

Science, Language and Literacy

Case Studies of Learning in Swedish University Physics

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Abstract

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This thesis presents an investigation of undergraduate student learning with respect to physics lectures attended in English and Swedish. The work studies three connected areas: student learning patterns, bilingual scientific literacy and disciplinary discourse.

Twenty-two 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 used to contextualize in-depth, semi-structured interviews with students.

When taught in English the students asked and answered fewer questions and reported being less able to simultaneously follow the lecture and take notes. Students adapted to being taught in English by; asking questions after the lecture, no longer taking notes in class, reading sections of work before class or—in the worst case—by using the lecture for mechanical note taking.

Analysis of student oral descriptions of the lecture content in both languages identified a small number of students who found it almost impossible to speak about disciplinary concepts in English. These students were first-years who had not been taught in English before. However, the findings suggest that, above a certain threshold level of disciplinary language competence, it does not appear to matter which language students are taught in.

Finally, the thesis makes a theoretical contribution to educational research. The initial language perspective is broadened to include a wide range of semiotic resources that are used in the teaching of undergraduate physics. Student learning is then characterized in terms of becoming fluent in a disciplinary discourse. It is posited that in order to achieve an appropriate, holistic experience of any given disciplinary concept, students will need to become fluent in a critical constellation of disciplinary semiotic resources.

Keywords: Physics, Learning, Higher education, Bilingualism, Language choice, Science education, Scientific literacy, Bilingual scientific literacy, Disciplinary discourse, Discourse imitation, Semiotics

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To my family

Preface to Licentiate 2006

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 in Swedish. 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 position—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

Preface to PhD thesis

In Sweden, the usual tradition for PhD theses in the natural sciences is to publish a number of papers and to then write a so called ‘kappa’—a text that summarizes the papers and situates them in the literature. Despite having more than enough papers for this route (see the following page), I have chosen to write this thesis in the form of a single book or monograph. The reason for writing the thesis in this way is that it provides a better opportunity to show how I have engaged with research data.

When I started this project very few Swedish researchers had interested themselves in questions of language choice in higher education. A lot has happened since then, and there are now a number of researchers working with various aspects of disciplinary language. This is important work. Although this thesis makes a significant contribution to our understanding of what happens when students are taught in a second language, the main conclusion is that we still know very little about the relationship between disciplinary languages, and disciplinary learning.

John Airey
Stockholm
January, 2009

Peer-reviewed articles and book chapters

During work on this thesis the following eleven articles/book chapters have been completed, arranged by year. For conference papers and other presentations made during the PhD see Appendix I.

- Airey, J. (2003). Teaching university courses through the medium of English: The current state of the art. In G. Fransson, Å. Morberg, R. Nilsson & B. Schüllerqvist (Eds.), *Didaktikens mångfald* (Vol. 1, pp. 11-18): University College Gävle.
- Airey, J. (2004) Can you teach it in English? The language choice debate in Swedish higher education. In R. Wilkinson (Ed.), *Integrating Content and Language: Meeting the challenge of a multilingual higher education* (pp. 97-108). Maastricht, Netherlands: Maastricht University Press.
- Airey, J. & Linder, C. (2006) Language and the experience of learning university physics in Sweden. *European Journal of Physics*. *European Journal of Physics* 27. 553-60
- Airey, J. (2006) När undervisningsspråket blir engelska. *Språkvård*, 2006 (4) 20-25
- Domert, D., Airey, J., Linder, C. & Kung, R. (2007). An exploration of university physics students' epistemological mindsets towards the understanding of physics equations. *NorDiNa, Nordic Studies in Science Education*. 3. 15-28.
- Airey, J. & Linder, C. (2007) Disciplinary learning in a second language: A case study from university physics. In Wilkinson, R. & Zegers, V. (Eds.), *Researching Content and Language Integration in Higher Education* (pp. 161-171). Maastricht: Maastricht University Language Centre.
- Airey, J. & Linder, C. (2008) Bilingual scientific literacy? The use of English in Swedish university science courses. *Nordic Journal of English Studies*. 7(3) 145-161.
- Airey, J. & Linder, C. (2009) A disciplinary discourse perspective on university science learning: Achieving fluency in a critical constellation of modes. *Journal of Research in Science Teaching*. 46 (1) 27-49.
- Airey, J. (in press) Estimating undergraduate bilingual scientific literacy in Sweden. Accepted for publication in the *International CLIL Research Journal*.
- Airey, J. & Linder, C. (in press). Bilingual scientific literacy. *Landscapes of scientific literacy* (working title)
- Airey, J. & Linder, C. (in press) Tvåspråkig ämneskompetens? En studie av naturvetenskaplig parallellspråkighet i svensk högutbildning. *Språkrådet*.

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Abbreviations

The following abbreviations are used in the text:

BET	best estimate of trustworthiness
CLIL	content and language integrated learning
ELF	English as a <i>lingua franca</i>
L1	first language
L2	second language
MLR	mean length of runs
PER	physics education research
SPRINT	språk- och innehållsintegrerad inläring och undervisning (the Swedish equivalent of CLIL)
SPS	syllables per second
WPM	words per minute

1. Introduction to the thesis

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 the three case studies attended lectures taught in Swedish and English, as part of their regular undergraduate programme and the intention was to examine the effects of this dual-language approach on physics learning. Besides student learning experiences, a related aspect of interest is the balance that needs to be struck between teaching in Swedish and teaching in English in an undergraduate degree programme. This aspect is explored with respect to the notion of *bilingual scientific literacy*, i.e., scientific literacy in two languages.

From this work an approach evolved which is underpinned by an internationally emerging area of interest in all disciplines—the characterization of learning as discourse acquisition. Within this context, oral and written Swedish and English can be viewed as four among a much wider range of semiotic resources (e.g. mathematics, diagrams, graphs, ways of working, etc.). In this thesis the *disciplinary discourse* of university science is characterized as consisting of appropriate combinations of this range of semiotic resources.

1.2. Who should read this thesis?

This thesis is a study of learning in undergraduate physics. The immediate findings will therefore naturally be of professional interest to those who are in some way involved with the education of university physics students. Similarly, since the research questions involve issues such as bilingualism, academic language proficiency and the relationship between language and disciplinary knowledge, the research will also be of interest to certain groups of linguists and language teachers.

The thesis also addresses policy issues related to language choice and the goals of undergraduate education with respect to science and society. This work will therefore be of interest to educational policy-makers and those involved in curriculum planning and development. For similar reasons the

thesis will also be of some interest to those involved with issues of language planning and wider concerns about the balance struck between global-English and the local language in society.

In the eyes of the researcher, however, this thesis is first and foremost a contribution to science education research. In this respect, the thesis makes a theoretical contribution to furthering our understanding of learning. Thus the synthesis of earlier research into the notion of disciplinary discourse along with its associated focus on discourse imitation, repetition and critical constellations of disciplinary semiotic resources should be of interest both to teachers and educational researchers.

1.3. The significance of the thesis

The work presented in this thesis is based on cross-case analysis of three different cases of student learning (see chapter 5). The thesis makes research contributions in four specific areas:

- An understanding of the way in which the learning of undergraduate physics changes when the teaching language changes from Swedish to English.
- The consequences for scientific literacy when two languages are involved in the teaching of undergraduate physics.
- A theoretical description of science learning in terms of fluency in a disciplinary discourse.
- The suggestion that science concepts can only be appropriately learnt through a critical constellation of disciplinary semiotic resources.

Each of these contributions will now be briefly presented.

1.3.1. Learning and the language of instruction

Swedish society has an impressive level of language skills in English, with the country consistently being rated at the top end in international surveys of language skills (Falk, 2001a). More sophisticated levels of English language skill are commonplace in Swedish higher education, where the use of English is widespread (Wächter & Maiworm, 2008). In university physics, the majority of textbooks and a sizable proportion of the teaching at higher levels are in English. Recently there has been much discussion about the effects of the use of 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 an indirect response to the *Bologna Declaration* on the harmonization of European higher education.

One of the reasons for the mixed signals in the higher education sector is the lack of research in the area of language of instruction and learning. A thorough literature review carried out at the start of this project revealed *no* studies carried out in Sweden into the content learning outcomes when lecturing in English at university level in any discipline. There are, however, a number of Swedish studies at pre-university level and a number of international studies at university level which have examined the disciplinary learning outcomes for students taught in a language other than their first language. Such studies have—rather inappropriately one might argue—attempted to correlate the language used to teach a course with results on examinations or researcher implemented tests. 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 contributes 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 within the three cases). Thus, instead of a ‘Which language is better?’ approach, the focus of this section of the thesis 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 undergraduate physics courses delivered in English in Sweden about specific areas which may be problematic, and makes recommendations about the organisation of such courses.

1.3.2. Bilingual scientific literacy

In this thesis it is posited that the goal of undergraduate science is the production of scientifically literate graduates in an extended sense of the construct (see Linder, Östman, & Wickman, 2007). Scientific literacy is defined in this thesis as both the ability to work within science and the ability to apply science to the problems of society. From this perspective, an immediate question arises about the implications for achieving scientific literacy when two languages are involved in the education of physics undergraduates. Here the term bilingual scientific literacy is introduced to characterize the situation where students are—at least to some extent—expected to become scien-

tifically literate in two languages. Since physics course syllabuses do not usually make explicit their goals with respect to disciplinary language development, a small-scale analysis was first made of thirty such syllabuses, in order to assess the *implied* bilingual scientific literacy. This was judged from the language input and output that had been organized for students on the courses. Here, a lack of practice in spoken disciplinary English and Swedish is identified. The consequences of this ‘oral deficit’ are followed up in an analysis of student ability to describe the same physics concepts in both English and Swedish within the three cases. Here, a number of techniques are used to build up a picture of student disciplinary skills in both languages. Estimates of the fluency of speech—in terms of amount said and the frequency of pauses—are combined with documentation of involuntary code-switching and an estimate of the disciplinary ‘correctness’ of the descriptions, in order to triangulate an estimate of students’ bilingual scientific literacy. This estimate is then related back to the language in which the concept was originally taught—English, Swedish, or both languages.

1.3.3. Disciplinary discourse

Reflective analysis of the interview data collected in the three cases led to the original language focus being expanded to include other important representations such as mathematics, graphs and diagrams. This in turn led to the adoption and development of a discourse perspective on learning in order to bring together these and other semiotic resources within a single framework. Drawing on work from a number of different sources in the literature, a related concept of *disciplinary discourse* is introduced. This disciplinary discourse is defined as the complex of *representations, tools* and *activities* of a discipline.

1.3.4. Critical constellations of semiotic resources

The students interviewed in the three cases describe a repetitive practice aspect to their learning. In this thesis, this is characterized as part of what is necessary to become fluent in the control of the various semiotic resources that go together to make up the disciplinary discourse. Here, instances of *discourse imitation* are identified—where students are seemingly fluent in one or more semiotic resource without having an appropriate disciplinary experience of the concept to which these resources refer. The examples lead to the suggestion that fluency in a *critical constellation of semiotic resources* may be a necessary (though not always sufficient) condition for gaining meaningful holistic access to disciplinary knowledge.

1.4. 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? Three separate cases of learning were examined. These three cases were selected pragmatically according to the availability of courses where the *same students* read physics in both English and Swedish. During the course of data collection and analysis of these three cases, the 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 in its widest sense. The six research questions for this thesis reflect this development:

1. *How do Swedish undergraduates experience the differences between being taught physics in English and in Swedish?*
2. *What type of student competencies with respect to bilingual scientific literacy do undergraduate physics courses appear to imply?*
3. *How does the teaching language affect the bilingual scientific literacy of undergraduate physics students?*
4. *How may learning in university physics be characterized in terms of learning a disciplinary discourse?*
5. *How do students become ‘fluent’ in the collection of semiotic resources that together form the disciplinary discourse of university science?*
6. *How are disciplinary semiotic resources related to an appropriate, holistic experience of a disciplinary concept?*

All research questions, with the exception of question 2, are addressed using cross-case analysis of interview data from the three cases. Question 2 is addressed by means of a small-scale study of 30 physics syllabuses from a major Swedish university.

1.5. Description of terms used in the thesis

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 within the list.

