erosion of a language, once started, is difficult to stop (Utbildningsdepartementet, 2002).

Meanwhile, with around 375 million first language speakers, 375 million second language speakers and 750 million foreign language speakers[1], the global spread of English is increasing (Crystal, 1995; Crystal, 1997; Graddol, 1997). According to Graddol (1999), second language speakers alone may amount to almost 670 million by 2050. It will therefore become more and more likely in the future that communication in English will be between non-native speakers of English.

> It only requires one German at a scientific conference for thirty Norwegians to change language to English. One Finn in a meeting at a major Swedish company can result in everyone speaking English. If one Dutch worker is placed in an IT department with 40 Danes all internal e-mail is written in English. Höglin (2002:10) (own translation)

The situation where English is used as a common working language is actually already with us, and it is against this background that this paper attempts to summarise the attitudes to language choice in Swedish universities.

2. English in Swedish higher education

There is great potential for English in Swedish society, with the country consistently being rated at the top end in surveys of language skills.

> Sweden is one of the countries in Europe with the highest percentage
> of bilinguals or multilinguals in its population. ... Approximately sev-
> enty-five percent of all adult Swedes can hold an everyday conversation
> in English. Falk (2001a:7) (own translation)

Much higher levels of English language skill are commonplace in Swedish higher education, and this fact coupled with the drive to internationalise Swedish universities has led to more and more courses and degree programmes being taught through the medium of English. The shift towards using English as the language of instruction has been seen as a natural and positive development for many reasons, for example:

- In a number of disciplines, the publication of academic papers takes place almost exclusively in English. Teaching in English is therefore seen as necessary in order to prepare students for an academic career.
- In many disciplines the majority of textbooks used are written in English and therefore the step to teaching in English may not be seen as a large one.
- The use of English develops the language skills and confidence of Swedish lecturers and can be seen as promoting movement/exchange of ideas in the academic world.
- Using English as the language of instruction allows the use of visiting researchers in undergraduate and postgraduate teaching.
- Teaching in English allows exchange students to follow courses at Swedish universities.
- Swedish students can be prepared for their own studies abroad.
- A sound knowledge of English has become a strong asset in the job market.

<div align="right">Airey (2003b:47)</div>

The privileged position held by English in Swedish universities was highlighted by Gunnarsson and Öhman (1997) in their survey of language use and language choice at the University of Uppsala. They conclude that the use of English as the language of instruction is widespread in engineering, natural sciences and medicine. For example, in the Faculty of Science and Technology 87% of undergraduate course literature and 100% of postgraduate course literature was found to be in English. This situation was later confirmed by Falk (2001a) in her report *Domänförluster i svenskan* (Domain Losses in Swedish) for the Nordic Council of Ministers. Falk's investigation suggested

that Gunnarsson and Öhman's findings could be generalised to other Swedish universities.

In general the Swedish government has been positive to this expansion of courses given in English as evidenced by the quote below:

> Swedish universities and university colleges have at present a signifi-
> cant number of courses and degree programmes where the language of
> instruction is English. Sweden is at the forefront in this area compared
> to other EU countries. In recent years the range of courses and degree
> programmes offered in English has increased dramatically. A question-
> naire administered by this commission shows the demand for teaching
> through the medium of English is steadily growing and that the choice
> of courses of this type seems likely to increase in the future. The gov-
> ernment sees this as both a proper and positive development. Utbild-
> ningsdepartementet (2001:15) (own translation)

In many ways the present situation in some sectors of Swedish higher educa-
tion can be likened to that of the very first universities where Latin was the
lingua franca. It is tempting to believe that English has simply taken over this
role as *the language of education* from Latin. This comparison is misleading,
however, since it neglects the enormous changes that have occurred in higher
education in recent years, and also fails to consider the reasons why Latin was
ultimately superseded by more widely-spoken national languages. The fact is
that today's universities are no longer in the business of producing a narrow
academic elite, but rather are faced with teaching obligations to much larger
sections of society. For example, the national target in Sweden is that by 2010,
50% of all adults under 25 should take part in higher education (Utbildnings-
departementet, 2001). Moreover, studies have shown that Swedes overesti-
mate their abilities in English. It is one thing to be able to manage everyday
conversation on holiday, but quite another to be able to use a language in a
more challenging cognitive environment (Falk, 2001a:7). From this perspec-
tive the logic of using English in higher education becomes less clear.

It would be incorrect to think that the movement towards what Falk
(2001a:22) calls the *anglicising* of Swedish universities has occurred without
criticism. Gunnarsson (1999:16) warns that the Swedish academic communi-
ty runs the risk of submitting to *diglossia* – a division of functions between
languages – where English is the academic 'high' language and Swedish is the
everyday 'low' language[2]. This sentiment is echoed by many of the university
departments in Falk's report.

Further serious criticism of the dominance of English came with the pub-

lication of the report of the Parliamentary Committee for the Swedish Language, *Mål i mun* (Utbildningsdepartementet, 2002). This report examines the use of language in Sweden. Following the format first laid out by Falk (2001a), the report deals with the way in which certain subject areas in society become impossible to discuss in Swedish – so-called *domain losses* to English[3]. Losing domains to English is seen as causing democratic problems as it effectively bars large sections of society from these areas. In the case of research, for example, large sections of society do not have the language skills necessary to critically assess the work of researchers. *Mål i mun* acknowledges the need for English in certain domains, but emphasises that Swedish should also be present in these areas. The problem here is seen as the lack of Swedish terminology in certain domains: "How can we ensure that Swedish terminology continues to develop in all areas whilst not hindering the use of English in those areas where it is needed …?" (Utbildningsdepartementet, 2002:21; own translation).

A major problem seen by the authors of *Mål i mun* with regard to university teaching in English is the *extra demand* on students when forced to learn subject matter through a language other than Swedish.

> Finally we would like to stress that it is well known that extra pressure is involved in students not being able to use their first language. We know very little about the consequences of the widespread use of English in certain disciplines. Research should therefore be carried out into the effects for learning, understanding, the teaching situation, etc., when Swedish students receive their education through the medium of English and how such teaching can be successfully achieved. Utbildningsdepartementet (2002:97) (own translation)

Could instruction through the medium of English actually inhibit content learning? Are students in programmes taught in English being pushed towards surface approaches to learning, instead of the deep/holistic approach recommended by Marton and Säljö (1984)?[4] Does embracing internationalisation also involve a risk that students no longer focus on understanding, but rather learn what Sawyer (1943:9) terms *imitation subjects*?[5] If this were indeed the case, it would signal the need for a total rethink of the movement to internationalise Swedish universities.

3. Research into Swedish bilingual education
As pointed out in *Mål i mun,* research into teaching through the medium of English at Swedish universities is limited (Utbildningsdepartementet

2002:96). In fact the author has been unable to locate any research into the *effects* of English-medium university instruction. There are, however, a number of studies from the pre-university world. Early Swedish attempts in education through the medium of English have been documented by pioneers such as Åseskog (1982), and continued by Knight (1990), Washburn (1997), Hall (1998), Falk (2001b) and Nixon (2000; 2001). A recurrent feature of these studies is that students and teachers agree that the resulting level of *English language skills* in bilingual programmes is higher than in a comparable monolingual class. Although encouraging, this evidence is unreliable, since the researchers were asking people involved in a particular pilot study – and therefore naturally positive to it – to express their opinions. In the two studies that actually attempted to *measure* differences in English ability (Knight, 1990; Washburn, 1997), no measurable difference could be shown. Despite the many variables affecting the measured learning outcomes, this is still somewhat surprising given the level of self-selection associated with this type of schooling[6].

As regards *subject knowledge*, Washburn (1997:261) claims that the students in her study did 'as well as could be expected'. An interesting observation is that at the start of the study, Washburn's experimental class averaged just as good or better grades than the control class. At the end of the study, students who had received teaching in English had significantly lower grades in chemistry than those who had been taught in Swedish. The experiment class also had lower (but not significantly lower) grades in physics than the control class, despite having higher grades than the control class before the experiment (Hyltenstam, 2004). The evidence for claims of minimal effects on content learning in Swedish bilingual education programmes is therefore at best inconclusive. Some of the teachers in bilingual studies acknowledge this criticism and admit that they are forced to cover less material. The reasons these teachers are still positive to teaching in English can be divided into two groups; either they welcome being forced to concentrate on the central issues of the subject, or they point out that the aims of their course are more than a simple transfer of subject knowledge. This latter group feel that the gains in English outweigh what they feel are the marginal negative effects on subject knowledge.

Further, it appears that English-medium education affects the *Swedish* of the students taught. Alvtörn (2002) found that students who study in bilingual education classes have poorer written Swedish than students in 'normal' schools. Interestingly, the types of mistakes made by these students were similar to those made by highly competent users of Swedish as a second language. The results show no effect as far as amount written, sentence length

and complexity are concerned, but do show statistically significant differences in the number of mistakes with prepositions, vocabulary, idiom and style.

4. Responses in higher education

As mentioned earlier, little research has been carried out at university level into the effects of teaching through the medium of English. It seems reasonable to assume, however, that at least some of the findings at pre-university level will transfer into the higher education sphere. In her article *Tvåspråkiga naturvetare*, Karin Carlson voices the concerns held by many in Swedish higher education.

> At present there has been no systematic research into the way in which student learning is affected by the language used, but my gut feeling and that of many of my colleagues is that students gain less robust knowledge and poorer understanding if the language used is not their mother tongue. Carlson (2002:15) (own translation)

This 'gut feeling' experienced by Carlson and her colleagues has led to a radical rethinking of teaching at the University of Uppsala. In a project named DiaNa (Dialogue for Natural Scientists), the academic departments of chemistry, biology and earth science now put a heavy emphasis on Swedish communication training in their courses. Students are expected to give presentations and write papers/reports of increasing difficulty throughout their degree course. This is of course nothing new – these features are present in all natural science degree courses; what is different with DiaNa is the system put in place to successively improve these skills throughout the whole university education. Communication exercises are integrated into elements of existing courses with peer feedback and self-reflection. Students document their exercises in a personal portfolio and are continuously following up on their development. Faculty are trained by language specialists to be able to act as supervisors for the communication exercises (Uppsala universitet, 2001).

As mentioned earlier, DiaNa only deals with *Swedish* language training. In fact, Carlson and her colleagues actually decided to go further than this, reducing the percentage of courses offered in English to third and fourth year biology students from circa 70% to circa 40%. All students now read at least one advanced course in Swedish. This apparent one-sidedness is claimed by Carlson (2002:17) to be a 'trade-off'; the students may well be worse off when it comes to English, but perhaps this is offset by deeper understanding when they can use their first language in discussions.

The recent changes introduced at Uppsala University would appear to be a laudable attempt to shift the balance of education back towards Swedish, and deal with perceived shortcomings in the Swedish scientific language of students. These changes are, however, neither more nor less justifiable than the original decision to change the language of instruction from Swedish to English made at some time in the past. Should such radical syllabus changes be based merely on 'gut feelings'? – Ideally not of course. As Carlson and her colleagues acknowledge, it seems highly unlikely that the choice of language is neutral in terms of its effect on student learning. A combination of the DiaNa project with integrated language training in English could be the way forward, but without solid research we can only guess at the educational consequences of any changes we make.