<i>activities</i>	used in this thesis to mean actions which are unique to a specific <i>discipline</i> —one of three categories of <i>semiotic resource</i>
<i>appresentation</i>	mechanism by which aspects which are not technically discernable in a given <i>semiotic resource</i> are ‘read into’ the <i>semiotic resource</i> —a necessary condition for a <i>semiotic resource</i> to acquire an appropriate, disciplinary meaning
<i>best estimate of trustworthiness (BET)</i>	a tentative conclusion drawn from professional experience, in the absence of definitive research data
<i>bilingual education</i>	education where two distinct languages are used for teaching
<i>bilingual scientific literacy</i>	<i>scientific literacy</i> in two languages
<i>case study research</i>	inquiry that examines a contemporary phenomenon in its natural setting
<i>code-switching</i>	use of two or more languages in the same utterance or conversation—here divided into <i>functional code-switching</i> and <i>involuntary code-switching</i>
<i>constructivism</i>	model of learning based on the premise that, knowledge cannot be unproblematically transferred from one person to another—we must always, to some extent, construct our own individual understandings of the world
<i>circumlocution</i>	filling a <i>lexical gap</i> by substituting a descriptive phrase for the required vocabulary item

<i>diglossia</i>	situation where a society has two languages in functional opposition—an everyday ‘low’ language and a formal ‘high’ language
<i>disciplinarity</i>	used in this thesis to mean a judgement made by the researcher about the disciplinary correctness of an utterance
<i>disciplinary discourse</i>	the complex of <i>representations, tools and activities</i> of a <i>discipline</i>
<i>discipline</i>	used in this thesis to mean an accepted, separate institutional site in society, a community with its own particular <i>ways of knowing</i> the world and a unique <i>order of discourse</i>
<i>discourse</i>	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—see also <i>primary discourse</i> and <i>secondary discourses</i>
<i>Discourse</i>	(with a capital ‘D’) a social identity—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 (see Gee, 2005)
<i>discourse imitation</i>	using <i>discourse</i> in line with the disciplinary <i>order of discourse</i> but without a holistic experience of the associated disciplinary <i>way of knowing</i>
<i>discursive fluency</i>	the ability to use a particular <i>semiotic resource (mode of disciplinary discourse)</i> in a legitimate way (that is in line with the disciplinary <i>order of discourse</i>) with respect to a certain disciplinary <i>way of knowing</i>

<i>domain</i>	a particular sector of society e.g. tertiary education, the workplace, the judiciary, the home, etc.
<i>domain loss</i>	a situation where certain societal domains become dominated by a <i>second language</i>
<i>epistemology</i>	student or teacher beliefs about what constitutes knowledge and thus, by association, what constitutes learning
<i>experience</i>	used in the phenomenographic sense, i.e., how we conceptualize, understand, perceive, apprehend etc, various phenomena in and aspects of the world around us
<i>facets</i>	the various attributes of a <i>way of knowing</i> which are necessary for constituting the complete <i>experience</i> of that way of knowing
<i>first language (L1)</i>	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. See also <i>primary discourse</i>
<i>functional code-switching</i>	<i>code-switching</i> used to convey more information than is possible in a monolingual description—usually used in situations where all parties understand the other language code
<i>fuzzy generalization</i>	(or <i>moderatum generalization</i>) generalization which states what may be rather than what is (see also <i>best estimate of trustworthiness</i>)
<i>immersion</i>	teaching where a <i>second language</i> is the sole means of communication, the student's first language is never used
<i>involuntary code-switching</i>	<i>code-switching</i> which occurs in a monolingual setting
<i>language of instruction</i>	the language used to teach a subject

<i>lexical gap</i>	used in this thesis to mean a word or phrase that is absent from a description. True lexical gaps occur when one language does not have a term for something that exists in another language. In this thesis, lexical gaps occur either when a student does not know a word in a particular language, or knows it but cannot access it spontaneously. Lexical gaps can be filled by <i>circumlocution</i> or <i>code-switching</i>
<i>literacy</i>	control of <i>secondary discourses</i>
<i>mean length of runs</i>	a linguistic fluency measure, defined as the phrase length in syllables between pauses
<i>mode</i>	(or <i>semiotic resource</i>) one among many forms of communication used in a discipline. Examples from university science are speech, writing, diagrams graphs, equations, ways of working, apparatus, etc. A <i>discipline</i> often has a highly developed, specific <i>order of discourse</i> for each mode
<i>moderatum generalization</i>	generalization where the object of study is seen as representative of a broader set of recognizable features (used here as a synonym for <i>fuzzy generalization</i>)
<i>naturalistic generalization</i>	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 (see also <i>moderatum</i> or <i>fuzzy generalization</i>)
<i>order of discourse</i>	a structured set of conventions associated with the use of <i>semiotic resources</i> in a given social space
<i>primary discourse</i>	ways of talking and acting acquired through primary socialization in the family (see also <i>secondary discourses</i>)

<i>purposeful repetition</i>	studying the same material over a period of time using a number of different approaches or focuses with the intention of experiencing <i>variation</i>
<i>repetition</i>	studying the same material in a similar way over an extended period of time
<i>representations</i>	those <i>semiotic resources</i> that have been specifically designed to communicate the <i>ways of knowing</i> of science
<i>scientific literacy</i>	defined in this thesis as both the ability to work within science and the ability to apply science to everyday life
<i>secondary discourses</i>	specialized ways of talking and acting in specific sites in society outside the home, acquired by building on and extending <i>primary discourse</i>
<i>second language (L2)</i>	any language other than the <i>first language</i> (L1) typically used for geographical, social, or political reasons
<i>semiotic resources</i>	<i>representations, tools</i> and <i>activities</i> that are used to communicate the <i>ways of knowing</i> of science
<i>shared space of learning</i>	the common ground between teacher and student with respect to the intended object of learning
<i>stimulated recall</i>	an interview method in which video clips of a situation are used to allow the interviewee to relate some of the thoughts and feelings experienced in the original situation
<i>tools</i>	used in this thesis to mean specialized, disciplinary specific, physical objects that members of a discipline draw on to create disciplinary <i>ways of knowing</i> . One of three categories of semiotic resource

<i>variation</i>	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
<i>way of knowing</i>	the coherent system of concepts, ideas, theories, etc. that have been created to account for observed phenomena in a <i>discipline</i>

1.6. A note about the language used in this thesis

Traditionally, science is reported in an impersonal manner, using the passive voice. The reason for adopting this writing style in science texts is the desire to imply that anyone doing the same work would produce the same results—the persons who carry out the research are seen as unimportant. In social sciences it is much more usual to write in the first person (i.e., ‘I did this or that...’). This choice signals an acknowledgement that all knowledge is socially constructed, thus the people who do the research *are* important.

Although this thesis is written within the field of physics, the data itself is qualitative in nature. Clearly, the most natural choice of language is therefore the first person, since this matches the data presented. In spite of this, I have chosen to use the ‘standard’ scientific genre of the passive voice. I realize that some may interpret this choice as a kind of self-censorship—a denial of my own presence in the text, or—worse still—an attempt to claim impartiality where no such claim can be made. However, I prefer to view my choice of the passive voice in this thesis as both an informed personal preference and a deliberate attempt to avoid alienating those readers who may potentially benefit most from this work.

1.7. Overview of the thesis

This chapter has presented the significance of the thesis, the research questions and descriptions of the specialist terms used in this thesis. Chapter 2 presents a literature review dealing with three specific areas; learning and science, learning and language, and learning and literacy. In the interests of clarity it was decided to separate general methodological issues from the specific methods needed to answer each of the research questions: thus chapter 3 situates the methodology of the thesis, while the discussion of the choice of specific methods for each of the research questions is presented in chapter 4. Chapter 5 gives a brief presentation of the three cases that were examined in this thesis. Chapter 6 presents *both the results of the thesis and the discussion*. This organization was chosen in order to retain the links be-

tween the results and discussion for the three separate issues of; language and learning, bilingual scientific literacy and disciplinary discourse. Chapter 7 gives a brief summary of the outcomes with respect to each of the research questions. Chapter 8 suggests topics for future work and, finally, chapter 9 provides a Swedish summary of the thesis. The interview protocols used for the three cases along with examples of transcripts and analysis can be found in the appendices.

2. Literature Review

2.1. Introduction

This chapter provides the general background necessary to situate the work presented in the thesis through an overview of 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 case study it became clear that language was not a sufficiently extensive unit of analysis for description of university physics learning. Other representations, such as equations, graphs and diagrams, proved to be significant parts of what was needed to make comprehensive sense of the richness in the interview data. This led to the initial language focus being broadened to focus on scientific literacy and the disciplinary discourse of physics as ways of bringing together all the semiotic resources that the physics community draws on in order to share disciplinary knowledge. To this end, the literature review presented here has been divided into three sections. First, a general overview of research in physics education is given, along with examples of specific research done in areas related to this thesis. This is followed by a presentation of relevant research into learning in a second language. The final section deals with the concept of literacy and the way in which learning has been characterized in discourse terms. As such, the aim is to prepare the way for the next two chapters which situate the methodology and describe the analytical methods chosen with respect to each of the research questions.

2.2. Learning and science

2.2.1. Physics education research (PER)

This thesis falls into the domain of physics education research (PER) in higher education. A useful way to further characterize this thesis work is one of discipline-based science education. This (relatively young) branch of educational research focuses on obtaining a better understanding of the teaching and learning of physics, and the relations between the two that may impact on learning outcomes. As such, the kind of knowledge claims that will be

produced are qualitatively different from the knowledge created by traditional physics research (Aalst, 2000). In physics research, measurements with models of low uncertainty are most often quantitative in nature—often the larger the sample the greater the accuracy. Characteristically, PER is often more usually concerned with qualitative results; here sample size becomes less important than *sample variation*. This is because PER is most often interested in the ways in which people *experience* physics and the ways in which this experience affects learning. Clearly, there are as many ways to experience physics as there are people, so PER can only attempt to produce general categories of the kinds of ways that physics tends to be experienced. Here, increased sample size is only useful when, for example, the additional sample illustrates a new category or type not seen before. Thus, the standard, incremental relationship between sample size and reliability does not hold, since it can never be predicted whether more data will lead to the creation of a new category.

Physics has been traditionally viewed as a difficult subject to study, particularly at the university level. Since the early 90s and continuing to the present day there has been a great deal of concern in the physics community about falling enrolment in physics courses, the student attrition rate, and the quality of the education given to undergraduates. (American Association of Physics Teachers, 1996; Johannsen, 2007; Seymour & Hewitt, 1997). 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 second-ranked subject, chemistry (Duit, 2007).

2.2.2. Situating this thesis in PER

The early work in PER in higher education was carried out within university physics departments rather than faculties of education. This work thus tended to be atheoretical and to attempt to treat PER as if it were work in natural science. 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, 2007; McDermott & Redish, 1999 and; Thacker, 2003 for bibliographies of PER in various areas). As an understanding of the 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 PER had uncovered (an excellent overview can be found in Redish, 2003). The situations being explored most often tended to be so-called service-course physics—introductory courses for students taken as a requirement for another subject area such as biology, and first-year 'calculus-based' mainstream physics courses.

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 science classes and those of the discipline (Duit, 2007). 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 these conceptions (for example, Clement, 1982; Driver & Erickson, 1983; Finegold & Gorsky, 1991; Linder & Marshall, 1998; 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; Linder, 1993; 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 was 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 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 of PER in the higher education sector was slow until physicists who had turned to other areas such as ethnography, education, and psychology, for example, Linder (1992), diSessa (1993), Redish (1994) and Hammer (1995), began to examine university learning using a constructivist philosophy. This philosophy began to dominate educational thinking at that time. At this point conceptual framing based on metacognition (e.g. Linder, Leonard-McIntyre, Marshall, & Nchodu, 1997; 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). The work in this thesis falls into this broader theoretical area of PER growth with its exploration of students’ experiences of learning by drawing on ideas embedded in the discipline’s ways of knowing.

2.2.3. Language and PER

A number of researchers have studied the relationship between language and physics learning. Here the work falls into two broad areas: first-language concerns and bilingual concerns. The first-language work is mainly concerned with *disciplinary accuracy*. Here, the types of student misconceptions that can be signalled by imprecise use of language in physics have been analysed. See for example, the discussion of the term ‘heat’ (Baierlein, 1994; Romer, 2001; Zemansky, 1970). Another strand of this first-language work looks at the ways in which physics terms which have everyday meanings such as force, mass may be misconstrued by students, even when they are used correctly in the discipline, see for example (Arons, 1997; Williams, 1999). A summary of this first-language work can be found in Brookes (2006).

The second area examines student understanding when physics concepts are presented in a second language. An early quantitative study by Ho (1982) found no differences when Chinese students were taught in English. However, in the same year, a somewhat more qualitative study by Mestre Gerace, & Lochhead (1982) found differences when Hispanic students were asked to use sentences in Spanish and in English to create a mathematical equation. Other work has examined the link between language, culture and physics learning, suggesting that some misconceptions may arise from the way in which ideas such as force are framed in certain languages/cultures (Moji, 1999; Moji & Grayson, 1996).

2.2.4. Representation and PER

There has been a great deal of work on representation in PER. Much of the work has dealt with the way in which a given type of representation can aid (or hinder) the learning of physics concepts, e.g., mathematics and equations (Domert, Airey, Linder, & Kung, 2007; Hestenes, 2003; Ragout De Lozano & Cardenas, 2002; Sherin, 2001), graphs (Aberg-Bengtsson & Ottosson, 2006), gesture (Scherr, 2008). Kohl & Finkelstein (2005; 2006b) illustrate how choice of specific representational format can affect physics learning, suggesting that such choices may not necessarily lead to the best results.

There has also been extensive work on the way in which representations can *function together* to make learning possible (Dufresne, Gerace, & Leonard, 1997; Kohl & Finkelstein, 2008; Kohl, Rosengrant, & Finkelstein, 2007; van Heuvelen & Zou, 2001). In perhaps the most well-known early work, van Heuvelen (1991) suggests that in order to learn to think like physicists, students should be taught a problem-solving strategy that involves the use of multiple representations, similar to the way physicists approach problems. Meltzer (2005) has also looked at the function and interrelation of representations with respect to mechanics problems (graphs, dia-

grams and mathematics). Kohl & Finkelstein (2006a) show how what they term a “reform-style” lecture course (i.e. a course using a more interactive style) leads to a richer use of representations, suggesting that this may well have a profound effect on student learning. An overview of work with multiple representations can be found in Rosengrant, Etkina, & van Heuvelen (2007). There has also been some work done on representation, metaphor, and analogy in the learning of physics (see for example, Brookes & Etkina, 2007; Podolefsky & Finkelstein, 2006, 2007a, 2007b).