At present few Swedish degree programmes have such a structured approach to acquisition of content-related language skills. All too often the language of instruction is changed from term to term depending on the presence or absence of international exchange students. This attitude assumes both that learning in one language is much the same as learning in another, and that the development of language skills is something that simply happens to students automatically. The title of this paper, 'Can you teach it in English?' refers to the experience of many Swedish university lecturers who have been asked this question by their head of department. Such decisions should be taken in order to better fulfil the aims of the syllabus, and not in order to solve temporary problems about what to do with a particular exchange student (Airey, 2003a:16). This demands a structured approach, where the language of instruction is an integrated part of the overall strategy to produce well-educated graduates.

> English is both essential and welcomed in Nordic universities. Students, lecturers and researchers must be able to understand academic English and use it regularly. However, this use of English must not be allowed to result in the Nordic languages disappearing from universities. We should be aiming for parallel use rather than monolingualism. (Höglin 2002:28) (own translation)

So, 'Can you teach it in English?' In Sweden it seems that at the moment we are unable to answer this question. Based on the little information available, the answer may be, 'Yes – but perhaps not quite as well as in Swedish'. Actually, a more pertinent question would be, 'What are you trying to teach – content knowledge, language skills or both?' Another related question is 'Should you teach it in English?' Here again we are unable to give a straight answer. Person-

ally, I believe the answer is '*Yes.*' but only as a part of an integrated strategy to develop dual language skills along with subject knowledge.

5. Future research in higher education

The author of this paper has recently been admitted to research studies in the Department of Physics at Uppsala University. The broad thrust of the research will be to examine what happens when Swedish students are taught physics in English. At this stage the scope and method of the study are still being defined, but the overall aim of the research is to help answer some of the questions raised in this paper.

NOTES

1   Language learning literature makes a distinction between the terms *second language* and *foreign language*. A second language has important social functions in a community, whereas the term foreign language implies the use of a language in a community where it is not the usual means of communication.

2   The term diglossia was introduced by Ferguson (1959) to describe a situation where society has two languages in functional opposition – a 'low' language used in everyday encounters (the mother tongue) and a 'high' language, learned largely by formal education and used for most written and formal purposes.

3   The idea of domains was first presented by Fishman (1967). Examples of domains are the family, school, the workplace, etc. The idea is that domains can dictate language choice.

4   Learners have been found to adopt one of two strategies when presented with input, either a surface approach or a deep approach. In surface learning the input is seen as something to be *memorised* for later recall (at an exam for example), whereas deep learning requires an *understanding* of the input. The two approaches have been found to result in students focussing on quite different aspects of any given input (Marton and Säljö, 1984). Learners have also been categorised according to how they *process* input. Here again there are two approaches – atomistic and holistic. The atomistic approach breaks down the input, distorts or ignores the original structure and focuses on the individual parts, whereas the holistic approach preserves the structure and focuses on the whole in relation to the parts. See Ramsden (1992:38-61) for an in-depth analysis of research in this area.

5   Sawyer (1943) puts forward the idea that for every subject there is a shadow or imitation. He uses the analogy of teaching a deaf child to play the piano, pointing out that although the child could conceivably reach a high level of competence, a true *understanding* of what has been learnt would be lacking. Students

who have learned imitation subjects can never relate to their discipline in the way a competent practitioner does. Such students may give the *appearance* of understanding – especially in situations which are familiar to them – but they lack the ability to generalise their knowledge to new situations. (Compare with the explanation of surface/atomistic learning in note four above.)

6   We can assume that a typical pupil in bilingual education is above average when it comes to grades, motivation, and language skills/interest.

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Paper II

Language and the experience of learning university physics in Sweden

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Abstract
This qualitative study explores the relationship between the lecturing language
(English or Swedish) and the related learning experiences of 22 undergraduate
physics students at two Swedish universities. Students attended lectures in
both English and Swedish as part of their regular undergraduate programme.
These lectures were videotaped and students were then interviewed about
their learning experiences using selected excerpts of the video in a process
of stimulated recall. The study finds that although the students initially report
no difference in their experience of learning physics when taught in Swedish or
English, there are in fact some important differences which become apparent
during stimulated recall. The pedagogical implications of these differences are
discussed.

1. Introduction

In many European countries the teaching of university physics is divided into two languages—
the national language and English. Surprisingly, we know very little about the effects of this
dual language approach for students' learning of physical concepts. Meanwhile, in the wake
of the recent *Bologna declaration* on harmonization of European education, the number of
courses given in English in European physics departments seems set to increase. With these
two facts in mind we believe that there is an urgent need to better understand the relationship
between physics learning and language. This study set out to illustrate this relationship
by examining one section of this teaching and learning system—namely the ways Swedish
students experience learning physics when the language of teaching varies between Swedish
and English.

2. Research background

Surveys of language use in Swedish higher education show that high proportions of English textbooks are prescribed in engineering, natural sciences and medicine (Gunnarsson and Öhman 1997, Falk 2001). The default position in undergraduate physics appears to be one of the lectures in Swedish with course texts in English, but the presence of even a single exchange student on a course can change the teaching language to English (Airey 2004). The reasons for the widespread use of English in university physics can, of course, be traced to many more factors than the presence of students who do not speak the national language. Other important factors influencing language choice in favour of English are availability of relevant up-to-date course texts, use of foreign academics, competitive advantages on the job market and preparation of students for an academic world dominated by English (Airey 2003).

Even without the added complication of a second language, we believe that language problems in physics lectures are particularly acute due to the experienced complexity and abstractness inherent in learning a science such as physics. As Östman (1998) points out, scientific language is abstract and represents special communicative traditions and assumptions. Moreover, Halliday and Martin (1993) claim that language is much more than a simple representation of disciplinary knowledge; it is actively engaged in bringing such knowledge into being. Learning a subject such as physics therefore depends on learning the language in which the knowledge of the discipline is construed (Lemke 1990). Thus, it can be argued that the relationship between a student's first language and physics learning is by no means straightforward. But what about the effects on physics learning when students are taught in a *second* language?

Surprisingly, there has been very little research into the relationship between student performance and the lecturing language at university level. In Sweden no studies have been carried out into the effects of lectures in a foreign language, although internationally a number of researchers have found negative correlations between learning in a second language and undergraduate performance (Neville-Barton and Barton 2005, Gerber *et al* 2005, Klaassen 2001, Vinke 1995). These studies are undoubtedly interesting for those faced with deciding *which* language to use in a given lecture situation. However, lecturers faced with the day-to-day reality of giving courses in their students' second language remain unsure as to any *specific* negative effects of such lecturing. We therefore believe that it is important to find out *what* students may find difficult in second-language lectures and *how* student learning patterns change as the lecture language changes. In his summary of research into second-language lectures in all disciplines, Flowerdew (1994) concluded that a great deal of work needs to be done before we can say what constitutes a successful second-language lecture. It was expected that the results of this study would contribute in some part to filling this particular gap in knowledge.

3. The study

The study set out to explore an illustrative relationship between the lecturing language and the learning experiences of 22 undergraduate physics students at two Swedish universities—one a larger, established research university and the other a smaller teaching university. The study focused on two lecture blocks at each university, one in each language—with each individual student attending both a Swedish and an English block. These lectures were video filmed. Prior to this filming, the lecturers had been interviewed about any areas where they expected students to have problems with the physics material to be covered. Guided by these interviews

and our methodological interest in capturing as much variation as possible, the video footage was edited down to four short segments for each lecture block.

Semi-structured interviews lasting for an average of 1 h 30 min were then held with each student. In the interviews, students were asked to describe their experiences of learning physics in the two courses. Thereafter, the 2 × 4 edited segments of video footage were used in what is commonly known in educational research circles as a process of *stimulated recall*. This process attempts to recreate a significant part of the atmosphere of the original learning situation, thus allowing students to better describe their learning experiences in the specific situations that they are shown (Bloom 1953, Calderhead 1981).

4. Findings

4.1. Language is seen as unimportant

The most striking aspect of the findings is that when asked directly, students say they notice very little difference in their learning when taught in English rather than in Swedish. This is something that is common for all students at both universities.

> Student: Language is not very important I think. It doesn't matter.
> Interviewer: Why's that?
> Student: Well, I think . . . Like I said, understanding English is not a problem for me.

This result is similar to those of Neville-Barton and Barton (2005) who find that the second-language mathematics students in their study self-report levels of understanding similar to those of first-language students. The overwhelming majority of students interviewed in our study feel that the lecturer should use the language he or she is most comfortable with—i.e. since the students are well versed in English from high school they do not see their *own* competence in English as problematic. Students suggest that the limiting factor for their learning is the lecturer's ability to mediate physics knowledge in the chosen language:

> Student: As long as he has a message to deliver it's fine . . . If it would be better for him then it's fine, he could take it in English.
> As long as he thinks he can do a better job.

However, despite *all* students initially maintaining that language was not an important factor for their learning, both our analysis of the videoed lecture material and the students' own accounts of their learning experiences during stimulated recall indicate a number of problems related to learning in English rather than Swedish.

4.2. Asking questions

We observed that the *willingness to ask and answer questions* was greatly reduced in English-medium lectures. This was also reported by the students themselves:

> Student: If you want to ask a question, you have something you want to ask, then I don't speak English so well as I speak Swedish, so its easier for me to ask . . . to talk in Swedish and ask things.
> Interviewer: I noticed in [the Swedish lecture] there were a lot more questions than in [the English lecture] is that common or is that just . . . ?
> Student: No . . . It's common, um actually [laughs]. Yes, that for sure has to do with the language, that people don't er . . . they're a little shy to speak English because they cannot speak English so well. Erm . . . For me it is like that.

That the traditional reluctance to ask questions is exacerbated when lectures are in English is all the more worrying when we take into account the fact that *lecturers* see a strong correlation between asking questions and student understanding:

> Lecturer: Of course there are exceptions, but typically those who, er, who perform better, those are the ones who ask questions.

In our observation of this particular lecturer's sessions we found that a number of students, though quiet in the lecture, came forward at the end of each session to ask questions.

4.3. Answering questions

Here is a student on the subject of *answering* questions when lectures are in English:

> Interviewer: Do you think it would have been easier to answer the question in a Swedish lecture rather than an English lecture?
> Student: Um I thought about that anyway when I had [the English lectures] that sometimes, you know, when he asked a question I was pretty certain I knew the answer but because it was English and so on you worried that it perhaps wasn't quite that he was looking for. Um, you get a little uncertain.

We believe this reduction in asking and answering questions to be an important finding. If lecturer/student interaction is reduced in this way (in extreme cases effectively limiting lectures to a monologue) then we would expect what is widely characterized as the shared space of learning (Tsui 2004) to be correspondingly reduced.

4.4. Focusing on note taking

When lectures are given in English, those students who take notes report spending a large proportion of their time concentrating on *the process of writing* rather than understanding lecture content:

> Student: You're not as used to listening to someone speak English as Swedish. ... You know speaking Swedish you can just er. You can listen and you can write what he's saying and you don't have to, you know, make such a big effort out of it. But if it's in English you've maybe got to focus a bit more on what he's saying and maybe the general message of the physics or maths gets lost a bit more ...

4.5. Work outside class

For students who take notes, their success in understanding the content of a lecture given in English appears to critically depend on the work done outside class after the lecture (or sometimes before the lecture, see section 4.6).

> Interviewer: To what extent do you think that you can follow what's going on in the lectures? Do you follow then or do you follow when you work through afterwards?
> Student: For me it's more, I, in the lectures I write down what the teacher says and do[es] and don't reflect on it under the lecture. But then when I come home I go through the notes and try to understand what the teacher has done! [laughs].
> Interviewer: So you feel like you're more, spending more time taking the notes than actually trying to follow what's going on?
> Student: Yep.
> Interviewer: It's more important to get down exactly what, what the person's written?

Student: Yeah.

Interviewer: And then you have to do the work afterwards?

Student: Umm. Er—usually the teacher's explains are more simple than to read in the book. So it's a combination of the teacher and the book and re-reading the notes. And some things, it can, go er, one or two weeks and then ooh! It's like that! [in Swedish] The penny's dropped!

Here, we do not mean to suggest that when the students attended lectures in Swedish they did not need to do work outside class. Rather, as we showed in section 4.4, the students in our study indicated that when they took notes in a lecture given in Swedish they were better able to *simultaneously follow the thread* of that lecture than they were when taking notes in a lecture given in English. Consequently, when the students took notes in a lecture given in English, they found they typically had to do more work outside class than when the lectures were given in Swedish.

4.6. Reading before the lecture

In some cases students had read through the relevant chapters *before* the English language lecture and, without exception, these students were those who claimed higher levels of understanding during the lecture.

Student: I've seen everything before and of course there's a lot of questions everywhere, but then I can spend the time on the lecture by straightening them out.

And here another student who does not take notes in class, on the same theme:

Student: I talked to the students that are in the third year. So they said you should read through everything before [the English lecture] so I've tried to do that—and I think it works really well. So, I read myself and I take notes, but I don't take any notes at the class because I think it's better just to listen then I can follow.

This reading done before class would probably have the same positive effect on the understanding of lectures given in Swedish; however, the students in our study only mentioned reading before class as a strategy they adopted when they were lectured in English.

4.7. Multi-representational support

In the case of both of the quotes in section 4.6, the lecturer followed one textbook very closely in lectures, working through each of its sections on the board. Often there was little difference between the pages of the book and what was written on the board. Our initial thought was that this would be a boring and unproductive lecturing strategy; however, this 'walking students through the landscape' was appreciated by all the students we interviewed:

Interviewer: Do you have [the textbook] with you in class?

Student: Er, *now* I have it because I don't have the time to listen to [the lecturer] and try to understand what he's saying and taking notes at the same time. So now I have this book with me and do some notes in the text.

So one useful lecturing strategy could be to follow a book or a set of lecture notes that students have already had access to—students can then simply annotate the text whilst concentrating on what is being said. Similarly, another student talked about the need for written support for oral descriptions:

Student: It's easier in a lecture when you have a . . . when they write things down on the board. That's actually something with English, that its difficult to sit and spontaneously make notes 'cause you've got enough on your plate trying to first understand the English and then understand the physics. If they only talk it's difficult to translate and make notes, you end up with a bit of a mixture, a bit of Swedish and a bit of English. I think it's easier—actually I think it's *always* easier when the teacher writes a lot on the board . . .

Interviewer: So the lecturer has to, if it's taught in English, has to write down a lot otherwise it becomes very difficult?

Student: Yep [. . .] I personally find it difficult to take things in when I only hear it and don't get written notes.

Here we can see that when lecturing in a second language, writing extensively on the board appears to help students. We can speculate that other forms of support such as handouts, overhead slides, demonstrations, computer simulations, etc would also help.

5. Conclusions and recommendations

5.1. Conclusions

Whilst we recognize that 22 students is a relatively small sample from which to draw conclusions, we believe that the results reported here provide a good illustrative case study of second-language lecturing. The main conclusion of this study is that there appear to be differences in the ways Swedish physics students experience lectures in Swedish and English—and that students are on the whole unaware of these differences.

When taught in English the students in our study asked and answered fewer questions and reported being less able to follow the lecture and take notes at the same time. Students employed a number of strategies to meet these problems by asking questions after the lecture, changing their study habits so that they no longer took notes in class, reading sections of work before class or—in the worst case—by simply using the lecture for mechanical note taking and then (perhaps?) putting in more work to make sense of these notes later.

5.2. Recommendations for second-language lectures

Some experienced lecturers might suggest that they could have anticipated the results reported here; however, the fact remains that with the increased movement of students throughout Europe envisaged in the Bologna declaration we need to base our pedagogical decisions on empirical work rather than gut feeling. Moreover, the finding that students initially see the lecture language as unimportant simply highlights the fact that empirical findings can be counterintuitive. In this spirit, the following are some tentative recommendations drawn from the results of this study and our own experience.

When lecturing in the students' second language we believe students will be helped if lecturers:

- *Discuss the fact that there are differences when lectures are in a second language.* A common response from students in our study was to thank us for the opportunity to discuss these issues. Students need to be aware that specific problems can occur in second-language lectures and that there are strategies (see below) that can minimize these problems.
- *Create more opportunities for students to ask and answer questions.* Three reasons for the lack of interaction in lectures appear to be student uncertainty about whether they have understood the question correctly, fear of revealing lack of understanding to the lecturer

and a fear of speaking English. We recommend using short, small-group discussions within a lecture to come up with answers to questions and to generate new questions. These small 'buzz groups' allow students to check their understanding in a less threatening forum than the whole class. Moreover, the resulting student interaction with the lecturer becomes less threatening since it takes place on a *group* level rather than an individual level. Each group can also choose one person to express their ideas. Those students with a particular aversion to speaking English will still avoid speaking in class but at least they participate in vicarious interaction with the lecturer (Bligh 1998).

- *Allow time after the lecture for students to ask questions.* Being available for informal questions at the end of the lecture allows students to come forward and discuss problems in a less threatening environment. In this respect it is probably a good idea to finish lectures early so that both students and lecturer do not need to be somewhere else. If possible students should be allowed to ask questions in their first language.
- *Exercise caution when introducing new material in lectures.* A typical approach to new subject matter is to introduce the topic in a lecture. Our research suggests that lectures may not always be the best way to introduce students to a topic, since students may have difficulty following and taking notes at the same time. If lectures are used to introduce a topic it may be prudent to simultaneously give out lecture notes that students can annotate.
- *Ask students to read material before the lecture.* A good strategy is to ask students to read about a subject *before* lectures; the lectures can then be used for confirmation and clarification of what students have already seen. Choose a book or use a set of lecture notes which are then followed closely in class.
- *Give as much multi-representational support as possible.* Lecturers should support their oral descriptions with a number of other types of representation such as overhead slides, handouts, demonstrations, computer simulations, etc. However, it is important that each representation reinforces the main themes of the lecture—using multiple representations without a clear reason will simply confuse students. Similarly, planning a logical structure and layout to any input on the board will also be useful.

5.3. Good lecturing techniques are the same in any language

The recommendations listed above could be said to apply equally well to lectures in the students' first language. We believe that changing the lecturing language merely accentuates communication problems that are already present in first-language lectures. In her study of Dutch engineering students Klaassen (2001) found that effective lecturing behaviour had a much greater effect on how students experienced lectures than the language used. We suggest that those teachers who were rated as more effective lecturers in Klaassen's study may have already used some of the strategies listed in section 5.2 to help students to cope with the shift in language.

5.4. Relevance for other teaching situations

The extent to which these results can be generalized to other types of student within Sweden and to other countries where the English language ability of both students and lecturers varies is an open question. We can, however, speculate that since Sweden is widely believed to be one of the countries in Europe with the highest levels of second-language English ability, that the problems we have described would perhaps be even more pronounced in countries with generally lower levels of English language competence.

This study set out to inform physics lecturers about what might be problematic when their students are taught in a second language. We believe we have succeeded in this task and that

physics lecturers will be able to transpose these results to other specific lecturing situations, devising their own strategies to mitigate any possible problems. Although there will always be questions about the generalizability of this kind of study, we believe the very fact that we have shown that problems *can* be experienced by students should be enough to prompt lecturers to rethink their strategies when presenting physics in a second language.

Acknowledgments

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Paper III

Representing disciplinary knowledge? Undergraduate students' experience of the equations presented in physics lectures.

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Introduction

As a discipline, physics is concerned with describing the world by constructing models—the end product of this modelling process often being an *equation*. Despite their importance in the representation of physics knowledge, physics equations have received surprisingly little attention in the literature. Whilst a great many studies explore the situated understanding of *specific* equations and their use in problem solving, (See Hsu, Brewe, Foster, & Harper, 2004) the *general* nature of physics equations and how they are experienced by students remains to a large extent unexplored. One exception is the work of Sherin (2001) who has examined students' ability to construct equations. Sherin explains his results in terms of *symbolic forms*—in essence, a limited generic set of templates and elements for equations, which he suggests students have learnt. In contrast, this study explores students' understanding of the equations presented to them in physics lectures. As such it extends Sherin's work by shifting the focus from *production*—representing ones own knowledge in equations, to *interpretation*—deciphering the disciplinary knowledge that the equation represents. In this study we map out the variation in students' experience of the meaning of physics equations, making a number of observations about the temporal development. We use this knowledge to suggest a set of pedagogical 'context questions' which we believe may help both lecturers and students to focus on appropriate components of a given physics equation.

Data collection

The study is based on interviews with twenty-two undergraduate physics students at two Swedish universities. The students attended lectures in a wide range of physics related courses. These lectures were videotaped and selected excerpts were then used to create a stimulated recall interview environment (Bloom, 1953; Calderhead, 1981). The interviews were semi-structured and posed questions such as "What do you see here?", "What does this equation mean to you?" etc. In order to access as wide a variation as possible, equations of different type and complexity from several different areas of physics were examined.

Data analysis

For this study our aim was to map the variation in students' experience of physics equations. We drew on qualitative data analysis as described by Marton & Booth (1997). The first step in the process was to identify overall themes in the raw data and tentatively group pieces of data into descriptive categories. The categories were given a descriptive heading, each piece of data being coded according to the origin and category. In the next phase of the analysis the categories emerging from the raw data were re-examined. Categories were iteratively compared and if necessary continuously modified, replaced, split or merged. During this phase it was

often necessary to go back to the raw data. In practice the two steps in the data analysis process were carried out simultaneously in iterative cycles. This process continued until the categories stabilized into an appealing bigger picture that in our view; gave a satisfactory answer to the research question, appropriately reflected the content and richness of the data and could be supported by illustrative examples from the data.