Lemke (1998)—a physicist who has turned to social semiotics—claims that scientists handle problems that would otherwise be impossible to solve by orchestrating movement between a wide range of representations:

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.

Lemke (1998:7)

This idea is central to the analytical framework presented in this thesis.

2.2.5. Summary of learning and science

This section has given a brief overview of the theoretical development of PER, in order to show how research interests have progressed, and the way in which the research questions of this thesis may be positioned in the literature.

2.3. Learning and language

2.3.1. Introduction

This section of the literature review deals with research into learning in a second language as it relates to this thesis. The immediate focus on a second language should not be seen as implying that the relationship between learning and our first language (L1) is unproblematic—far from it. In fact, it could be argued that language related problems in disciplinary learning may be *more* acute in L1—simply because this language is taken for granted and thus learners seldom reflect on the meaning of words or phrases. However,

the relationship between L1 and learning will be examined within the context of a wider discussion of secondary discourses and literacy in section 2.4.

2.3.2. Background to teaching and learning in a second language

Teaching a selection of academic 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. Another aspect of bilingual education can be found 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 in 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* that is taught through the medium of a second language have therefore often been treated as being of secondary importance.

2.3.3. The Swedish debate

Swedish higher education institutions are currently preparing for a major influx of exchange students. The reason for this is the recently signed Bologna declaration on harmonization of European education, which promises freedom of movement for students from the 46 countries now involved in the process by 2010 (Bologna Process, 2007). In many cases, one aspect of this preparation has involved adopting English as the default teaching language in a wide selection of courses. In this respect, the Nordic countries already feature strongly in Europe, with recent surveys of European programmes taught through the medium of English showing only the Netherlands offering more student places on this type of course (Maiworm & Wächter, 2002; Wächter & Maiworm, 2008). At postgraduate level, for example, approximately half of the masters courses offered by Swedish higher education institutions in autumn 2007 were expected to be taught in English (Swedish National Agency for Higher Education, 2007). Even at undergraduate level many courses in Sweden are now taught exclusively in English. This is particularly true in the natural sciences, engineering and medicine, where the

majority of course literature has long been published in English, and where English is playing an increasingly dominant role as the de facto language of science (see Ammon, 2001; Falk, 2001a; Gunnarsson & Öhman, 1997). These developments recently prompted one Swedish university vice-chancellor to predict that all their programmes would be delivered in English within 10-15 years (Flodström, 2006).

Some of the reasons for the already high usage of 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. As already argued, the 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.

Ministry of Education and Research (2001:15) (*translation JA*)

It would, however, be incorrect to think that the movement towards what Falk (2001a) calls the anglicizing of Swedish universities is occurring without criticism. For example, Gunnarsson (1999) argues 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' language¹.

Further in-depth criticism of the dominance of English came in the report of the Parliamentary Committee for the Swedish Language, *Mål i mun* (Ministry of Education and Research, 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* that would be experienced by many students when required to learn subject matter through a language other than their first language.

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

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.

their education through the medium of English and how such teaching can be successfully achieved.

Ministry of Education and Research (2002:97) (*translation JA*)

Similarly, 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*)

This ‘gut feeling’ experienced by Carlson and her colleagues has led to a radical restructuring of some of the courses at Uppsala University. In a project named DiaNa (Dialogue for Natural Scientists), the academic departments of chemistry, biology and earth science now put a greater 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 being grounded in research run the risk of leading to outcomes other than those originally intended.

Similar ideas to those expressed by Carlson were discussed at a symposium on language policy in higher education held at Södertörn University, Sweden in 2006. The symposium brought together representatives from the Swedish National Agency for Higher Education, the Swedish Language Council, the Swedish Academy, the Swedish Student Union, the Swedish Research Council and the Parliamentary Working Group that drafted the 2002 report on language *Mål i mun* (Ministry of Education and Research, 2002) and its 2005 follow-up report. At this symposium, concern was expressed about issues of diglossia and domain losses to English, with the ‘fear’ being that certain subject areas in society might become impossible to discuss in Swedish. There was also general agreement that *both* English and Swedish are needed in Swedish higher education, with the term *parallel language use* being adopted to describe the desired situation (see Josephson, 2005). However, questions about what the term parallel language use actually means and how it might be implemented remained largely unanswered.

Airey & Linder (2008) suggest that the term parallel language use appears to focus primarily on the educational system itself, i.e., the language *used* when educating students rather than the language *competencies* that graduates should attain with respect to their subject of study. They have therefore suggested operationalizing the parallel language requirement, insisting that

“[...] each degree course should be analyzed in terms of the *desired combination of language-specific disciplinary skills that we would like to be attained within that course.*”(Airey & Linder, 2008:150).

2.3.4. Research into teaching and learning in a second language

So what does research have to tell us about teaching and learning in a second language? As pointed out in *Mål i Mun* (Ministry of Education and Research, 2002), research into the effects of teaching through the medium of English at Swedish universities is extremely limited. However, teaching in a second language is better-documented in the Swedish compulsory school system. This is a pattern that is repeated 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) (see CLIL Consortium, 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), culminating in a recent comparative, ethnographic/linguistic study of two high school classes (Falk, 2008). Traditionally, research in CLIL has been limited to the pre-university level, however, recently there has been a move towards using the term at tertiary level (e.g. Dafouz Milne & Llinares García, 2008; Dalton-Puffer, 2007; Núñez Perucha & Dafouz Milne, 2007; Smit, 2007; Wilkinson & Zegers, 2007). The Swedish term for CLIL studies is *språk-och innehållsintegrerad inläring och undervisning* (SPRINT). The main interest of the SPRINT programmes is improving students’ 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 schooling³.

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 significantly 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 have to ‘cover’ less material. The reasons these teachers are still positive towards 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 the possibilities for learning disciplinary concepts.

Further, it appears that English-medium education may affect 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 differences in the number of errors with prepositions, vocabulary, idiom and style. Falk’s (2008) longitudinal study brings more clarity to the situation. Falk finds that there is very little interaction when the language of instruction is English, and the interaction that does occur is often in Swedish. Moreover she contends that Swedish disciplinary language is poorer when students have been taught in English. Working at university level, Söderlundh (2008) is also interested in the effect of the use of English as a language of instruction on the Swedish language, she also finds that despite university courses being nominally taught in English, there is a large amount of Swedish interaction to be found.

In the same way that Swedish is subject to change as a result of students being taught in English, English is also changing as a direct result of the fact that non-native speakers of English now account for the vast majority of English communication (Graddol, 2006). Internationally, there is a growing

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

interest in what is termed *English as a Lingua Franca* (ELF). This new research area examines the way in which English changes from the narrow prescriptive norms supported by native speakers, to a more universally intelligible form (Ammon, 2000; Firth, 1996.; Jenkins, 2007; Mauranen & Ranta, 2008; Seidlhofer, 2004; Shaw, 2008; Smit, 2007). Working at a Swedish technical university, Björkman (2008a, 2008b) has collected a corpus of 70 hours of high-stakes speech events (lectures, and group work). Her analysis of non-native English usage finds little breakdown in communication, this suggests that changes take the form of added clarity or reduced redundancy. Interestingly, this is similar to the strategy employed when creating ‘artificial’ codes such as the *standard marine communication phrases* (International Maritime Organization, 2001).

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) challenge these results, claiming that limitations in L2 may inhibit students’ 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 earlier bilingual studies has been on *achievement in languages* with “*a remarkable 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 unproblematically 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 grades 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. In this respect, it has been claimed that disciplinary language is much more than a representation of disciplinary knowledge, it is actively engaged in bringing such knowledge into being (Halliday & Martin,

1993). From this point on, the remainder of this review will therefore 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 (e.g. Brandt & Schwach, 2005; Carroll-Boegh, 2005; Falk, 2001a; Gunnarsson & Öhman, 1997; Hellekjaer & Westergaard, 2002; Höglin, 2002; Melander, 2005; Teleman, 1992; Tella, Räsänen, & Vähäpassi, 1999; Wilson, 2002). Surprisingly, there has been very little research into the relationship between *disciplinary learning* and the *teaching language* at university level. In Sweden no studies have been carried out into the effects on disciplinary learning of attending lectures in a foreign language. Two studies have, however, examined the understanding of written text, both concluding that the ability to judge broad relevance is greatly reduced when text is in English (Karlgrén & Hansen, 2003; Söderlundh, 2004). However, the results of these two studies should be seen in the light the recent work of Shaw & McMillion (2008), who compared the English disciplinary reading comprehension of Swedish and British university students, concluding that, given sufficient time, Swedish students had similar levels of reading comprehension to their British counterparts.

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 (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; 2007) 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.

2.3.5. The need for research into learning in a second language

The studies reported in the previous section 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 about what the specific negative effects of such lecturing may be, 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; 2007) which forms part of the work reported on in this thesis.

2.3.6. Summary of learning and 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 only 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) may well be associated with *negative effects* on subject knowledge, and this has been borne out in the few studies that have been carried out at high-school level and above. The reasons for these negative effects may be related

to the demands placed on language due to increasing levels of abstract knowledge at higher levels of education. At the same time, however, there is some evidence that students may be able to *adapt over time* to being taught in a second language. Whether this is the case—and if so, the mechanisms by which such adaptation may occur—is one of the main interests of the work carried out for this thesis.

2.4. Learning and literacy

2.4.1. Disciplinary learning and a student's first language

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 science. Lemke (1990) points out that learning science critically depends on the ability to understand the disciplinary language in which the knowledge is construed. However, Östman (1998) reminds us that this type of language is abstract and represents special communicative traditions and assumptions. Säljö (2000) takes this further, arguing 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. However the problem appears to be even more complex than this. Geisler (1994:xi-xii) observes that disciplinary language can “[...] 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”. Thus it has long been known that students often do not appropriately understand the disciplinary language that they meet in lectures and then later use themselves (Bourdieu, Passeron, & De Saint Martin, 1965/1994). In this respect, Englund (1998) suggests analyzing the causes of problems in student understanding with a view to changing institutionalized communicative patterns, thus making the discourse of disciplines more accessible. However, the other side of the coin is expressed by Wickman & Östman (2002) who insist that learning itself is a form of *discourse change*.

2.4.2. Learning and disciplinary discourse

Every discipline has been built up and sustained by many thousands of individuals, each playing their own roles in creating the shared ways of knowing that make up the discipline. By shared ways of knowing is meant the coherent system of concepts, ideas, theories, etc. that have been created to account for observed and theoretical phenomena. What allows these individuals to share and refine their disciplinary ways of knowing is the system of semiotic resources they develop to represent this disciplinary knowledge. In the early

seventies, cultural critics such as 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 whole 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. This discourse approach to learning has been adopted by a number of researchers in the literature (Florence & Yore, 2004; Lemke, 1990, 1995, 1998; Northedge, 2002, 2003; Roth, McGinn, & Bowen, 1996; Swales, 1990; Säljö, 1999; Wickman & Östman, 2002). It has been shown, however that many dimensions of disciplinary ways of knowing are often taken for granted by university lecturers in their teaching (Middendorf & Pace, 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”.

2.4.3. Discourse and the concept of literacy

Gee (1991:7) sees language as divided into one primary and many secondary discourses. Primary discourse is the oral language learned as a child, “It is the birthright of every human and comes through primary socialization within the family [...]”. Secondary discourses, on the other hand, are specialized for use in other specific sites in society outside the home. Secondary discourses are mastered by building on and extending primary discourse. Gee goes on to define *literacy*, as the control of these secondary discourses. Thus there are as many applications of the word literacy as there are secon-

dary discourses or, put differently, there are as many types of literacy as there are specific sites in society. It also follows that secondary discourses will have varying degrees of separation from a person's primary discourse. For example, the language a person uses to write to childhood friends may be quite similar to that person's primary discourse, whereas, the type of language control necessary to write a scientific paper is probably very far removed from the oral language the person grew up with.

2.4.4. Scientific literacy

The term scientific literacy (or science literacy) was first coined by Hurd (1958). Although seemingly unproblematic, there has been little agreement in research circles as to the precise meaning of the term (see Laugksch, 2000). Note, that from Gee's (1991) definition of literacy, *scientific literacy* now becomes the ability to use the specialized language of science in a particular site in society. The way in which the term scientific literacy is used in this thesis with respect to this site in society will be explained in section 4.4.1.

2.4.5. Much more than just language—multi-modal discourse

Tsui (2004:167) 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”. However, this definition does not specifically challenge the traditional view that disciplinary discourse is synonymous with the specialized *language* used within a discipline. Here, Hall (1997:6) is much more explicit, viewing discourse 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”.

Although Gee's discussion of secondary discourses only refers specifically to the *control of language*, his view of discourse is not limited to language alone. Following Fairclough (1995), the New London Group (2000:20)—of which Gee is a member—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 subtle change in emphasis is a direct result of the work of another member of the New London Group, Gunther 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 semiotic resources or *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, Jewitt, Ogborn, & Tsatsarelis, 2001:1)

This multi-modal approach to disciplinary learning is further developed in chapters four and six of this thesis.

2.4.6. The multimedia effect

Before moving on, it is necessary to briefly discuss the differences between the multi-modal approach taken in this thesis and closely related work in multimedia teaching and learning. A comprehensive overview of work in this area can be found in Ainsworth (2006).