Results – mapping the variation of student experience
Our analysis of the interview data indicated that the variation in students' experience of equations could be mapped out as shown in Table 1. We find a layered structure of increasing complexity. At level A, students can identify the equation by name. At level B students can read out the symbols of the equation, e.g. $V = f\lambda$ (vee equals eff lambda). Level C involves students substituting terms for symbols e.g. velocity equals frequency times wavelength. At level D students show evidence of *understanding* the parts of the equation. We differentiate this from level C since it is far from clear whether saying 'frequency', for example, carries any disciplinary meaning. As diSessa (1993) and others have pointed out, a student can easily learn to express an equation in linguistic terms repeating it as a *slogan* without actually understanding *what* the slogan means. Level E relates to being able to appreciate the meaning of the equation *as a whole*. Each of the observed levels has one or more focuses as shown in table 1

	Category	Description	Focus		
			Maths	Physics	World
A	Equation having a name/label	A name is attributed to the equation	▓	▓	
B	Symbolic recognition of parts	The *symbols* of the equation can be read out	▓		
C	Linguistic recognition of parts	The symbols in C can be appropriately identified as physics/mathematics terms.	▓		
D	Understanding of the parts	The student shows evidence of *understanding* the physics, mathematics or real world meaning of parts of the equation	▓	▓	▓
E	Understanding of the whole	The equation as a whole is related to appropriate mathematics/physics/real-world situations	▓	▓	▓

Table 1: *Students' experience of the disciplinary knowledge represented by a physics equation.*

Results – what do students focus on?
What was interesting from our point of view was the *order* in which students appeared to focus on these different components of understanding. All students seemed to initially concentrate on the *mathematical nature* of a new equation. For a number of students this ability to handle an equation mathematically was equated with understanding. This was particularly obvious when students claimed to understand mathematically simple physics equations, but could not say what the terms in the equation represented.

Other students claimed to use their mathematical knowledge to access the physics of the equation:

Student: *Often I recognize the mathematical terms before I understand the physics. And then I apply the mathematics and try to do some problem-solving and then it all—not all but much of it—falls into place.*

And here another student on the same theme:

Student: *If I can see the mathematical connections with all the terms and variables then I can usually go back and see the physical part. So I go that way. First I go to the math and then I try to understand [the physics].*

In some cases, this finding could be explained in terms of students using Sherin's (2001) symbolic forms to decipher the meaning represented by the equation. A number of students appeared to 'stop' at this level, equating ability to use the equation to solve physics problems as understanding. Only a smaller number of students claimed to be looking for real-world applications as a means to 'understand' the equation.

Conclusions and pedagogical implications

Our results suggest that when students are presented with an equation, they initially focus on the mathematical complexity. They appear to ask themselves the question "Can I handle this mathematically?" For some students, if the answer is, "Yes" then they claim that they understand the equation. We suggest that this claim may hinder students from noticing the physics and real-world relevance of the equation. Other students appear to equate understanding with ability to solve physics problems. Here again, the real-world applications of the equation may go unnoticed. Drawing on these results led to the production of a generic list of 'context questions'.

Context questions

Epistemological Status	What is the status of this equation? Is it a law, axiom, pseudo law, or just some sort of mathematical 'fix' used to tidy things up or express them in a form that is recognizable and 'solvable'?
Name	Does this equation have a name? How do physicists refer to this equation?
Mathematical structure	What type of equation is this? What do I need to do mathematically to use this equation? What measurements/values do I need to have to be able to use this equation?
Dimensions and units	What are the dimensions of the terms in the equation? What are the units that the various terms are measured in?
Range of validity	When and where can I use this equation? What are the limits to the area of use? What happens when we approach those limits or exceed them?
Approximations and idealizations	What approximations are 'built into' this equation? What is it that makes this a *mapping* of the real world rather than a perfect description? What consequences do the approximations and idealizations have for being able to use the equation from a mathematical point of view. What consequences do the idealizations and approximations have for the predictions of the equation in the real world?
Origin	Where did this equation come from? What real-world problem was it originally designed to solve?
Use	What area of physics does this equation belong to? What things in the real world does this equation adequately describe?
Meaning	What does this equation mean? What does it tell us about the real world?

We believe these context questions may be a useful tool for both lecturers and students to focus attention on appropriate components of a given physics equation, thereby broadening and increasing the awareness of the disciplinary knowledge that is represented by the equations.

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Paper IV

Necessary Conditions for Learning? Modes of Representation and the Disciplinary Discourse of University Science

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Abstract: In this article we explore student learning in university science from the perspective of entering a *disciplinary discourse*. We define disciplinary discourse as the complex of representations, tools and activities of a discipline, and describe how it can be seen as being made up of various modes. For university science, examples of these modes are: spoken and written language, mathematics, gesture, images (including pictures, graphs and diagrams), tools (such as experimental apparatus and measurement equipment) and activities (such as ways of working—both practice and praxis, analytical routines, actions, etc.). We present an extended analytical framework for exploring the relationship between the ways of knowing the world that constitute a discipline and the modes of disciplinary discourse used within the discipline to represent this knowing. In our study, Swedish physics undergraduates from two universities are interviewed about their learning experiences in lectures using a stimulated recall approach. These interviews are then interpreted using our analytical framework. Since we have documented lectures, the data best illustrates the *representations* aspect of disciplinary discourse. Students describe a temporal aspect to their learning, achieving "fluency" in the various modes of disciplinary discourse with respect a particular disciplinary way of knowing through a process of *repetition*. However, we find instances where students are seemingly fluent in one or more modes of disciplinary discourse but have clearly not appropriately experienced the related disciplinary way of knowing. By referring to the phenomenographic view that variation underpins all learning, our analysis leads to the suggestion that a degree of fluency in a critical *constellation of modes* of disciplinary discourse may be a necessary (though not always sufficient) condition for gaining meaningful access to disciplinary ways of knowing. Pedagogical implications are discussed.

**Necessary Conditions for Learning? Modes of Representation and the
Disciplinary Discourse of University Science**

Introduction: Characterizing learning as entering a discourse
        One person does not constitute a discipline. Every discipline has been built up and
sustained by many thousands of individuals each playing their own role in creating the
shared ways of knowing the world that make up the discipline. By shared ways of knowing we
mean here the coherent system of concepts, ideas, theories, etc. that have been created
to account for observed phenomena. What allows these individuals to share and refine
their disciplinary ways of knowing are the systems of semiotic signs they develop to
represent this disciplinary knowledge. As early as the seventies Postman and Weingartner
(1971) pointed out that "A discipline is a way of knowing, and whatever is known is
inseparable from its symbols (mostly words) in which the knowing is codified" (p. 103).
One way of collectively referring to this "system of symbols" is to use the term *discourse.*
        The argument that the ways of knowing that constitute a discipline are inseparable
from their discursive representations has led to the suggestion that a significant part of
learning may be regarded as "discovering" the meaning of the discourse employed by a
discipline through participation (Kuhn, 1962/1996; Northedge, 2002, 2003; Östman,
1998). For example, Kuhn (1962/1996) makes the following claim:

> If, for example the student of Newtonian dynamics ever discovers the meaning of terms
> like 'force', 'mass', 'space', and 'time', he does so less from the incomplete though
> sometimes helpful definitions in his text than by observing and participating in the
> application of these concepts to problem-solution' (pp. 46-47).

        Northedge (2002) further argues that "We encounter [words] embedded within
discourse, and come to apprehend their meaning in the process of participating in the
discourse which generates them" (p. 257). Learning may then be characterized as a
coming to experience disciplinary ways of knowing as they are represented by the
disciplinary discourse through participation.
        It has been shown, however, that many dimensions of these disciplinary ways of
knowing are often taken for granted by university lecturers in their teaching (Pace &
Middendorf, 2004; Tobias, 1986, 1992-1993). In this respect, Northedge (2002) believes
university lecturers often do not fully appreciate "…the sociocultural groundings of
meaning. Their thoughts are so deeply rooted in specialist discourse that they are
unaware that meanings they take for granted are simply not construable from outside the
discourse" (p. 256). In a similar vein, Geisler (1994) claims "Texts, like other objects of
expert knowledge, appear to afford and sustain both expert and naïve representations:
the expert representation available to insiders to the academic professions and the naïve
representation available to those outside" (p. xi-xii). Thus a number of authors have
made the case that problems in student learning are largely a function of difficulties in
handling and understanding highly specialized forms of communication that are not
found to any great extent in everyday situations, for example, Driver & Ericksson (1983),

Solomon (1983) and Säljö (2000). Learning is therefore increasingly being characterized in terms of *entering a discourse* (Florence & Yore, 2004; Lemke, 1990, 1995, 1998; Northedge, 2002, 2003; Roth, McGinn, & Bowen, 1996; Swales, 1990; Säljö, 1999; Wickman & Östman, 2002).

In this article we first define a new concept that we call *disciplinary discourse* (the representations, tools and activities of a discipline) and go on to develop an extended analytical framework for dealing with such discourse from an educational perspective; thereafter, we present our study and use the framework to analyze our data. Since our study deals with student learning from lectures, our data best illustrates the representations aspect of disciplinary discourse.

Disciplinary discourse: an analytical framework

If we take the point of view that there are useful insights to be gained by characterizing learning as entering a discourse, then for the purposes of the analysis presented in this article we first need to define what we mean by such discourse. Tsui (2004) recently defined discourse for the purposes of contemporary educational research work as "a process in which meanings are negotiated and disambiguated, as well as a process in which common grounds are established and widened" (p. 167). This definition fully matches our own view of disciplinary discourse; however, there is a risk that using such a definition can become unintentionally limiting. This is because the definition does not *specifically* challenge the traditional view that disciplinary discourse is synonymous with the specialized *language* used within a discipline. Such a language-based interpretation of Tsui's definition proves to be limiting when attempting to capture the conditions necessary for learning university science, since it takes for granted or ignores other important representations (such as diagrams, graphs and mathematics).

Our own interest in exploring a broader notion of discourse grew out of an interest in the two main languages, English and Swedish, used in the teaching and learning of university physics in Sweden: If we characterize learning as entering a discourse, then what is the nature of the discourse that students are expected to enter into, we wondered, when *two* languages are involved? The broader study that is drawn on for this report was thus aimed at capturing the relationship between language use and the experience[1] of learning in university physics.