As Reimann (2003) points out, two important ideas in multimedia teaching and learning are dual-processing theory (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 describes 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 multimedia research was presented in a recent special issue of *Learning and Instruction* (volume 13, 2003). In contrast to the multi-modal approach of Kress et al. (2001) a common factor in the research programmes 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.

This thesis focuses on the way in which the modes of disciplinary discourse can be seen as offering different affordances, i.e., different possibili-

ties for representing disciplinary ways of knowing. It is this ability to more fully represent disciplinary ways of knowing through certain combinations of modes that is pertinent for the work of this thesis, rather than the learner's limited ability to simultaneously process input from a collection of modes.

2.4.7. Modes or semiotic resources?

The original use of the word *mode* signals a connection to the human senses. Thus, in the most basic sense, there are five possible modes through which something can be perceived: sight, sound, smell, touch and taste. However, since written language has such a privileged position in the representation of knowledge, there has been a tendency by some linguists to treat writing as a separate mode in itself (e.g. Gee, 2003; Kress et al., 2001). In order to avoid potential confusion between the broader interpretation used by some linguists and the fundamental interpretation favoured by cognitive psychologists, the term *semiotic resources* will be substituted for *modes* in this thesis. Breaking the link to the senses in this way facilitates the recognition of the differences between such diverse resources as: written accounts, diagrams, equations, pictures and gesture, which would all be part of the same visual mode in a strict interpretation of the term. Note, however, that in the interests of brevity, the term multi-modal will be retained and used in this thesis to refer to an approach with multiple semiotic resources. The introduction of the term semiotic resources necessitates a brief overview of the field of semiotics.

Semiotics is the study of signs, where a sign is at one and the same time both an object, and an idea (semioticians use the terms *signifier* and *signified*). The study of modern semiotics is built on the work of Saussure, which was published by two of his students after his death in 1913 (Saussure, Bally, Harris, Sechehaye, & Riedlinger, 1986). Saussure suggested that the relationship between the signifier and the signified was largely arbitrary and governed by agreed conventions. Thus, for Saussure, affection might just as easily have been communicated by a bag of stones as a single red rose—society simply chooses the signifier at random. This view was rejected by Peirce (1955) who insisted that there was always an *intention to model reality* in sign production. Peirce divided signs into three categories; *iconic*, *indexical* and *symbolic*. Iconic signs resemble the things they signify—a good example of this is the Swedish road sign that warns us to look out for a moose on the road. Indexical signs are related to the signified, both in time and place; the simplest version of this is simply pointing at something. Peirce's final category, symbolic, closely matches Saussure's description of signs, and is related to the signified by convention. However, here Peirce referred to the historical nature of such symbols, suggesting that at some time in the past there had always been an attempt to model the signified in some way—even though this may be unrecognizable today. This historical

aspect of sign making has been discussed by Säljö (2005). In this respect the study of semiotics has been likened to detective work:

[...] detective stories are semiotic investigations in disguise [...] In 2003 Dan Brown's *The Da Vinci Code* became a runaway international best seller and pop culture phenomenon in large part because it was based on semiotic method, certainly not on historical fact. [...] a large part of the allure of that novel comes, arguably, from the hero's ability to interpret the signs of the mystery in the same tradition of other fictional detective "symbologists," from Auguste Dupan to Sherlock Holmes and Poirot. "Symbology is Dan Brown's rendering of "semiotics".

Danesi (2008:16)

In this thesis, this 'detective work' is encapsulated in a description of the way in which a number of semiotic resources may function together in order to make possible the learning of a disciplinary idea or concept.

Van Leeuwen (2005:1) explains the preference for the term semiotic resource instead of the more traditional 'sign' by suggesting that "[...] it avoids the impression that what a sign stands for is somehow pre-given, and not affected by its use". This is because, following Halliday (1978), the disciplinary order of discourse is seen as a flexible *resource* for meaning making, rather than a set of prescriptive rules, where meaning is fixed, definite and unproblematic.

2.4.8. Summary of learning and literacy

Literacy has been defined in this section in terms of Gee's (1991) control of secondary discourses. By association, scientific literacy then becomes the ability to use the discourse of science in a particular site in society. This site in society will be further discussed in section 4.4.1.

As regards learning, several researchers have suggested that it may be framed in discourse terms; however, many of these researchers have seen discourse as being synonymous with *language*. For this thesis it was important to include other semiotic resources such as diagrams, graphs and equations. In this respect, a number of researchers do include extra linguistic 'stuff' in their analyses of discourse, however the multi-modal approach adopted by Kress et al. (2001) provides the most complete description of the data collected from university physics lectures and will, therefore, be drawn on in the development of this thesis. In the interests of interdisciplinary clarity, the term 'semiotic resources' will be preferred to the term 'modes' used by Kress et al.

2.5. Summary of the literature review

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

A brief overview of PER development was presented in order to show the way in which the research direction reached a point where the kind of research done in this thesis has a contemporary place in the literature.

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 ‘blind spot’ 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 disciplinary 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 teaching 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 idea of literacy was presented, together with discussion of multi-modal discourse. These ideas of literacy and multi-modality will be further developed in chapter 4.

3. Situating the methodology

3.1. Introduction

The previous chapter served to situate the thesis within the relevant research with respect to learning in science, bilingual education and the concepts of literacy and discourse. This chapter will now examine methodological issues related to the intended work, explaining the general approach that has been adopted and the knowledge claims of the thesis.

3.2. Case study research

3.2.1 What is case study research?

This thesis is an example of *case study research*. However, this is not as straightforward a position as it may first appear. Merriam (1998:26) for example, claims that “[...] while many have heard of case study research, there is little consensus on what constitutes a case study or how this type of research is done”. Thus it is therefore important to briefly map out the main ways in which case study has been characterized in the literature—in order to unpack the specific way this term is used for the purposes of this thesis.

Bassey (1999) summarizes case study in an educational setting as follows:

An educational case study is an empirical enquiry that is conducted:

- within a localized boundary of space and time (i.e., a singularity);
- into interesting aspects of an educational activity, or programme, or institution, or system;
- mainly in its natural context and within an ethic of respect for persons;
- in order to inform the judgments and decisions of practitioners or policymakers, or of theoreticians who are working to these ends;
- in such a way that sufficient data are collected for the researcher to be able to:
 1. explore significant features of the case;
 2. create plausible interpretations of what is found;

3. test for the trustworthiness of these interpretations;
4. construct a worthwhile argument or story;
5. relate the argument or story to any relevant research in the literature;
6. convey convincingly to an audience this argument or story; and
7. provide an audit trail by which other researchers may validate or challenge the findings, or construct alternative arguments.

Bassey (1999:58)

Such case studies can take many forms. Stake (2005:445) offers a useful division of case study research into two types: *intrinsic* and *instrumental*. In intrinsic case studies, understanding the object of study—the case itself—is the primary focus, whilst for instrumental case studies, the case is used as a means to provide insight into an issue or a problem—the case itself is of secondary focus. Stake also discusses a third type of case study, *multiple*. Multiple case studies are instrumental case studies where there is even less interest in a specific case—a number of cases are studied jointly in order to draw conclusions about a general condition. Borman, Clarke, Cotner, & Lee (2006:123) suggest that in comparison to single cases, such studies “[...] allow for greater opportunity to generalize across several representations [of the phenomenon of interest]”.

Yin (2006:112) claims that case study research is a useful approach when “[...]research addresses either a descriptive question (*what* happened?) or an explanatory question (*how or why* did something happen?)”—examination of the research questions of this thesis shows that they involve both descriptive and explanatory threads. Moreover, Yin (2006:112) also points out one of the major strengths of case study research—its ability to “illuminate a particular situation” using “direct observations” rather than “derived data” such as test results, statistics and questionnaires. As pointed out in the literature review (section 2.3.4.) earlier research into the effects of changing the language of teaching using derived data has often proved inconclusive and not very useful in informing teaching practices.⁴

The analytical approach used in case study research 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 either a rich description or a trustworthy explanation of the data (see for example Bogdan & Biklen, 1992:153).

⁴ In fact, the stimulated recall interviews used in this thesis could be argued to be a form of derived data, depending as they do on student *descriptions* of their experiences of a videoed lecture rather than direct analysis of the video footage by the researcher. See Säljö (1997).

3.2.2 Trustworthiness: a substitute for validity and reliability?

In natural science the concepts of validity and reliability are well established—they constitute the yardstick by which such quantitative research is judged. However, interpretive, qualitative work in the social sciences belongs to an altogether different paradigm. In an early attempt to bridge the gap between positivist-oriented natural science and interpretively-oriented social science, Lincoln & Guba (1985) suggested that in social science the terms *dependability* and *consistency* might be substituted for the well-established validity and reliability used in natural science. Their argument is summed up nicely by Borman et al. (2006):

“[...] rather than demanding that outsiders obtain similar results in replications of the study in question, the aim should be that outsiders concur that given the data collected, the results make sense—they are consistent and dependable.”

(Borman et al., 2006:130)

There was much debate about whether it was in fact appropriate to attempt to ‘map’ natural science concepts to social science in this way. On the one hand, writers such as Lincoln & Guba argued that the relatively young social sciences have much to learn from the gradual development that natural science has undergone over the years. They advocated the adoption of concepts in social sciences that are *parallel* to those of natural science:

These criteria for judging adequacy [...] are called *parallel* [...] because they are intended to parallel the rigor criteria that have been used within the conventional paradigm for many years.

(Guba & Lincoln, 1989:233)

Thus, each measure of quality in the natural sciences would have its social science equivalent. Others, however, argued that—belonging as it does to a completely different paradigm—social science must create its own ways of deciding what counts as a valuable knowledge claim (see discussion in Williams, 2000). Today, in interpretive, qualitative research, the emphasis is on *trustworthiness*, (Cohen, Manion, & Morrison, 2007), with the researcher being seen as the key research instrument:

In qualitative study the investigator is the primary instrument for gathering and analysing data [...] the investigator as human instrument is limited by being human—that is, mistakes are made, opportunities are missed, personal biases interfere. Human instruments are as fallible as any other research instrument.

(Merriam, 1998:20)

This reliance on the ‘skill’ of the individual researcher is discussed by Corbin & Strauss (2008) in relation to the method of analysis used in the social sciences:

Qualitative analysis is many things, but it is not a process that can be rigidly codified. What it requires, above all, is an intuitive sense of what is going on in the data; trust in the self and the research process; and the ability to remain creative, flexible, and true to the data all at the same time. Qualitative analysis is something that researchers have to feel their way through, something that can only be learned by doing.

(Corbin & Strauss, 2008:16)

To summarize then, trustworthiness in interpretive, qualitative research hinges on the relationship between the researcher, the data and the research questions. Judgements about the extent to which a given study is trustworthy can only be made independently by the individual readers of the study.

3.2.3 Generalization from case study research

There has been a great deal of discussion about generalization and qualitative research. In broad terms Williams (2000:100) argues that there are three main types of possible research generalization:

1. Total generalizations, where situation S1 is identical to S in every detail. Thus S1 is not a copy of S but an instance of a general deterministic law that governs S also.
2. Statistical generalizations, where the probability of situation S occurring more widely can be estimated from instances of S.
3. *Moderatum* generalizations, where aspects of S can be seen to be instances of a broader recognizable set of features.

The first of these are almost certainly impossible in the social sciences and in the natural sciences mostly restricted to a few fundamental laws of nature. The second [...] form the basis of aggregate description in the social sciences. Both [...] are neither possible or desirable outcomes of interpretive data, but [...] the third seems to be an attainable goal.

Williams (2000:100)

It is this final notion of ‘moderatum generalization’ which is adopted as the knowledge claim of this thesis.

A competing type of knowledge claim with respect to case studies is Stake & Trumbull’s (1982) ‘naturalistic generalization’. This is used in this thesis to describe the generalization that can be expected from single case study research. Drawing on Geertz (1973) Stake & Trumbull argue that a thick, situated description can resonate with the readers’ tacit knowledge, allowing them to make connections and associations for themselves. This has been interpreted by some as suggesting that researchers should avoid

generalizing from case studies, and rather *let the case speak for itself*. Bassey (2001:5) for example, explains that during the 1980s he “[...] argued that there were no empirical generalizations of use to teachers”. Thus he called for “[...] the proliferation of case studies of what teachers considered to be good practice”. However, after many years of educational case study work, Bassey now argues for an altogether different perspective on the term generalization. “In place of the scientific generalization, which states what is, I have introduced the idea of fuzzy generalization, which states what may be” (Bassey, 2003:119). Using this argument, Bassey has claimed that it *is* possible for a researcher to generalize, even from single cases—albeit only in fuzzy terms (Bassey, 2001). He argues for employing a “best estimate of trustworthiness” (BET) approach, which he defines as “[...] a professional judgement, based on experience, in the absence of [definitive] research data.” (Bassey, 2003:119). The possible approaches to generalization in case study research are illustrated in Figure 3.1.

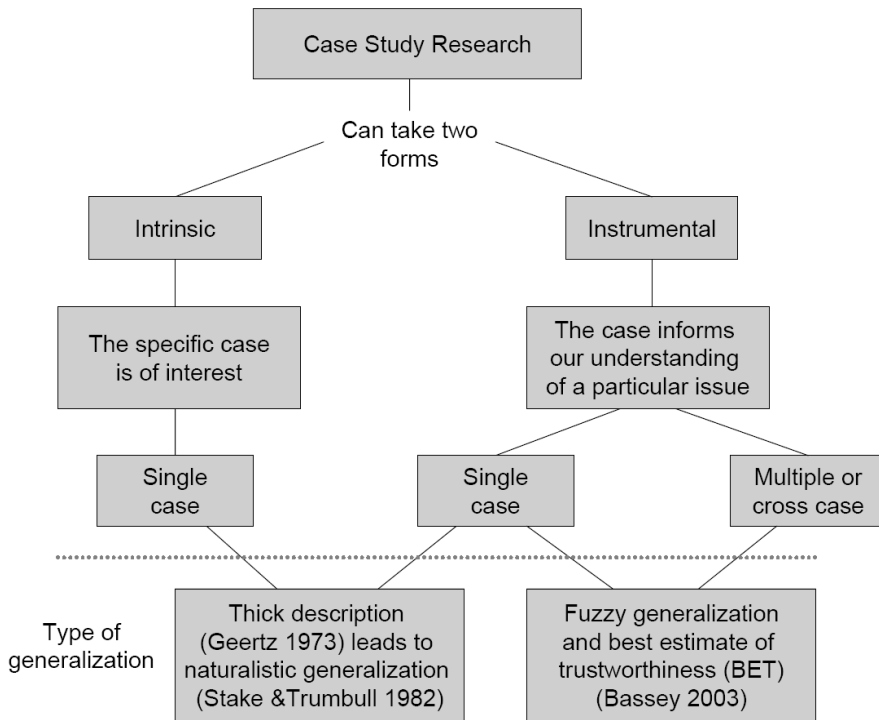


Figure 3.1. Diagram of the possible types of case study research and their related generalizations, following Bassey (2003).

Drawing on Bassey's constructs, this thesis, therefore, follows the right-hand side of Figure 3.1. i.e., it is an example of instrumental, multiple, case study research creating fuzzy or moderatum generalizations about what may be rather than what is.⁵

3.3 Summary

This chapter has given an overview of the different ways in which case study research has been treated in the literature. A discussion of what counts as a knowledge claim in this type of research was also presented, along with a discussion of the types of generalization that can be made from case study work. Having made clear the knowledge claims of this thesis, the next chapter deals with the particular methods used to address the research questions.

⁵ It could be argued that fuzzy generalization and BET are, in fact, unnecessary constructs for the social sciences. Clearly, many researchers have made generalizations from case study work prior to the introduction of Bassey's terms. The reason for adopting Bassey's constructs here is purely a matter of making the knowledge claims of this thesis more explicit, and should not be interpreted as a statement about case study generalization *per se*. Thus the reader will note that the watertight division between fuzzy and naturalistic generalization as presented in Figure 3.1. is contested. However, this distinction (or lack of it) is unimportant for the development of the knowledge claims of this thesis.

4. Research design and analytical methods

This chapter describes the way in which decisions about the analytical methods of investigation were taken with respect to the particular research questions and how these were further developed during the work carried out for this thesis. Definitions of the constructs of bilingual scientific literacy and disciplinary discourse are also presented along with the respective analytical frameworks for their use in this thesis.

4.1. Research design

4.1.1. The initial research problem: studying experience

At the outset of this PhD it was decided to study the *experience of attending physics lectures* in relation to the language of instruction. There were two reasons for the choice of lectures: First, this form of teaching 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. Lectures are also particularly interesting since there has been a great deal of criticism of this characteristically academic university tradition (Bligh, 1998; Bourdieu et al., 1965/1994; Ramsden, 1992, 2003). The second reason for choosing to study lectures was much more pragmatic—a lecture is generally both accessible and analytically documentable.

4.1.2. Quantitative vs. qualitative

One of the fundamental assumptions of this thesis is that the language of instruction used in a lecture may have a bearing on the learning of a science such as physics. From here the challenge is to frame a study so that it produces results that are useful, meaningful and of recognizably high quality. As explained at the beginning of this thesis in the preface to the licentiate, 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 stud-

ies which could perhaps be adapted to suit the emerging research questions of this thesis. Thus, the original idea was to carry out a quantitative study with a research group and a control group. However at this stage two important issues came to the fore, related to *project design* and *relevance*.

4.1.3. 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 stay constant in a controlled study and how would that be achieved? As pointed out in the literature review, the earlier attempts to find statistically significant 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 challenged (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. For example, although Klaassen (2001) working in the Netherlands with engineering students who were lectured in English did report an initial negative effect on engineering learning, she concluded that by far the most important factor in such learning was not the language of instruction, but rather the pedagogical approach of the teacher. However, such studies failed to dampen the feeling amongst experienced practitioners that the language of instruction *must* play an important role in learning. It seemed logical that if there was a ‘language effect’ this effect would be difficult to isolate from other much stronger effects related to the teacher’s approach, and student-linked effects such as, prior knowledge, epistemology, academic self-concept, gender, social and educational background, etc. 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. Suppose, for the sake of argument, that a quantitative study *could* be carried out and that such a study produced conclusive results—say, for example, that students scored 10% lower on identical physics assessments when taught in English rather than in Swedish. How exactly would physics lecturers be able to use this information? Perhaps there might be some shift towards teaching fewer physics courses in English, but a lot of physics content would need to continue to be taught in English for all the reasons discussed in the literature review (Airey 2003).

Since physics will continue to be taught in English, a ‘Which language is better?’ approach is arguably rather irrelevant. What would be useful, however, are investigations of the ways in which *student learning* differs 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 point of view is well summarized 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.

McDermott and Redish (1999:757)

Thus, instead of attempting to equate learning with assessment, it was decided to examine students' *experiences of learning*.⁶ At this point research question 1 was formulated, which deals with student experiences of lectures in different languages. This 'experience' includes capturing both the differences across learning experiences and the situatedness of the individual learning experience.

The project design thus required the identification of parallel physics courses, one taught in English and the other taught in Swedish, which had a number of students in common. These students could then be interviewed about their experiences of learning on the two courses.

4.2. Interviews and stimulated recall

4.2.1. Stimulated recall

Having decided on a qualitative study that examines student experiences of learning, the next question was how to operationalize the planned work. For the data collection to be meaningful, the students would need to be able to describe their thinking during lectures. The student interview would thus be an extremely important source of data for this task. Following Klaassen's (2001) recommendations, it was decided that an appropriate approach would be to use *stimulated recall*. This technique uses video footage for the recreation of the central elements 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;

⁶ 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.

Haglund, 2003). There are a number of approaches to the use of stimulated recall, and since at the planning 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.

4.2.2. Creating interview protocols

At the beginning of each of the three case studies, the lecturers of the courses were interviewed in order to: gain an overview of the course as a whole, decide which particular lecture it would be appropriate to video, and to obtain some idea of the structure, form and content of the various types of activity of the chosen lecture. An example of the protocol used to interview the lecturers in the three case studies 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 similar physics content in both languages and for both lectures. The student interview protocols for each of the three case studies can be found in Appendices B, D and F respectively.

4.2.3. Data collection

A total of six physics lectures with different lecturers were videotaped. Each student in the individual case studies 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, the field notes taken during the lecture and an interest in sampling as many of the types of activity as possible, the resulting video footage was edited down to four to five segments for each lecture. These segments always included a part of the teaching sequence where the lecturer presented a diagram and where a mathematical representation was discussed. The total running time of these segments was between seven and ten minutes for each lecture. 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.

All told, twenty-two volunteer students were interviewed using a semi-structured interview protocol. These interviews were open-ended and each 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 contin-

ued 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. Finally, the 2x4 edited segments of video footage were then used to create the stimulated recall environment. The way in which this was achieved can be seen in the interview protocols for the three studies (appendices B, D and F), and the student interview transcripts (appendices C, E and G).

4.3. Analysis of interview data

4.3.1. Digital sound files vs. transcription

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 for research question 1: The digital interview files were ‘cut’ into sections where students discussed similar themes in relation to learning in English and in Swedish. In order to help efficiently build up an overall picture of what students were saying both as individuals and as a group, 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. It was then easy to either listen to all the excerpts dealing with a given topic, or to select excerpts from a given student.

This method was adopted, in part, to address the argument that the audio recording is a step further away from the interview itself, which is in turn several steps away from the actual learning experience in the lecture (c.f. Kvale, 1996; Säljö, 1997). At the same time it is argued that this approach had the benefit of better capturing the situatedness of the interview when working with the transcriptions. Maintaining this situatedness was considered important since the interviews 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 be easily 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 which is similar to the way of working described here is given by Pea (2006).

For the later research questions the digital data analysis described above turned out to be inadequate. Rough transcriptions of the student interviews were therefore made using the transcription software *Transana*. These tran-

scriptions were used to select material for further study. Checked and corrected examples of these transcriptions can be seen for each of the three case studies in Appendices C, E and G respectively.

4.4. Scientific literacy: an emerging analytical framework

Two research questions for this thesis (2 and 3) deal with the concept of scientific literacy. This section details the analytical framework used when addressing these questions.

4.4.1. Scientific literacy: the goal of university science

Why do students spend three or four years learning undergraduate science? One answer to this question—the one subscribed to by the author of this thesis—is in order to produce *scientifically literate graduates*. Naturally, for this statement to make any sense, a definition of what is meant by scientific literacy is required. Unfortunately, since its introduction by Hurd (1958), there has been little useful agreement as to the precise meaning of the term scientific literacy, particularly for higher education teaching-learning environments (see the overview in Laugksch, 2000). So, for the purposes of this thesis the term will need to be defined.

Earlier, in the literature review (section 2.4.4.) Gee's (1991) concept of secondary discourse was drawn on to suggest that scientific literacy may be interpreted as the control of the language of science in a particular site in society. There are three further observations that can be made here. First, it is necessary to point out that scientific literacy is about much more than acquiring a control of *language*—there are in fact a large number of semiotic resources that come together to make up the secondary discourse of university science. In this thesis, these disciplinary semiotic resources are divided into three categories; representations, tools and activities (see also Airey & Linder, 2009). It is suggested in section 4.5. that for natural science the *representations* category includes; oral and written language, mathematics, tables, graphs and diagrams. The *tools* category refers to any physical objects used within science, whilst *activities* refers to the methods and praxis of the discipline. Thus, it is claimed here that students need to learn to control a particular constellation of these semiotic resources in order to be classed as scientifically literate. This then leads to the second observation—that there are in fact two types of control necessary for each semiotic resource: interpretive control and generative control. Interpretive control is the ability to appropriately *apprehend* the ideas that are represented, i.e., to be able to 'read' the semiotic resource. Generative control goes one step further and

refers to the ability to appropriately *use* the semiotic resource to make meaning for oneself. Clearly, scientific literacy involves both types of control. The final observation returns to the question of the particular site in society to which scientific literacy refers. Generally scientific literacy has been taken to refer to an everyday use of science. In this respect, Miller (2007) suggests that the strongest predictor of adult scientific literacy is the number of college science courses taken. It is suggested that such correlations are self-serving and not particularly useful, since they do not provide any information on what within a college science course might influence the development of scientific literacy. Moreover, it is unclear whether students who take more science courses are simply more scientifically literate (selection effect).

Others—including the author of this thesis—have argued for a broader interpretation of the term scientific literacy. Here, scientific literacy is also connected with the ability to *do* science (for example, Linder et al., 2007). In this respect, Roberts (2007) has moved the debate forward by introducing the notion of two *visions* of scientific literacy: Vision I—learning to work within science itself, and Vision II—learning to apply science in relation to everyday situations. Roberts suggests that when people refer to scientific literacy they are in fact referring to some specific combination of Vision I and Vision II. Thus, it is argued that the type of scientific literacy fostered by any given undergraduate science course will place itself somewhere on a continuum between these two complementary visions. Following this division, scientific literacy is defined for the purposes of this thesis as both the ability to work *within science* and the ability to apply science to *everyday life*. This modelling is illustrated in Figure 4.1.

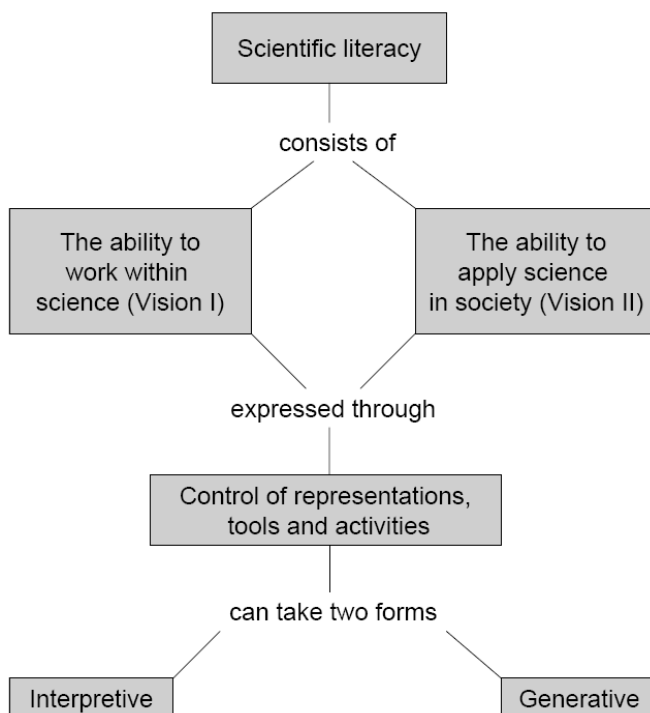


Figure 4.1. *Modelling scientific literacy within a natural science degree (adapted from Airey & Linder, 2008).*

It is suggested that Figure 4.1 is a simple tool that can be used for the analysis of the various components of scientific literacy present in a given university course.