When, during the early stages of our study, the value of including representations other than language in our analytical framework emerged, Hall's (1997) view of discourse became a central pillar in our developing analytical framework. Here, discourse is viewed as a concept describing "…ways of referring to or constructing knowledge about a particular topic of practice: a cluster (or formation) of ideas, images and practices, which provide ways of talking about, forms of knowledge and conduct associated with, a particular topic, social activity or institutional site in society"(p. 6). This facilitated a further extension by drawing on Kress, Jewitt, Ogborn & Tsatsarelis (2001) to depict the discourse of a discipline as being made up of a number of *modes*, where spoken and written language are examples of two such modes. Each of these modes is seen as having

different *affordances* or, as we prefer to put it, *different possibilities for representing disciplinary ways of knowing:*

> Several issues open out from this starting-point: if there are a number of distinct modes in operation at the same time (in our description and analysis we focus on speech, image, gesture, action with models, writing, etc.), then the first question is: "Do they offer differing possibilities for representing?" For ourselves we put that question in these terms: "What are the *affordances* of each mode used in the science classroom; what are the potentials and limitations for representing of each mode?"; and, "Are the modes specialized to function in particular ways. Is speech say, best for this, and image best for that?" (Kress et al., 2001, p. 1)

For our analytic needs we consequently started developing a notion which we have called *disciplinary discourse* to characterize this collection of modes. It is this disciplinary discourse that students are expected to enter into and make their own. In this spirit, we now define disciplinary discourse as *the complex of representations, tools and activities of a discipline.*

Representations

By representations we mean semiotic signs that have been designed to convey the ways of knowing of science. This stems from the notion that in university science such a system of semiotic signs is made up of far more than simply the representational modes of oral and written language. Other modes such as images (e.g. graphs and diagrams), mathematics and gesture also play a central role in this system (Kress & van Leeuwen, 2001; Roth, Tobin, & Shaw, 1997; Roth & Welzel, 2001) and should therefore be included in our framework.

Tools

Every discipline has its own specialized tools that its members draw on to create disciplinary ways of knowing, and indeed the scientific community excels itself in this respect. Thus, learning to use the tools of science can be regarded as an integral part of being able to *do* science. But there is another perhaps less obvious characteristic of tools. From a cultural-historical perspective it is possible to see a tool in terms of a *condensation of meaning.* Thus, for example, Wartofsky (1979) has argued that it is possible for a tool, in certain circumstances, to mediate the knowing that went into its production. In other words, appropriate interaction with a tool can lead to more than a simple, situated understanding of how to *do* a piece of science, and thus students may also gain access to some of the ways of knowing the world implicit in a given tool's development. We therefore believe that the tools of a discipline—though not explicitly designed to mediate scientific ways of knowing—must be included as a separate mode in any characterization of the system of mediating signs of that discipline.

Activities

Similar to tools, the things that are done in the name of scientific activity need to be assimilated and learned by apprentices of the discipline. And, as with tools, these activities can be characterized in terms of condensations of meaning. Thus the ways of

knowing that underpin the activities may be opened to students through participation and observation. (See for example Crawford, Kelly, & Brown, 2000; Kuhn, 1962/1996; Roth & Lawless, 2002; Wells, 2000). We believe that this idea is the *leitmotif* of student laboratory work. Thus we include activities as a further mode of disciplinary discourse.

In our framework, then, the modes of disciplinary discourse include not only the words, symbols, gestures, diagrams, formulas, etc. used by a discipline; but also the artifacts, pieces of apparatus, measuring devices, etc. and the actions, practices and methods residing within the discipline. We can therefore argue that the disciplinary discourse of university science serves a dual purpose; it is first and foremost the physical application of the ways of knowing of the scientific community—quite simply it is how we *do* science, and it is also the sole means we have of sharing and evaluating this knowing.

Languages and modes

One of the research questions of the broader study that this report was situated in was: *How do English and Swedish relate to the system of modes of disciplinary discourse?* Halliday (1993) has shown how switching from one language to another (English to Chinese) whilst totally changing the discourse of a science text, has very little effect on the meaning that the text represents. We therefore suggest that in university physics discourse (the focus of our study) the modes that go together to make up English and Swedish may be viewed as *parallel.* This is because the modes that constitute English and Swedish instruction offer similar possibilities for learning. Naturally we are not suggesting that students experience English and Swedish modes in the same way. Rather we suggest that, given a student who was equally fluent in both Swedish and English, the potential of say, oral English to represent physics ways of knowing would be similar to that of oral Swedish. Note again here that in our characterization, neither English nor Swedish can be viewed as being fully representative of the ways of knowing of university science. Modes other than spoken and written language, such as mathematics, image, gesture and the tools and activities of science are also major components of disciplinary discourse. We will return to this point in our analysis section.

"Big D" Discourse

In a number of respects our notion of disciplinary discourse is similar to Gee's (2005) "big D" Discourses. Gee uses Discourse (with a capital letter) to designate the combination of discourse—that is language-in-use with other, non-language "stuff" (p. 20). The difference between disciplinary discourse and Discourse, is that disciplinary discourse carries a much more focused meaning—being defined as the complex of representations, tools and activities of a discipline. Gee's Discourse is a much wider concept which includes the *whole context* within which disciplinary discourse may be used. Indeed, in contrast to our own view of disciplinary discourse as *representing* a particular way of knowing, Moje, Collazo, Carrillo & Marx (2001) in the following quote appear to suggest that Discourse *is* a particular way of knowing: "Any stretch of language

(discourse) is always embedded in a particular way of knowing (Discourse)…" (p. 470). Thus Discourse can be characterized as including such things as students' epistemology, group dynamics, gender, social status, etc[2]. These aspects, whilst certainly important in student learning, are purposefully not part of our constitution of disciplinary discourse. Our reason for excluding such important aspects is that we are interested in analyzing *basic necessary conditions* for learning disciplinary ways of knowing with respect to the discourse perspective laid out earlier. By basic necessary conditions we mean conditions without which learning disciplinary ways of knowing may become impossible, regardless of any other factors.

Appresentation and facets of a way of knowing

If each of the modes of disciplinary discourse has different possibilities for representing disciplinary ways of knowing, then we can say that each mode has certain potentials for revealing particular *facets* of a given way of knowing. By facets we mean the various attributes of a way of knowing which are necessary for constituting the complete experience of that way of knowing. An example of these facets of a way of knowing can be seen in the teaching and learning of Ohm's law. A student may experience Ohm's law in a number of different ways through, say: hands-on activities (with batteries, wires and bulbs), a circuit diagram, oral descriptions from the teacher, written descriptions in a textbook, the mathematical formula **V=IR**, a table of voltages and currents for a given circuit or a simple line graph of these voltages and currents. In each of these situations certain facets of Ohm's law are brought to the fore, whilst others remain in the background (or are simply not present). Thus each disciplinary way of knowing may only be partially represented by a particular mode of disciplinary discourse. As Marton & Booth (1997) point out, the experience of a disciplinary way of knowing depends on the phenomenological concept of *appresentation:*

> When we have a perceptual or sensuous experience of something, which is to say we see, hear or smell it, we can talk about the mode in which it presents itself, that is, the way in which it appears to one or more of our senses. But in addition to what is "presented" to us—that is what we see, hear, smell—we experience other things as well. If we look at a tabletop from above, for instance, we hardly experience it as a two-dimensional surface floating in the air, in spite of the fact that what we see is, strictly speaking, a two-dimensional surface separated in some mysterious way from the ground. But in looking down on a tabletop we experience the legs that support it as well, because the experience is not of a two-dimensional surface, but of a table… That which is not seen, is not even visible is appresented … We wish to apply the concept of appresentation to experiences of abstract entities as well as concrete ones. If we think of the gravitational constant, g, for instance, then the highly abstract formulation made by Newton of how bodies affect one another at a distance is appresented, given that we have acquired sufficient education in and experience of classical physics (pp. 99-100).

Thus one mode of disciplinary discourse opens up the possibility to experience a particular number of facets of a disciplinary way of knowing, but, in order to appropriately experience this way of knowing, the other facets of the way of knowing need to be appresent. We therefore argue that students of the discipline may be unable

to fully experience a disciplinary way of knowing until two criteria are met: First, at some stage they must have experienced each of the various facets of the way of knowing. This we argue entails *multimodal representation*. Second, they need to be able to experience these facets simultaneously—that is when one group of facets is presented to them through a particular mode of disciplinary discourse, the other facets need to be appresent. We suggest this second criterion can only be met after students have familiarized themselves with the disciplinary discourse to such an extent that experiencing the various facets simultaneously becomes second nature, or as we term it, when they have become *discursively fluent* in a number of modes.

Discursive fluency

Following Fairclough (1995) the New London Group (2000) argue that each semiotic domain has its own specific *order of discourse* that is "a structured set of conventions associated with semiotic activity (including use of language) in a given social space" (p. 20). Building on this, with our interest in the individual modes of disciplinary discourse, we constituted the notion of *discursive fluency* to characterize the ability to use *a particular mode* of disciplinary discourse in a legitimate way (that is in line with the disciplinary "order of discourse") with respect to a certain disciplinary way of knowing. Thus, in our characterization, if a person is said to be discursively fluent in a particular mode they have familiarized themselves with the ways in which the discipline generally uses that mode when representing a particular way of knowing. Taber (2002) suggests this familiarization is needed because: "…the logical structure needed to develop the new ideas may exceed the processing capabilities of the student. Although each step in an explanation may itself be manageable, the overall structure may 'swamp' the student and seem much too complicated" (p. 73). Whilst we believe such an appeal to inner mental processes to be unnecessary for our description of learning in university science; the point that students often feel swamped by new material which they most likely will later experience as straightforward is a valid one. Thus, we suggest that a degree of discursive fluency may be necessary before the facets of a disciplinary way of knowing that are made available by a given mode of disciplinary discourse can be appropriately experienced.

In this respect there is always the possibility that discursive fluency may not necessarily lead to an appropriate experience of the related facets of the disciplinary way of knowing—students might simply learn to *imitate* the "order of discourse" of a discipline. Clearly if students are imitating the "order of discourse" they will encounter difficulty when they are required to use disciplinary discourse in a creative way in unfamiliar situations. We further develop this *discourse imitation* argument in our analysis section.

The multimedia effect

As we suggested in the previous section, our notion of complementary discursive modes in which students need to become "fluent" carries no assumptions about cognitive processes in the mind of learners. We feel it is important to point this out due

to the great deal of closely related work which has been carried out into what can be characterized as "multimodal teaching and learning", not least in the area of digital multimedia interfaces. As Reimann (2003) points out, two important ideas in this area are dual-processing theory (J. M. Clark & Paivio, 1991; Paivio, 1986) and cognitive load theory (Chandler & Sweller, 1991).

Dual-processing theory posits that the human brain has separate processing systems for visual and verbal input. This notion has been exploited by Mayer (1997; 2003) who finds a multimedia effect—that is students learn more deeply from words and pictures than from words alone. Cognitive load theory, however, posits that human processing ability is extremely limited, thus creating an upper limit to any multimedia effect (Miller, 1956). A selection of papers by leading researchers in this area of multimodal research was presented in a recent special issue of *Learning and Instruction* (volume 13, 2003). A common factor in the approaches described is a "snap-shot" interest in the most *efficient* method for communicating a certain "message" given the assumed limited processing capacity of the brain and the possibility of dual processing channels.

In contrast, our own interest in the modes of disciplinary discourse focuses on the necessary conditions for students to appropriately experience the ways of knowing of a discipline. And, following ideas such as Bruner's (1960) spiral curriculum, we suggest this occurs *over an extended period of time*. As we have already outlined, in our framework the modes of disciplinary discourse are seen as offering *different possibilities for representing disciplinary ways of knowing*. Thus it is this ability to *more fully represent* ways of knowing through certain combinations of modes that is pertinent for our study.