4.4.2. Bilingual scientific literacy

If it is accepted that the goal of natural science degree courses is the production of scientifically literate graduates, in line with the definition in the previous section, then what is the nature of this scientific literacy with respect to the dual-language approach to teaching university science that is the focus of this thesis? At this point a new term is introduced, *bilingual scientific literacy*, which is simply defined as *scientific literacy in two languages*. This notion is used to characterize the particular collection of language-specific science skills fostered within a given degree course with respect to Roberts' two visions. This relationship is mapped out in Figure 4.2.

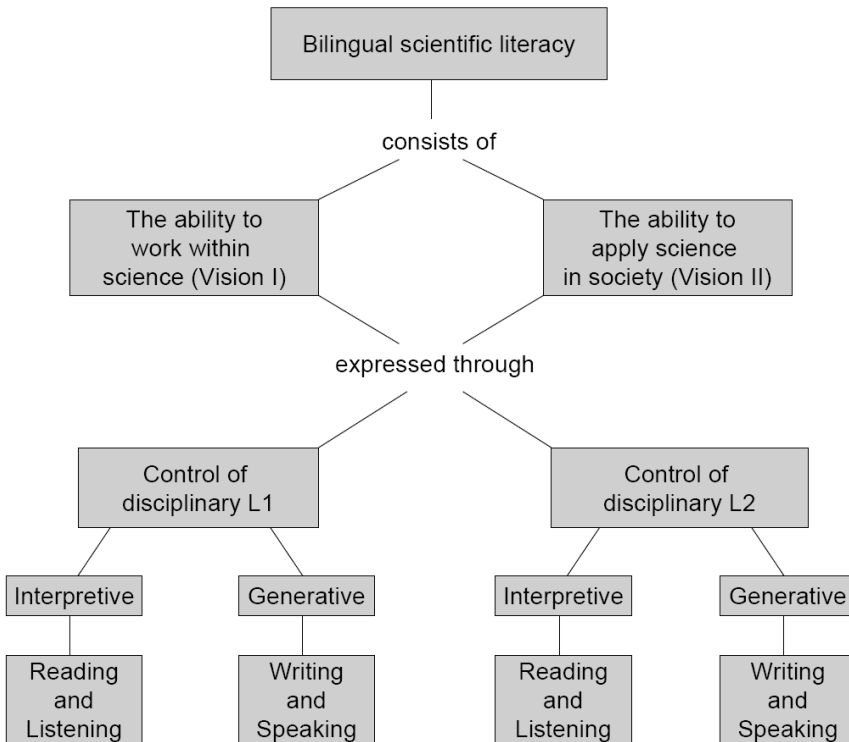


Figure 4.2. *Modelling bilingual scientific literacy within a natural science degree (adapted from Airey & Linder, 2008).*

Thus, it is suggested that it is important that any science degree course syllabus clearly identify the particular blend of bilingual scientific literacy that is intended in terms of a combination of three factors: the vision (I and II), the disciplinary language (L1 and L2), and the form of literacy (interpretive and generative).

4.4.3. Implied bilingual scientific literacy

It is argued that it is uncommon for course syllabuses to specify educational outcomes for all the components of scientific literacy and bilingual scientific literacy as illustrated in Figures 4.1. and 4.2. in an explicit manner. Thus, it becomes interesting to examine the *implied* goals, with respect to these suggested components of scientific literacy, that form part of the ‘hidden curriculum’ of natural science degree courses. At this point the second research question was formulated (see section 1.4.). In order to address this second research question, a sample of 30 syllabuses from undergraduate courses in physics offered during spring term 2008 at one of Sweden’s foremost universities in science and engineering were audited (Airey & Linder, 2008).

For each syllabus the course content was analyzed in terms of the practice (and hence it is argued the implied control) in the representations, tools and activities of science. Following the initial analysis, informal discussions were held with lecturers to ascertain typical types of course activities and the languages used in these. This information was then used to build up a picture of the types of student competencies that the course activities implied. The results of this work can be found in section 6.3.

4.4.4. Towards assessing levels of spoken bilingual scientific literacy

After auditing the 30 syllabuses in terms of implied bilingual scientific literacy, the next step was to use the descriptions provided by students in the three case studies presented in chapter 5, to attempt to assess their actual levels of spoken bilingual scientific literacy.

The main question that presents itself when contemplating the assessment of spoken bilingual scientific literacy is one of validity. What constitutes a legitimate measure of a student's ability to speak about science? In the field of linguistics there are a number of methods for assessing levels of speaking ability that can be used here. The majority of these linguistic measures assume a connection between speaking ability and speech rate—this is because higher speech rate is seen as an indicator that knowledge has become proceduralized (Anderson, 1982). The most basic method used in linguistic studies is *words per minute* (WPM)—this method has the benefit of being easily recognisable to most readers as a well-established measure of typing speed. However, Hincks (2005) points out that when comparing speech rate *between* languages it may be more appropriate to use *syllables per second* (SPS) rather than WPM. This is because average word length can vary significantly between languages. Another related method used in linguistics involves documenting pauses. Chambers (1997) discusses the types of pauses that exist in speech, dividing them into natural and unnatural pauses:

Natural pauses, allowing breathing space, usually occur at some clause junctures or after groups of words forming a semantic unit. Pauses appearing at places other than these are judged as hesitations, revealing either lexical or morphological uncertainty. These hesitations may be either simply a silent gap or marked by non-lexical fillers ("uh", "um"), sound stretches (or drawls on words) or lexical fillers with no semantic information (such as "you know", "I mean").

(Chambers, 1997:539)

It can thus be expected that the difference between first- and second-language speech will be in the frequency of unnatural pauses, indicating lexical gaps in the second language. However, a number of studies have

claimed that the most statistically significant measure of speaking ability is the amount of speech uttered *between* pauses (Kormos & Dénes, 2004; Towell, Hawkins, & Bazergui, 1996). Here, the average phrase length in syllables is calculated. In the literature, this value is termed mean length of runs (MLR). Incidentally, MLR is also better suited to interview situations like the ones described in this thesis since it eliminates the need to isolate and calculate the total speaking time for a given individual.

Hincks (2005; 2008) compared presentations on the same topic given by the same students in English and Swedish using the SPS and MLR measures. Her main finding is that when Swedish students speak English they pause more often, use shorter phrase lengths and speak on average 23% slower. However, Hincks advises caution when comparing speaking ability *between* students based on SPS and MLR, pointing out that there is a strong effect of individual speaking style which carries over from a student's first language to their second-language use. Students who speak slowly with frequent pauses in their first language show a similar pattern in their second-language speech. Thus, any attempt to compare scientific literacy between students using MLR or SPS methods will need to account for individual differences in speaking patterns in some way. In her survey of earlier linguistic studies, Hincks (2008:22) found that in the majority of studies the length of time used to designate a pause varies "between 200 and 300 milliseconds". The analysis presented in this thesis takes a different approach, using a qualitative rather than quantitative assessment of pauses. Hence, in this thesis, only those pauses that are experienced as such by a listener are recorded. Whilst this method obviously makes comparison with earlier work problematic, it is argued that it would provide a more accurate measure of scientific literacy—trading as it does reliability for validity. The method also goes some way to taking into account the problem of variation in student speech patterns noted by Hincks. Analysis of a short transcript using quantitative methods similar to those used by Hincks showed that this qualitative method appears to designate as pauses everything with a length over 400 milliseconds, with the minimum length that was noticed as a pause being at around 250 milliseconds.

Where two languages are involved, lexical gaps may also be filled by *code-switching* (i.e., inserting a word or phrase from another language). The benefits of code-switching in the learning environment have been widely documented. Researchers from a range of backgrounds acknowledge that the use of two languages concurrently offers better opportunities for representing and accessing knowledge (See, for example, Fakudze & Rollnick, 2008; Liebscher & Dailey-O'Caine, 2005; Moreno, Federmeier, & Kutas, 2002; Moschkovich, 2007; Üstünel & Seedhouse, 2005). However, for this thesis, the term *involuntary code-switching* is adopted to characterize a situation where code-switching occurs in a monolingual setting. In the interviews described earlier, students were instructed to use one language exclusively

for a given description. Any code-switching that occurred was thus deemed involuntary and indicative of a lexical gap in the language being spoken.

Finally, in order to be deemed scientifically literate, what is said needs to make sense from a disciplinary perspective—in this case it needs to be recognizable as physics. Similarly, speech must also be relevant to the task at hand—students' fluent meta-descriptions of their lack of understanding, although rating highly on the linguistic measures described above, may not provide much information about scientific literacy.

To summarize, then, it is suggested that it should be possible to triangulate bilingual scientific literacy by considering; fluency (in terms of SPS, MLR) involuntary code-switching and a judgement about the disciplinarity of what has been said.

4.4.5. Selection of texts for assessing bilingual scientific literacy

Assessing the bilingual scientific literacy of students was not an intentional focus during the interviews for case studies 1 and 2. However, for case study 3, a deliberate attempt was made to elicit student descriptions of the same disciplinary way of knowing in Swedish and English. This was done in order to answer research question 3. Student descriptions of their understanding of the Schrödinger equation were collected in both English and Swedish for this purpose. Unfortunately, the students in case study 3 had only recently met the Schrödinger equation, thus the descriptions collected in this way were almost exclusively meta-descriptions of a lack of understanding of the equation and were therefore unusable. This meant that descriptions of *exactly* the same content were not available for analysis for research question 3. As a fall-back position, student descriptions of closely related content in both languages were compared. Although this was clearly not as powerful methodologically, it did mean that material from all three case studies could be used on an equal footing. As such, the choice of texts for analysis was made pragmatically from a survey of the student descriptions of ways of knowing that were available in both languages for each case study.

4.4.6. Analyzing the texts

The raw transcripts were prepared for analysis in four stages. First, all speech by the interviewer was deleted and marked by a double return in the transcript. Next, all noticeable pauses—both filled and unfilled—were marked by entering a single return. This created a transcript of phrases of various lengths, each on a separate line. Then, all utterances in filled pauses—where the student uses sounds such as aah, um, er, etc.—were deleted. Finally, each word in the transcript was divided up into syllables. The SPS value was calculated by dividing the total number of syllables in the transcript by the total student speaking time (interviewer speaking time was

first subtracted from the total time). MLR was calculated by dividing the total number of syllables in the transcript by the number of text lines (excluding empty lines). Instances of code-switching were highlighted in bold and a subjective judgement about the disciplinaryity of the description was made, using the following criteria:

Grade	Label	Description
1.	Weak:	Student clearly has major problems when talking about disciplinary concepts in this language.
2.	Intermediate:	Student uses some disciplinary terms appropriately, but either has clear disciplinary lexical gaps or uses other terms inappropriately.
3.	Good:	Student uses disciplinary terms appropriately in the sequence, but does not develop ideas fully.
4.	Excellent:	Expert explanation.

An example of the way in which this data analysis was carried out can be found in Appendix H.

4.5. Disciplinary discourse: an analytical framework

4.5.1. Defining disciplinary discourse

Research questions four, five and six are answered using the concept of *disciplinary discourse*. It is this disciplinary discourse that students in the three case studies encounter in lectures and are expected to learn to control (see section 2.4.3.). The concept of disciplinary discourse was formulated during engagement with the interview data, and draws on a variety of published work, such as that of Lemke (1990; 1995; 1998), Kress, Jewitt, Ogborn & Tsatsarelis (2001), Duval (2002; 2006), and diSessa (2004). The development of this analytical framework represents one of the main theoretical contributions of this thesis. The complete analytical framework will be laid out here in this section of the thesis and later illustrated from the interview data in the results section (6.3.).

For the purposes of this thesis, disciplinary discourse is now defined as *the complex of representations, tools and activities of a discipline*.

4.5.2. Representations

By representations is meant those semiotic resources that have been designed specifically to convey the ways of knowing of a discipline. This stems from the notion that in university science such a system of semiotic resources is made up of far more than simply oral and written language. Other semiotic resources such as images (e.g. graphs and diagrams), mathematics and gesture also play a central role in this system (Ainsworth, 2006; Givry & Roth, 2006; Kress & van Leeuwen, 2001; Roth, Tobin, & Shaw, 1997; Roth & Welzel, 2001) and should therefore be included in the framework.

4.5.3. Tools

Every discipline has its own specialized physical tools or apparatus that its members draw on to create disciplinary ways of knowing, and, indeed, the scientific community excels in this regard. Thus, learning to use the physical 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 and apparatus. 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 student interaction with a physical tool can lead to more than a simple, situated understanding of how to do a piece of science—students may also gain access to some of the ways of knowing implicit in a given tool's development. An everyday example of this is a person using a claw hammer to knock in nails who discovers, through close examination of the hammer, the nail-extracting function of the claw end. One can imagine that historically, this part of the hammer developed out of a specific need in the working environment. Note here, that the discovery of the nail-extracting function could conceivably be made *before* the need to remove a nail arose. In such a situation, the tool itself would have taught the user something about the activity for which it was designed. Thus the tools of a discipline—though not explicitly designed to mediate scientific ways of knowing—must be included as a separate semiotic resource in any characterization of disciplinary discourse.

4.5.4. Activities

Similar to tools, the things that are done in the name of disciplinary activity need to be assimilated and learned by apprentices of the discipline. 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 are included as a further semiotic resource.

4.5.5. Disciplinary discourse and semiotic resources

The relationship between disciplinary ways of knowing and the system of semiotic resources that collectively make up disciplinary discourse can be seen in Figure 4.3.

In this framework, then, the semiotic resources that together constitute a disciplinary discourse include not only the words, symbols, gestures, diagrams, formulas, etc. used by a discipline; but also the artefacts, pieces of apparatus, measuring devices, etc. and the actions, practices and methods residing within the discipline. It may therefore be argued 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 science is *done*, and it is also the sole means available of sharing and evaluating this knowing.

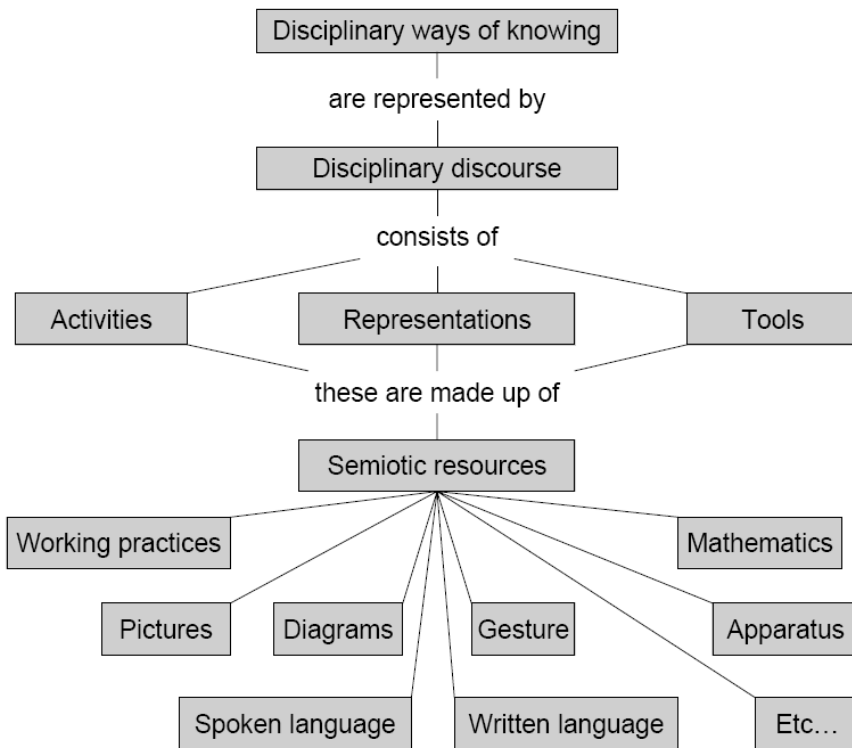


Figure 4.3. Diagram showing the relationship between disciplinary ways of knowing and the semiotic resources of disciplinary discourse.

4.5.6. Why not use ‘big D’ Discourse?

In a number of respects the notion of disciplinary discourse is similar to Gee’s (2005:20) ‘big D’ Discourse. 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 all the attributes of the learners themselves. Indeed, in contrast to the view presented here where disciplinary discourse is seen as facilitating access to 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) [...]”. For a good illustration of the Discourse approach the reader is referred to Kittleson & Southerland (2004) who use the concept to analyze engineering students’ group knowledge construction. Thus Gee’s Discourse can be characterized, in relation to social identity, as including such things as students’ epistemology, group dynamics, gender, social status, etc. 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 thesis is concerned with the analysis of the system of semiotic resources, in terms of disciplinary discourse, that a discipline offers students. Clearly, without appropriate access to these semiotic resources, learning disciplinary ways of knowing becomes extremely problematic, regardless of any student-specific factors.

4.5.7. Appresentation and facets of a way of knowing

DiSessa (2004:296) has suggested that scientists are designers of representations, claiming that “[...] the invention of representations constitutes a fundamentally important class of advances”. New representations give scientists the ability to view disciplinary ways of knowing in new ways. These specialized functions of representations have been discussed and categorized by Ainsworth (1999; 2006). From a disciplinary discourse perspective it can be said that the semiotic resources of disciplinary discourse have different possibilities to allow access to disciplinary ways of knowing, and thus each semiotic resource 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 a broader and richer experience of that way of knowing. An illustration of these facets of a way of knowing can be seen in the semiotic resources used in the teaching and learning of Ohm’s law. A student may experience facets of Ohm’s law via a

number of different semiotic resources, for example, current-voltage relational representation through the use of: circuit diagrams, oral descriptions, written descriptions, demonstrations, hands-on activities (with batteries, wires and bulbs), a table of voltages and currents for a given circuit, the mathematical formula $I=V/R$ and its graphical illustration. Each of these resources potentially brings certain facets of Ohm's law to the fore, whilst others remain in the background or are simply not present. It is thus only through combining a number of these semiotic resources that a holistic experience of the disciplinary way of knowing called Ohm's law can be constituted (analogous to viewing a physical object from different angles). Thus, typically a disciplinary way of knowing may only be partially represented by one semiotic resource (or even more than one in certain cases). This relationship is illustrated in a highly simplified and idealized manner in Figures 4.4 through 4.8.

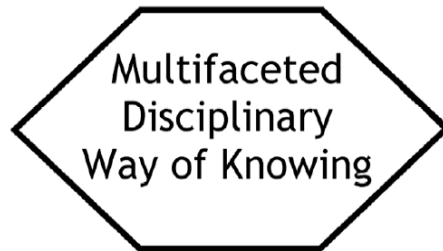


Figure 4.4. *Disciplinary ways of knowing have multiple aspects or facets as they are termed in this thesis. Here is an idealized representation of a disciplinary way of knowing using a hexagon. Each side of the hexagon represents one facet of the disciplinary way of knowing.*

In Figure 4.4, a hypothetical disciplinary way of knowing has six separate facets. These are represented by the six sides of a hexagon (Note: in reality disciplinary ways of knowing will have many more facets and the picture will be much more complex in nature).

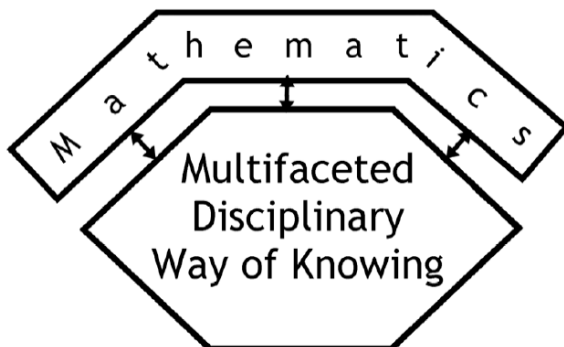


Figure 4.5. *In this case, representation using mathematical resources potentially allows access to three facets of the disciplinary way of knowing*

Suppose it is possible to represent three of these facets using mathematical resources (Figure 4.5), whilst two further facets may be represented through the experimental work (Figure 4.6).

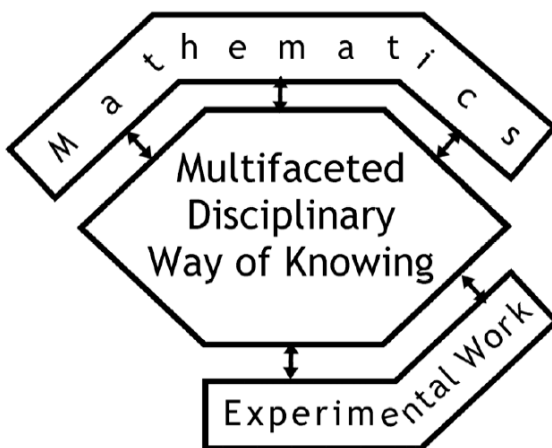


Figure 4.6. *Experimental work potentially allows access to two further facets of the disciplinary way of knowing.*

The sixth and final facet needed for a complete constitution of the disciplinary way of knowing is only available through a resource other than mathematics or experimental work. In Figure 4.7, this resource is denoted by a question mark reflecting the present situation in university science where very little is actually known pedagogically about the constellation of semi-otic resources needed for complete representation of disciplinary concepts.

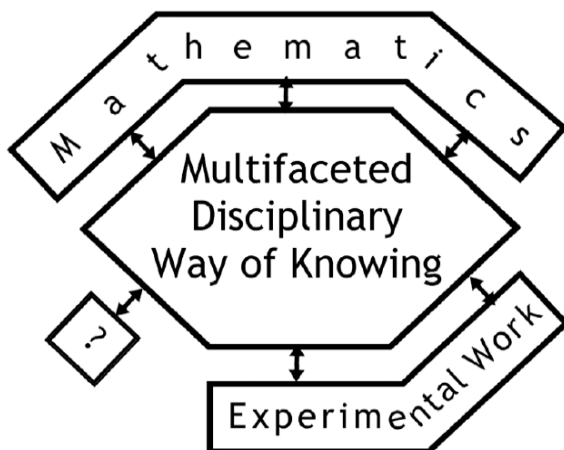


Figure 4.7. Complete constitution of the disciplinary way of knowing is still impossible for students without access to the sixth facet. Here the resource which gives access to this final facet is denoted by a question mark, highlighting the present situation in university science, where little is known about the particular constellation of semiotic resources which is needed to allow appropriate holistic access to any given disciplinary way of knowing.

In Figure 4.8, the addition of a diagram fails to represent this missing facet, but does provide a link between the mathematical and experimental resources.

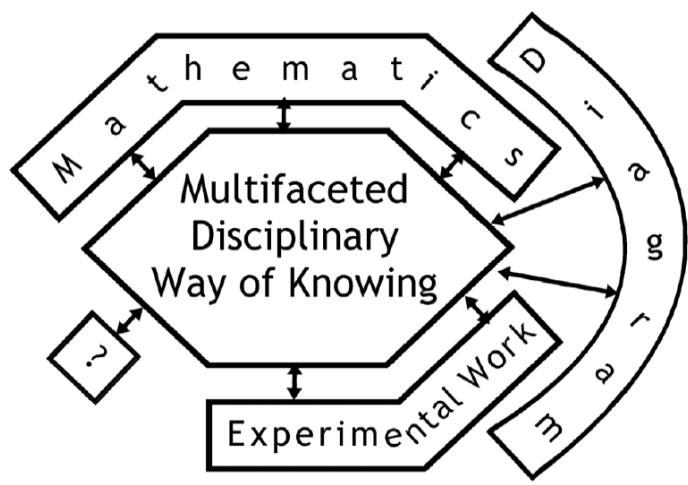


Figure 4.8. In this final figure, a diagrammatic resource is added. In this particular case, the addition of the diagram provides a link between the mathematical and the experimental resources, but complete holistic constitution of the disciplinary way of knowing is still impossible.

The relationship between semiotic resources and disciplinary ways of knowing has been discussed by Marton & Booth (1997) who posit that an appropriate experience of a disciplinary way of knowing will depend 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)

For the purposes of this thesis appresentation should be thought of as the ability to spontaneously infer the presence of further facets of a disciplinary way of knowing over and above those made available through the semiotic resource a student has been presented with. Any given semiotic resource opens up the possibility to experience a particular number of facets of a disciplinary way of knowing, but, in order to holistically 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 students must have experienced each of the various facets of the way of knowing. This, it is argued, entails exposure to multiple semiotic resources. Second, students need to be able to experience these facets simultaneously—that is, when one group of facets is presented to them through a particular semiotic resource, 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 semiotic resources.

4.5.8. Discursive fluency

Following the earlier discussion of Fairclough's (1995) order of discourse in section 2.4.5, the notion of *discursive fluency* was constituted to characterize the ability to use a *particular semiotic resource* in a legitimate way (that is in line with the disciplinary order of discourse) with respect to a certain disciplinary way of knowing.⁷

Thus, in this characterization, if a person is said to be discursively fluent in a particular semiotic resource, they have familiarized themselves with the ways in which the discipline generally uses that resource 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". Whilst the individual processing capabilities of students is not the focus of the description of learning in university science presented in this thesis; the point that students often feel swamped by new material, which they most likely will later experience as straightforward, is obviously a valid one. 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 semiotic resource, 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. This *discourse imitation* argument is further developed in sections 6.4.3. and 6.4.6.

4.5.9. Languages and disciplinary discourse

An important question for this thesis is: *How do the languages English and Swedish relate to 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. It is therefore suggested that in university physics discourse (the focus of this thesis) the semiotic resources that go together to

⁷ Note that each of the semiotic resources of disciplinary discourse has a generative and an interpretive form 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 an interpretive form of a semiotic resource. See the earlier discussion of interpretive and generative forms in section 4.4.1.

make up English and Swedish may be viewed as *parallel*. This is because the resources that constitute instruction in English and Swedish offer similar possibilities for learning. Naturally it is not being suggested that students experience English and Swedish semiotic resources 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. Resources 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.

4.6. Summary

This chapter has presented the reasoning behind the thesis and the way in which decisions were taken about the design of data collection using video clips together with semi-structured interviews. Finally, the specific methods used to address the individual research questions were presented, along with definitions and analytical frameworks for the concepts of bilingual scientific literacy and disciplinary discourse.

5. Presenting the cases

5.1. Introduction

This chapter briefly presents the three cases and the informants (pseudonyms) that the work in this thesis is built around. For this thesis, data was collected from five courses at two universities. In case study 1, five students at a larger, research-based university were interviewed about their experiences in a course on electromagnetism taught in English, and a course on mathematical methods for physics taught in Swedish. In case study 2, three students at a smaller, teaching-based university were interviewed about their experiences from a course on classical mechanics in English and a course on oscillations and waves in Swedish. Finally, for case study 3, fourteen students at the original, larger, research-based university were interviewed about their experiences from a course on 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. The data sources for the three studies are summarized in table 5.1.