The study

For our study, the research questions were as follows:

1. How do students characterize their learning of the disciplinary discourse of university science in a subject such as physics?
2. How does learning disciplinary discourse relate to the students' experience of disciplinary ways of knowing?

The study data came from two Swedish universities—one a larger, mainly research oriented university and the other a smaller, more teaching oriented university. Six physics lectures with different lecturers were video filmed, each student in the study being present at two of these lectures. Prior to filming, the lecturers had been interviewed about; their aims for the lecture and how it fitted into the "whole", their experiences of the group as learners and any areas where they expected students to have problems with the material to be covered. Guided by these interviews, and our interest in sampling as many modes of disciplinary discourse as possible the resulting video footage was edited down to what turned out to be four short segments for each lecture. These four segments always included one clip where the lecturer presented a diagram and one where a mathematical formula was discussed. The total running time of these four segments was between seven and ten minutes.

Twenty-two volunteer students were then interviewed using a semi-structured interview protocol. These interviews were open-ended and lasted approximately 1hr 30mins. Students were first asked to talk about their experiences of learning physics through different representations such as diagrams, text, oral descriptions and mathematics. The interviews continued by exploring student expectations of; the two lectures they participated in, the two courses of which these lectures formed a part and their entire degree program to date. Further themes dealt with such issues as student experiences of other "input" such as laboratory work and problem-solving sessions, their use of the course text, etc. The amount of work-time students put in outside class and their work-time with other students was also explored. The 2x4 edited segments of video footage were then used to create a *stimulated recall* environment (Bloom, 1953; Calderhead, 1981). This approach attempts to recreate the central atmosphere of the original learning situation, thus allowing students to better describe and reflect on their learning experiences in the specific situations that they are shown.

All interviews were recorded digitally, enabling direct access to their various sections. This, together with the structure generated by the stimulated recall approach, led to the following form of data analysis. Each of the digital interview files were "cut" into sections where students discussed similar themes. Each of these sections was given a filename consisting of the topic discussed, the student's name and a five digit identification code which was in fact the excerpt's time stamp in the original master recording. This allowed us to cycle through the data listening to several students talking about similar and related themes, efficiently building up an overall picture of what students were saying as individuals and as a group.

This method of analysis had two benefits: first we could begin analysis within a few days of collecting the data, bypassing the lengthy process of transcription, and second, more of the situatedness of the interview was maintained—transcripts being generally acknowledged as one step further away from the phenomenon under study than the audio recording[3]. Maintaining this situatedness was considered important since in the interviews we were attempting, through stimulated recall, to vividly recapture for the students the essentials of their experience of being in a specific lecture. Student files could also easily be re-related to the whole of the interview due to the timestamp identification code we used which led us directly to the correct position in each master recording.

Analysis

The analysis now presented illustrates the use of the analytical framework described earlier and how the results were obtained. Since the students in the interviews are commenting on their experience of learning in lectures (where the sole purpose of the lecture is to communicate the ways of knowing of the discipline) the data best illustrates those modes of disciplinary discourse that we have characterized as *representations*. Work which focuses on the modes which constitute the *tools* and *activities* of a discipline will be reported elsewhere.

Discursive fluency through repetition

The students in our study describe their learning of disciplinary discourse through a process we characterize as *repetition*; working with a large number of problem sets and reading and re-reading lecture notes and prescribed textbooks. For example:

> Student: [*You learn physics] by working with lots of problems—solving problems that's the way.*

And here another student on the same theme:

> Student: *…it's a combination of the teacher and the book and re-reading the notes. And some things, it can go one or two weeks and then ooh! It's like that! The penny's dropped!*

With the growth of constructivist ideas about students constructing meaning for themselves, the behaviorist idea of repetition as an important dynamic in learning became widely unfashionable. However, recently there has been renewed interest in repetition. Marton & Trigwell (2000) for example put forward the idea that *variation* rather than repetition should be focused on when giving consideration to making learning possible. It is the variation in the object of learning (that *can* occur through repetition) which allows a student access to a disciplinary way of knowing. Thus in Marton & Trigwell's framework, repetition which offers no new variation in the object of learning should be viewed as playing no meaningful role in learning. This idea of variation has also been developed by Linder & Marshall (2003) who put forward the idea of *purposeful repetition*. In their argument learning may involve using the *same material* over a period of time if this is done with the *intention* of experiencing variation. Thus, despite

repeating exactly the same task, critical variation in an object of learning can be achieved if the student's *focus* changes from one iteration of repetition to the next. From this perspective it is possible to interpret some dynamics of repetition in terms of searching for variation. As we will describe later, this variation approach is central to our theoretical framework when accounting for the way in which students experience the ways of knowing of a discipline. However we found that characterizing learning through variation alone did not fully describe our empirical data. We argue that there is another, complementary way of viewing student repetition, namely as an attempt to achieve *discursive fluency*. By discursive fluency we mean a process through which handling a mode of disciplinary discourse becomes almost second-nature[4].

In order to illustrate our interpretation we will refer to a well-known and widely respected example of variation. Marton, Runesson & Tsui (2004) illustrate the central role variation plays in learning by referring to Moxley's (1979) experimental study on motor learning. In Moxley's study children were asked to practice hitting a target with a ball. One group of children practiced throwing the ball from the same position all the time, whilst the other group practiced from a number of different places. When the two groups were compared in their ability to hit the target from a position that was new to both groups, the group which had had experience of several positions was found to be better at hitting the target.

An interpretation of the ball throwing example feasibly includes more than variation alone. This is because the children in Moxley's study *practiced* throwing. Put simply, the experience of variation would not seem to be sufficient for them to learn to hit the target, what was also needed was a repetitive, temporal aspect. Repetition over time led to improved performance. Similarly, the students' descriptions in our study also pointed to a repetitive, temporal aspect being involved in the learning of physics. We believe that just as oral fluency in a foreign language is a product of repeated practice, the students in our study attain *discursive fluency* in the various modes of disciplinary discourse through a process that includes repetition—what Kuhn (1962/1996) has likened to "finger exercises" on the piano (p. 47).

Discursive fluency as a route to experiencing a disciplinary way of knowing

In our characterization, then, gradual familiarization with the way meaning about a particular way of knowing is constituted in a particular mode leads to increased discursive fluency in that mode. We further suggest that discursive fluency is a necessary condition for experiencing the associated facets of a way of knowing that the disciplinary discourse represents. In the following quotes students suggest that they use their discursive fluency (here in the mathematical mode) in order to experience facets of the ways of knowing of the physics discipline.

> Student: *Often I recognize the mathematical terms before I understand the physics. And then I apply the mathematics and try to do some problem-solving and then it all—not all but much of it—falls into place.*

And here another student on the same theme:

Student: *If I can see the mathematical connections with all the terms and variables then I can
            usually go back and see the physical part. So I go that way. First I go to the math and
   then I try to understand [the physics].*

We interpret these statements in terms of students using their discursive fluency in the mathematical mode as a stepping stone to experiencing some of the facets of a disciplinary way of knowing. In our characterization, these facets of the way of knowing that are provided by the mathematical mode help these students to structure input in other modes and hence experience further facets of the disciplinary way of knowing. These facets could be described as acting like a "seed crystal" around which other representations can be collected and "decoded". Following our framework such decoding can itself only occur when students have become discursively fluent in these other modes of disciplinary discourse. This notion is corroborated by the observation that when discursive fluency is not present students seem unable to experience the associated facets of a disciplinary way of knowing.

When students are not discursively fluent

An illustrative example of a lack of discursive fluency is given below (visual mode). In this section of a lecture the lecturer drew a diagram of a transformer on the board (fig.1) and gave the following oral and written description.

Teacher :   *And now we will look at section 7.2.2 which is about transformers.
            <u>A transformer is just a device for</u> transforming—that means <u>changing the value of</u>—
            <u>either currents or voltages.</u> [underlined text written on the board]
            And concretely it looks like this.
            [starting to draw fig. 1] You have a metallic core which has some permeability, μ. And
            as you will see it will be interesting to take ferromagnets—that means that μ is large.
            And we take two coils which are wound on this core, one is to the left and another one
            to the right. And let's assume that there is a current I_1 in the coil to the left and there
            are N_1 turns in this coil, and here we have N_2 turns and the current I_2*

Figure 1. *Diagram of a transformer drawn by the lecturer on the whiteboard*
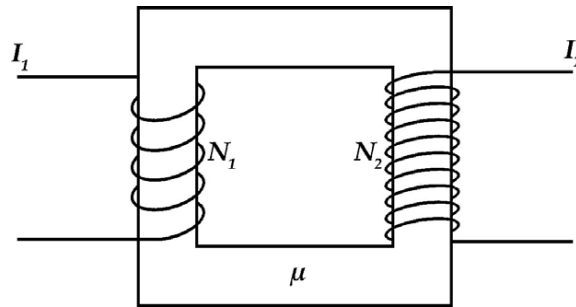
The following is the transcript of an interview with a student after having seen this short video clip during stimulated recall:

Interviewer:	*This is him starting this thing about transformers—what, what did you think about this particular part?*
Student:	*Ummmh. Yeah, I don't know what this is. I didn't know what he was writing…*
Interviewer:	*Okay, he's drawing some kind of diagram, but you don't really know what that is that he's drawing or…?*
Student:	*No.*
Interviewer:	*Okay, so…*
Student:	*—And I think it's, it's, quite often like that in the lectures—that he's drawing something on the whiteboard and he assumes that we know this from before.*
Interviewer:	*So er, you—you've got, er, no idea what this transformer thing is?*
Student:	*[laughing] No.*
Interviewer:	*What do you think makes this difficult to understand, then … just for you?*
Student:	*[sighs] errm … errm—at first I think he should tell us what this is!*

Our interpretation here is that this student has not experienced the facets of the way of knowing described by this diagram (visual mode) and appeals for help. Paradoxically, as can be seen from the teacher's description of the transformer, the teacher provided a clear description of what the diagram represents, both orally and on the board. We suggest that the interviewed student has not become discursively fluent in this visual mode, i.e., the student has not become appropriately proficient in seeing and handling this particular representation. Had the student instead answered that "The teacher drew a diagram of a transformer with a core and two coils" then we could have inferred that this student was discursively fluent in this mode—note, however, that this is not the same as saying that the student would then *know what a transformer is*. If the student has never *seen* a transformer, nor understood *why* changing voltages, currents and associated electric fields could be of any interest, then discursive fluency—in this case simply knowing that this is a standard representation of a transformer—will not give the student access to the disciplinary way of knowing.

This student transcript nicely illustrates Northedge's (2002) claim that some meanings cannot be construed from outside the discourse. All the other students in this part of our study appeared to relate the diagram to a shared way of knowing of the discipline. As we discussed earlier, in phenomenological terms, the way of knowing was *appresent* for them. Logically, however, there must also have been some stage when the diagram did not carry this disciplinary way of knowing even for these students. At some stage in the past, these students learned to "see" something *beyond* the diagram, but now they (and the lecturer) take this meaning for granted—in our terms they have entered the discourse of the discipline. Thus we believe students need to achieve discursive fluency within a particular mode before they are able to experience the associated facets of a disciplinary way of knowing.

Necessary but not sufficient, discourse imitation

If we accept that discursive fluency is necessary for experiencing facets of a disciplinary way of knowing, the next question is whether this discursive fluency is a sufficient condition for experiencing these facets. Put simply, does familiarization with a representation automatically lead to a student experiencing the associated facets of a disciplinary way of knowing? Our study suggests that discursive fluency is a *necessary but not sufficient condition*, that is students may learn to use disciplinary discourse appropriately, but still not experience the associated facets of a way of knowing. This ability to use disciplinary discourse without experiencing the associated ways of knowing has in fact been documented by a number of researchers. For example, diSessa (1993) reports the following:

> One of the most striking findings from the interviewing studies on which this work is based is that MIT undergraduates, when asked to comment about their high school physics, almost universally declared they "could solve all the problems" (and essentially all had received A's) but still felt they "really didn't understand at all what was going on" … these students' impressions of incomprehension are ironically more correct than their school assessments: They did not understand, even though they could perform (p. 206).

diSessa accounts for this phenomenon as follows:

> Symbolic and verbal propositions are prominent in instruction. It is possible to view these as being learned prior to the broader co-ordinations in intuitive knowledge that are eventually required. This is like the way learning slogans may precede a deeper commitment to a political ideology (p. 152).

We believe these "slogans" to be a common part of learning. In our analytical framework we use the term *discourse imitation* to describe discursive fluency without a corresponding experience of the associated facets of a disciplinary way of knowing. This notion of discourse imitation is by no means new, being a theme which dates back to the ancient Greek and Roman rhetoricians and a commonly discussed factor in the teaching of academic writing (D. Clark, 1951; Mintock, 1995; Rider, 1990). Below we present examples of discourse imitation—instances where students are fluent in one or more modes of disciplinary discourse of the university physics community, but where they have apparently not experienced the corresponding facets of the way of knowing which the segment of discourse represents.

Interviewer: *You've seen these equations before..?*
Student: *Yeah I've seen them before er… but I really don't know exactly what they mean [laughs].*
Interviewer: *Can you tell me what this means to you?*
              [pointing to the formula $\nabla \times E = 0$]
Student: *Um, I think the E is er the intensity of er an electric field. And then the curl of E… [quietly to herself] mmh equals zero…*
              Erm, I think this is erm a conservative vector field—and I know how to calculate it but I don't know what it means.

This student is discursively fluent in the mathematical and oral modes with respect to this particular way of knowing. Here we can see strong supporting evidence for diSessa's (1993) slogans in the words "conservative vector field". The student appears to have heard or read this expression many times, but it is clear that the student has not experienced the way of knowing it represents. In our terms this is discourse imitation. Moreover, the student can *calculate* answers using this formula—in fact this student had been one of the more successful participants on the degree course up to that point and self-reports finding mathematics easy. However, it is evident that in this case the student does not know *what* it is that has been calculated. This ability to use a mode of disciplinary discourse but not experience the way of knowing that it represents—in this case, to be able calculate, but not know *what or why*—is taken up by another student with respect to a parallel course.

Student: [*talking about tensors] I know it's an important concept in physics so now I think I've got some kind of abstract idea of what it is [laughs] but er, er, I still haven't seen any er, almost no applications.*
Interviewer: *So this is like what you were saying about curl, but worse?*
Student: *Yeah, a lot worse! But I, I know mathematically very well what it [tensors] is, I just don't know how I can use it.*

In contrast to the previous student, this particular student can do more than just calculate answers, here the student claims to understand mathematically what tensors *are*, but the disciplinary way of knowing the world that this mathematical mode represents is still not available to the student.

Imitation-revelation

At this point we would like to make a brief digression on the theme of discourse imitation. If discourse imitation continues for any length of time without an experience of the corresponding facets of a disciplinary way of knowing, students may set out on an *imitation-revelation* learning trajectory. On this trajectory students may experience the disciplinary way of knowing in a sudden "Ah-ha!" moment or revelation. In such cases, the discourse in which a student has become fluent is suddenly linked to the disciplinary ways of knowing that it represents.

Ahlberg (2004) documented cases where student interns first experienced something in their internship in one way and then came to experience it in another (the disciplinary) way. From our perspective we interpret these early student experiences as extreme instances of discourse imitation—that is students described situations where they had become fluent in disciplinary discourse (in this case participating in the day-to-day activities of a hospital) without experiencing the associated ways of knowing that this discourse represents. We suggest that usually, however, this linking of disciplinary discourse to facets of ways of knowing occurs in much smaller, less noticeable steps. Thus, although almost all the students in Ahlberg's study could identify one situation when they noticed such a change in their experience of a way of knowing, we suggest that science students will, for the most part, find it difficult to point out precisely when discursive fluency has led to them to experience a particular disciplinary way of knowing.

Translation between modes

The students in our study suggest that discursive fluency in some of the representative modes of physics discourse may be insufficient to constitute an appropriate disciplinary experience of physics ways of knowing. Here is a student talking about learning quantum physics:

Student: *You can calculate using a mathematical formula in physics but you don't understand what's happening. You want to translate into plain Swedish—what's happening in physics through the math—but that's not always easy. Especially not now because now you can't really see a picture of it or understand really what it is that's happening in quantum physics.*

Interviewer: *Mmm, that's interesting. Do you think there are some things that can only really be described with math in this subject?*

Student: *Yeah, I think so.*

Interviewer: *There aren't really adequate Swedish words to describe what's going on?*

Student: *Yeah—and no English ones either. It's only math, only math can describe it properly. And just that—that there aren't really any words for this—gives you a feeling that it doesn't really exist—you can't really 'see' it—it doesn't really exist you can only calculate it.*

We interpret this student's suggestion that only mathematics can describe quantum physics as further confirmation that different modes of disciplinary discourse play different roles in offering access to physics ways of knowing. Moreover, different disciplinary ways of knowing appear to be best represented through different combinations and "proportions" of modes. Perhaps, as this student suggests, the disciplinary way of knowing the world which we call quantum physics is best represented through a higher "proportion" of mathematics in relation to oral and written language than say Newtonian mechanics.

This student is obviously struggling to understand quantum physics and consequently is attempting to translate the meaning in the mathematical mode to meaning in the oral and visual modes. Following Stern, Aprea, & Ebner (2003) we believe that such re-representation of meaning is a natural part of learning and that such translation between modes can reveal further facets of a disciplinary way of knowing that students were previously unaware of. This interpretation can be seen to be supported by the following dialogue taken from an interview with another student:

Student: *It's different for me to… maybe I think I understand and then I should calculate and then I cannot do it—so maybe I haven't understood er, maybe I just* **think** *I understand but I, I don't actually because it's hard to calculate.*

Here one can see how the student recognizes in moving from the written and oral modes of disciplinary discourse—reading about and listening to descriptions of a way of knowing—to the mathematical mode—"calculating"—that there is a mismatch between her own way of knowing and that of the discipline. In this respect, Lemke (1998) claims that scientists handle problems that would otherwise be impossible to solve by orchestrating movement between a wide range of discursive resources (modes):

> We can partly talk our way through a scientific event or problem in purely verbal conceptual terms, and then we can partly make sense of what is happening by combining our discourse with the drawing and interpretation of visual diagrams and graphs and other representations, and we can integrate both of these with mathematical formulas and algebraic derivations as well as quantitative calculations, and finally we can integrate all of these with actual experimental procedures and operations. In terms of which, on site and in the doing of the experiment, we can make sense directly through action and observation, later interpreted and represented in words, images, and formulas (p. 7).

Similarly, since each mode has different possibilities for meaning-making it therefore seems reasonable to argue, following Marton & Tsui (2004), that from a variation point of view a *multimodal* approach to teaching will enhance the possibility of appropriate learning. For example, here we have a student describing the usefulness of multimodality in her own learning:

Student:	*I usually write down more or less everything the teacher writes on the board.*
Interviewer:	*Even though it's there in the book?*
Student:	*Yeah. At least with the theory..*
	I think it's more comfortable to write down derivations and so on—if you write it down
	it goes in another, one more way so to speak.
Interviewer:	*Aha, so the doing in some way…?*
Student:	*Yes I think so.*

We see this student's use of a multimodal approach as an example of Linder & Marshall's (2003) notion of *purposeful repetition* which we briefly described earlier, that is we equate the student's translation between modes with an attempt to experience critical variation in the object of learning.

Critical constellations of modes

From the point of view of disciplinary discourse, we can say that *no one mode in itself can be fully representative of a disciplinary way of knowing the world*, and therefore it is impossible to experience disciplinary ways of knowing through input from one mode alone.[5] That is not to say that mono-modal discourse may not be useful within the scientific community. Once students have experienced the ways of knowing of a discipline, (or as we have characterized it, "entered the discourse" of the discipline) a few short phrases, or an equation, or a simple diagram can allow them to share meaning with others—those facets of a way of knowing which are not present in the immediate representation are automatically appresent. For example, as we pointed out earlier for the majority of students in the lesson with transformers the diagram that the lecturer drew on the board *meant something appropriate*—simply drawing this diagram evoked a whole dimension of shared meaning. One way of characterizing this is to use Wittgenstein's (1958) idea of students and lecturer *playing the same language game*. This kind of mutually accepted system can only occur if both student and lecturer have fully experienced the ways of knowing of some part of the discipline. And, as we have argued here, such ways of knowing may perhaps only be fully experienced through certain types of disciplinary discourse.

What we are suggesting, then, is that each way of knowing in, for example physics, may only be constituted by a certain *critical constellation of modes*. Once a way of knowing has been experienced, it can be activated in other modes, but the *initial possibility to experience* may only be available by experiencing critical variation in a particular constellation of modes.

Based on these findings and following the ideas of variation and purposeful repetition, we argue *first*, that multimodal teaching has the distinct potential to achieve better learning outcomes than teaching with a reduced number of modes. And, *second*, that it is of utmost importance that research be carried out into *which* constellation of modes opens up the possibility for experiencing each of the particular ways of knowing of physics. Without this knowledge lecturers will have little possibility of systematically building their teaching around a "variation approach" (Marton & Tsui, 2004) and then we argue that there is a risk that their teaching may in fact not offer the specific constellation of modes needed make a particular way of knowing accessible to students.

At this point it is perhaps appropriate for us to once again remind the reader of our intentions. We do not mean to suggest that providing students with access to a certain combination of modes is sufficient in itself to guarantee learning—far from it. A great deal of research has pointed to the importance of other factors that need to be considered in descriptions of learning science, such as gender and power relations (Conefrey, 1997; Seymour & Hewitt, 1997; Thomas, 1990), student epistemology (Hammer, 1995), culture (Brown, 2004), group dynamics, (Bianchini, 1997), etc. Thus much of our interview data could be gainfully interpreted from any or all of these perspectives. What we are arguing for here is that, irrespective of these other factors, certain disciplinary ways of knowing may be *impossible to appropriately constitute* without discursive fluency in a critical combination of modes. However, even when discursive fluency in a critical constellation of modes is achieved, discourse imitation may still continue for any number of reasons which are related to the particular context (See Gee's (2005) concept of Discourse which we described earlier).

Using disciplinary discourse—"discoursing" in university science

From our multimodal viewpoint, simple *exposure* to disciplinary discourse is not enough for students to experience disciplinary ways of knowing, students need practice in *using* disciplinary discourse to make meaning for themselves. Northedge (2002) has suggested that teachers ought to scaffold student meaning making. Students should be expected to initially make "fuzzy" meaning—that is their discourse will initially be a *poor imitation* of disciplinary discourse, but, with appropriate guidance, gradually this will spiral towards something closer to the discourse of the discipline (they achieve discursive fluency). Examples of such scaffolding of multimodal student discourse can be seen in Stern, Aprea, & Ebner (2003) and Kozma, Chin, Russell, & Marx (2000), and as we argued earlier, may also be related to Bruner's (1960) notion of a spiral curriculum. From our interviews with teachers and students and our own experience of university physics one can find evidence that the supporting of students' own meaning making within disciplinary discourse is not a typically a common practice in university science. In

university science, such scaffolding of student *use* of disciplinary discourse appears to be limited to guidance in using the tools and carrying out the activities of science in laboratory work, along with some mathematical guidance in formal problem-solving sessions (although in the latter situation it is not uncommon that students are reduced to passive observers whilst the lecturer "models" the mathematical mode of disciplinary discourse).

Lemke (1990) believes that students should be given the chance to *"talk science"*, whilst Tobias (1986) has suggested that learning would be enhanced if science students were encouraged to *"kick the ideas around"* as they are in the social sciences and humanities. From our perspective we reformulated these assertions by suggesting that students need to be given the opportunity to "*discourse*" in science, in order to gain the necessary fluency. That is students need opportunities to engage with the various modes of disciplinary discourse with respect to each separate disciplinary way of knowing the world. Here is an example of a student talking about such "discoursing":

Student: *We usually sit, on the afternoon and do some calculations together, me and another guy so then we talk about, discuss things and try to…*
Interviewer: *So you work in a pair so to speak?*
Student: *Yeah, Yeah…*
Interviewer: *With mathematical problems?*
Student: *Yeah … Yeah problems for this course.*
Interviewer: *Is that because these are difficult so that it needs quite a bit of perspective from…*
Student: *Yeah, I think so, because I tried to sit on my own in the beginning 'cause—sometimes I think that's good because I can think in another way—but this was… Well its very good to have sometimes someone to discuss things with.*

The students in our study repeatedly reported that a large proportion of their learning occurs when "discoursing" in science, that is engaging in sharing meaning using the various modes of disciplinary discourse with other students, this is similar to the findings of Svensson & Högfors (1988). This "discoursing" occurs in *ad hoc* problem-solving study groups, rather than when interacting with university lecturers. We therefore suggest that the knowledge of the lecturer as a competent user of disciplinary discourse is often under-exploited in university science.

Expecting discourse imitation

Part of our analysis has brought to the fore the notion that a natural step on the way to entering a disciplinary discourse includes at least some element of *discourse imitation*, that is students appear to initially achieve discursive fluency without appropriately experiencing the associated disciplinary ways of knowing the world. If this is indeed the case then lecturers need to be reflective about student learning not only when students answer questions "incorrectly", but even when students give the expected "correct" answer. Lecturers need to be sure as they can be that their students are playing the same "language game" (Wittgenstein, 1958) as the rest of the discipline. This in turn suggests what many in university science education argue, namely that the traditional

method of examining science courses through problem-solving and calculation may lead to students passing examinations without experiencing the appropriate ways of knowing of the discipline. Furthermore, since disciplinary discourse is multimodal, examinations using mainly the mathematical mode may encourage discourse imitation, particularly at introductory levels. Why should a student pay attention to all those other modes if the perception is that only the mathematical mode is formally graded? Wickman & Östman (2002) discuss how Wittgenstein's language games can be operationalized, using the idea of *lingering gaps* in conversation. An experienced teacher, using classroom evaluation techniques will notice these gaps and see them as a cue for further probing of student understanding (Angelo & Cross, 1993; Gipps, 2002).

Conclusions and implications

The results presented in this article represent a starting point in the work of characterizing learning in a university science such as physics as entering a disciplinary discourse. As part of our analysis we suggested a number of emerging relationships between our notion of disciplinary discourse and the experience of the ways of knowing university science. What follows is a summary of our findings and these relationships.

Our research questions were introduced as follows:

1. How do students characterize their learning of the disciplinary discourse of university science in a subject such as physics?
2. How does learning disciplinary discourse relate to the students' experience of disciplinary ways of knowing?

With respect to the first question of how students characterize their learning of the disciplinary discourse, the data indicates that:

- *The disciplinary discourse of university science is of necessity multimodal.*
  We have observed that in university physics, disciplinary knowledge is constituted using a wide range of modes over and above written and oral language, such as mathematics, diagrams, gesture, physical apparatus and activities.

- *A temporal, repetitive element is a necessary part of learning university science.*
  All the students in our study indicated that repetition over time played a key role in their coming to experience disciplinary ways of knowing.

- *Repetition is the means by which students become discursively fluent.*
  In our analysis we proposed that students use repetition in order to familiarize themselves with the way meaning about a particular way of knowing is constituted in a particular mode. We characterized this familiarization as *discursive fluency*.

With respect to the second research question regarding the way in which learning a disciplinary discourse relates to students' experience of the disciplinary ways of knowing, we concluded that:

- *Discursive fluency in a mode is a necessary but not sufficient condition for experiencing facets of a disciplinary way of knowing.*
  We propose that students need to become discursively fluent in a particular mode of disciplinary discourse before the facets of the way of knowing the world that are described by that mode can become available to them. However, our data strongly suggests that discursive fluency does not automatically lead to a student experience of the related facets of a disciplinary way of knowing. Some of the examples used in our analysis section illustrate how students can be fluent in a particular mode of disciplinary discourse but clearly not experience the associated facets of the disciplinary way of knowing the world. Our dataset contains many more such examples. We therefore propose that discursive fluency is a necessary, but not sufficient condition for experiencing a disciplinary way of knowing. We characterize this ability to use disciplinary discourse without experiencing the associated way of knowing as *discourse imitation*.

- *An element of discourse imitation may be a natural stage on the way to experiencing a disciplinary way of knowing.*
  Since we find a number of students who are discursively fluent in a mode (modes) of disciplinary discourse but who show no appropriate experience of the corresponding way of knowing the world, we believe that this state of affairs may be wide-spread in university science education.

- *Only certain constellations of modes of disciplinary discourse may be able to afford access to disciplinary ways of knowing.*
  By appealing to the phenomenographic[6] idea that variation underpins all learning, we have proposed that learning how to appropriately represent the ways of knowing the world that constitute a discipline requires a wide range of modes, with each way of knowing requiring differing proportions of these modes. Moreover, by referring to the phenomenological concept of *appresentation*, we further propose that in order for students to have the possibility to fully experience disciplinary ways of knowing the world they need to become discursively fluent in a critical combination of modes of disciplinary discourse.

- *Translation between modes can help students notice discrepancies between their way of knowing and that of the discipline.*
  If, as we have proposed, each disciplinary way of knowing the world can best be learnt through a critical combination of modes, then a student who has not appropriately experienced a disciplinary way of knowing may have the possibility

for such an appropriate experience opened up for them by translation between modes.

Based on these outcomes we have also proposed the following pedagogical implications:

- *Students need opportunities to use the representations, tools and activities of the discipline as an integral part of their science education.*
  Since the disciplinary discourse of university science is multimodal in nature and since we have suggested that students need to acquire discursive fluency in a critical constellation of modes; it may be argued that students need to be able to practice using these modes within their degree courses.

- *To improve the possibilities for learning, lecturers need to come to better understand the specific constellations of modes necessary for a full representation of each individual disciplinary way of knowing.*
  We argue that if university science lecturers do not come to better understand which modes are necessary for an appropriate experience of a disciplinary way of knowing; it will be difficult to adequately constitute learning experiences which provide the necessary variation in critical constellations of modes of disciplinary discourse.

- *The assessment criteria for university science courses should reflect the multimodal nature of disciplinary knowledge.*
  It is now well established that assessment plays an important role in influencing *what* students learn (for example, see the review in Scoulier & Prosser (1994), and discussions by Newble & Jaeger (1983), Fransson (1977), Marton & Säljö (1976) and Hakstian (1971). For an example from university physics education see Peters (1982)). If disciplinary ways of knowing are best experienced through a critical constellation of modes, then we suggest that designing of assessment which takes into account these modes will promote better desired learning and minimize discourse imitation.

- *The specialist knowledge of lecturers as experts in using disciplinary discourse may often be under-exploited in university science lectures.*
  In our experience many science lectures appear to at best *reconstitute* the representations, tools and activities of science in language terms, or at worst even take them for granted. Following Northedge (2002) we propose the lecturer, as a person competent in disciplinary discourse should rather act as a guide in this respect, not only *modeling* disciplinary discourse but also actively engaging students in their attempts to make meaning with such discourse for themselves. Ironically, at the moment this role seems to be filled by fellow students, who are themselves struggling to learn the discourse of the discipline.

Much of the research carried out in university science education focuses on new ways of understanding old problems. Our study suggests that viewing learning as entering a disciplinary discourse with an emphasis on repetition, discursive fluency and critical constellations of modes, opens up another useful dimension in the characterization of learning in university science which may be helpful to teachers and students alike.

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Notes

[1] We use the term *experience* in the phenomenographic sense (See note 6 below).

[2] For a good illustration of Discourse see Kittleson & Southerland (2004) who use the concept to analyze engineering students' group knowledge construction.

[3] The audio recording is of course one step further away from the interview itself, which is in turn several steps away from the actual learning experience in the lecture. See Säljö (1997) and Kvale (1996) for discussions of the limitations of interview studies as a source of information about classroom learning.

[4] Note that each of the modes of disciplinary discourse has a productive and a receptive version e.g. reading and writing, speaking and listening, etc. The term discursive fluency is not limited to production and can refer equally well to familiarization with a receptive version of a mode.

[5] We do not mean to suggest here that a course text or a lecture is of necessity mono-modal in nature. The majority of physics texts and lectures are multimodal, using for example mathematical notation, diagrams, graphs and pictures along with the written or spoken mode of English or Swedish.

[6] Phenomenography is the study of the qualitative variation in ways of experiencing the world around us—how we conceptualize, understand, perceive, apprehend etc, various phenomena in and aspects of the world around us. (Marton, 1986; Marton & Booth, 1997).