Table 5.1. *Overview of data sources for the three case studies*

	Case study 1	Case study 2	Case study 3
Number of Students	5	3	14
Course taught in English	Electromagnetism	Classical Mechanics	Quantum physics*
Course taught in Swedish	Mathematical methods for physics	Oscillations and waves	

* *single course taught by the same teacher to the students in both languages*

The choice of the specific situations that these case studies examine was made pragmatically, based on the availability of courses where the same students were taught in English and Swedish.

5.2. Case study 1

As can be seen in table 5.1. the two courses for this case study were Electromagnetism (in English) and Mathematical Methods for Physics (taught in Swedish). More information about the specific lectures attended can be found in Appendices B and C. The five students in this study are presented below:

Andy

Andy has experienced teaching in English before. He feels it's almost better to have courses in English—after all, the teachers often speak better English than Swedish, and all the literature is in English. Thus, Andy suggests that when taught in English the knowledge is linked better because of the match between book and lectures. However, he feels that there is a downside to being taught in English—he doesn't always know what disciplinary terms are called in Swedish. When taught in English, Andy writes everything in English, both lecture notes and the regular problem sets for the course. He says that he *almost* speaks English with others when working through the problem sets in small groups outside class. In the past, Andy has always found physics easy. He takes his studies seriously and spends a lot of time working outside class. Andy also likes maths—and he suggests that that's probably why he doesn't find physics so difficult. As far as speaking English is concerned, he doesn't use it every day, but he feels that he can always explain what he wants to say, so he doesn't worry about it. Andy suggests that understanding English is no problem for him. Andy also read French in high school, but he didn't find that so easy.

Ben

Ben came directly to this degree programme from high school, without any work experience. Because of this, Ben suggests that he remembers most of the work he did in school. He therefore thinks that it is therefore easier for him than for some of his classmates who had longer periods of work experience. Ben enjoyed his physics in high school. He wrote an essay about the Big Bang and had contact with some of the teachers at this university (he interviewed them for the project). Ben also really liked chemistry at school—perhaps even more than physics. The reason for this was that he felt he had a very good chemistry teacher at high school. So when it came to choosing a degree programme it was difficult to decide whether to do physics or chemistry, but, because Ben also really likes mathematics he chose physics. Ben says that he doesn't like topics where you have to read a lot to understand—like history, for example. With mathematics, if you know it you know it—there is just one meaning and one way to understand it. Ben likes

languages, he speaks English, Swedish, German and Serbo-Croat. He watches English movies and reads English books, but he feels his English grammar isn't so good. Ben had 3 years of schooling in Serbo-Croat before moving to Sweden. Once in Sweden he learned Swedish very quickly. Ben feels that this was because he wasn't isolated from Swedish culture—he made many Swedish friends directly. Ben had no experience of being taught in English before university, but since then all but one or two courses at university have been in English. The books are in English and he feels he understands more because of the match between teaching language and the language of the texts. Reading English texts is not a problem, although it's a little more difficult to speak English. Ben feels that there is no difference between learning in English and learning in Swedish.

Cole

Before joining this programme Cole worked as a lathe operator. He didn't do theoretical studies at high school. He took an evening course in computing and after other courses he finally ended up teaching adult education courses in computing. Cole then decided to return full-time study, reading adult education courses. He found he liked science, and this led to him starting this physics degree. He is 29 years old now, and describes the courses as “more fun than difficult”. Cole thinks that maths is easier than physics, he also finds languages easy—although speaking is more difficult than writing. When lectures are in English, Cole asks less questions. He explains that it is harder to be precise, and “if you don't really know what the problem is then it's difficult to ask a question, even in Swedish”. He suggests that when taught in English students ask more questions of their course mates. Cole doesn't think that learning in English affects his learning of physics. He feels that learning physics is like learning a new language—there are lots of new words.

Dave

Dave has always been interested in physics—it was his favourite subject at high school. He has read lots of books about physics and never had any other thoughts about studying anything else at university. Dave also liked maths at high-school. Dave is interested in understanding why the world is like it is. However, the programme has not turned out as he thought it would. Dave finds the course very mathematical, and he can't really see the connection between the maths he does and the world he is so interested in describing. For example, there was one whole term of this degree programme where he read only maths—now he is tired of it. Dave always liked languages at school and was always good at them. This is the second course that he has read that has been taught in English. The last time there were three teachers

on a course and one of them couldn't speak Swedish, so the whole course was taught in English. Interestingly, he points out that this year that course is back to being taught in Swedish again. Because the books are in English Dave feels that perhaps it is easier to be taught in English—that way there is a match between the book and the lectures. He isn't sure, but it could be more difficult to take notes when someone teaches in English. Dave feels that he can't automatically explain in one language ideas that he has learned in another language, he—can't find the words. He thinks that it is difficult to move from one language to another—it's something that takes practice.

Eva

Originally, Eva studied maths and mechanical engineering at another large university. She decided to move to the more theoretical side of things because she “didn't like the machines”. Eva enjoys maths, and likes to know how things work. She describes herself as being quite lazy at high school, where she found it easy to learn. Now it's a little different and she needs to study quite a lot! Eva doesn't find English difficult, but she doesn't really like it. At her earlier university, every course was in Swedish. Although she finds this particular course good, other courses that have been taught in English have been difficult. For example, one earlier course was taught by someone from Eastern Europe and she couldn't understand the lecturer's accent. To her it sounded as if the lectures were in Russian! Eva feels that she didn't get anything out of those lectures—in fact, she claims she did the whole course herself. Eva believes that the lecturer's level of English is the critical factor in deciding which language to use. Even so, she thought it was hard to learn new terms in English, when she didn't know them in Swedish. “Sometimes I don't know the Swedish term—I have the English term, and I know what it means, but I don't necessarily have the Swedish term”.

5.3. Case study 2

The two courses for this case study were Classical Mechanics (in English) and Oscillations and Waves (taught in Swedish). More information about the specific lectures attended can be found in Appendices D and E. The three students in this study are presented below:

Fred

Fred didn't read natural sciences at high school, so he had to do an introductory year before he could join this programme. This means that Fred's only previous experiences of learning physics come from this introductory year. Fred has always been interested in science, but at high school he didn't want

to put in so much effort so he didn't choose that route. Fred also likes maths, but he feels that there is a big difference between the maths he reads now and the maths he read at school. As Fred puts it "You can't do anything in physics without maths". Fred doesn't like languages (in fact he chose to do the introductory part of this interview in Swedish—even though the questions were in English). However Fred doesn't really think that learning in English causes any problems—"Sometimes you have to look up the odd word when it's in English, that's all".

Gary

Gary felt that science was much easier at high school. He had taken a combined course in natural science at high school, and because of this at first he didn't really know what physics was—the disciplinary boundaries were unclear to him. Because of this, Gary was confused at the beginning of this programme. Gary finds physics much easier than chemistry, but biology is more relaxed and easier than physics. Gary likes the teaching to be structured—he does a lot of weekly problem-solving, and thinks that this is a good way to learn. Gary says that he wouldn't be able to understand if he only attended lectures. In the lectures he writes everything down, and then goes through the notes and tries to understand it later. Gary finds the teacher's explanations helpful—they are a lot easier to understand than reading the book. The tempo is slower in English and the whiteboard is more structured. This means that he can reflect more in English lectures. In Swedish the tempo is higher and the whiteboard is less structured, but Gary feels it is still easier to learn in Swedish. Gary doesn't see himself as being good at maths, but he really liked it at high school. Now he finds maths boring and difficult, but maths in physics is more interesting than maths on its own. Languages are not Gary's strong point. At high school, Gary hated the grammar lessons. He hasn't been taught in English before, but he does watch a lot of movies in English without subtitles, so he feels his receptive skills are good. Writing and speaking is more of a problem. Gary hasn't really got any goals for his education—he just likes doing what he is doing now. "I don't think too much about the future".

Hope

Hope comes from another European Union country, but has lived in Sweden for seven years. When she came to Sweden, Hope had no formal qualifications. This had not been a problem in her own country, but things were different in a small Swedish town, and finding work was difficult. Hope worked in a factory for two-and-a-half years before she decided she "had to get an education". She studied in adult education before coming to this university. Initially she read chemistry, but then swapped to this course. Hope

had good grades in physics at the pre-university level, but she felt that she didn't really understand—perhaps this was because of her lack of mathematical knowledge—now it's much easier. Maths at night school was really easy, but maths at university is much more difficult—there's a big difference. Hope studies a lot. She didn't need to spend a lot of time before, but now needs to study a lot. Neither English nor Swedish are her first language, but Hope feels she understands just as much as in her first language, it's easier to speak Swedish than to speak English. Hope hasn't been taught in English before. There are a lot of things that she doesn't know the words for in her first language—only in English and Swedish. Hope can't remember reading physics in her home country, but she didn't find school difficult up until she lost interest and didn't go to school for a while. Initially it was confusing to change from one language to the other—she needed to make a decision about the language of note-taking—this confusion only lasted for a few days.

5.4. Case study 3

This case study deals with one course in Quantum Physics taught to the same students in both English and Swedish. More information about the specific lectures attended can be found in Appendices F and G. The fourteen students in this study are presented below:

Ian

Ian worked as a car mechanic before coming to university, then he studied the introductory year before starting this programme. Ian finds maths much more comfortable than physics. He also likes languages. He watches a lot of English movies and uses English on the internet. Ian says that he sometimes needs to think twice because of technical words when working in English, but otherwise there isn't much of a problem. Ian takes notes in a mixture of English and Swedish. He wants a better job with more freedom and thinks that this course will help him in this goal. Ian thinks that the speed in this programme is too high for him to really understand—he can pass the exams, but he would rather spend more time so that he could really feel that he understood the physics. Ian goes to all the lectures, labs and calculation sessions. Outside class he also does a lot of work, and usually works the whole weekend. The book for this course is very good, but if it hadn't been, he would have tried to find another himself. This is important because Ian likes to read through a chapter before attending classes in English—it's like getting a second lecture. Ian works mostly alone, but when he does work in a group, the language used is Swedish. He doesn't usually ask questions in

class—though he might ask if he was allowed to use Swedish—otherwise no.

Jon

Jon got bored in the final year of high school. Because of this, he feels that the other students on the course have better prior knowledge when they meet new concepts. Jon has always found maths easy—maybe that’s why he likes physics. As far as languages are concerned, Jon rates himself as “ok” but he thinks that English is interesting and useful. This is the first time Jon has been taught in English and he feels he can sometimes get stuck on certain words. On a previous course (taught in Swedish) the lecturer gave out a wordlist to help them with the English course text—he thinks this was a useful strategy. Jon thinks it’s good that they have this course in English. He doesn’t think that there is a problem with having the book in English when he is taught in Swedish either. Of course, Swedish would have been the easiest for everything though. Jon doesn’t think that there is any difference with how he learns in English—it might take longer if he gets stuck on a given word. He would like new words to be presented in both Swedish and English. Jon thinks that a new word in English is questioned, whereas in Swedish it wouldn’t be. Anyway, certain things don’t really exist in either language—especially when we talk about quantum physics. Jon seldom speaks English, he only listens. He thinks the whole programme could probably be taught in English, but increasing amounts of English would perhaps be best. Jon doesn’t really find his studies interesting, but he thinks it is useful to “sacrifice a few years now” in order to have a better life later. He doesn’t see his studies as useful in themselves—he just wants the qualification. In general, Jon goes to about 90% of everything. He usually misses some of the calculation sessions, but not on this particular course. Jon finds this course quite difficult to understand—the level is actually quite low, but the ideas are difficult. So it’s a good course! He has used the website for questions and he solves the problems from the book too, but he refers to his lecture notes rather than the book. During lectures, Jon writes in English, but he feels he needs to ‘translate’ to Swedish afterwards. He doesn’t write down everything. If Jon gets stuck he asks other students, otherwise he just sits with it until he makes a breakthrough. If he got really stuck he might ask the lecturer, but he wouldn’t ask questions in the lesson.

Ken

Ken is studying in the engineering programme. He chose the programme because of the specialization in industrial economics. Ken is really interested in business studies, but he believes that this programme can give him a competitive advantage over other business graduates—business is interesting but

it's good to have physics and maths too. Ken has always found physics easy, maths has been easy too, but it isn't so much fun, even if he doesn't need to work so hard. Ken spent a term in the USA reading economics and business, but he hasn't read *physics* in English before. He has always found English easy. He also spent a month in Canada playing ice hockey when he was a high-school student. Ken sees no real differences between learning in English or Swedish—he never really liked Swedish as a subject at high school. Ken wants to get good grades on everything in economics, but he is only interested in passing the engineering courses—it might be a bit boring now, but it will pay off in the future. Even so, Ken hasn't got any fixed plans for the future—this is a good program so he will have this as a good base in the future, that's all that matters right now. He feels this course is a good reflection of what he expected from the whole programme. He goes to almost everything—he has missed one lecture. He uses the book and the website for problem-solving. “When I do something I learn what I am doing. Working through the problems is how you learn physics”. Sometimes it's difficult to find the right term or to understand a term mismatch between the book and problem-solving sessions. In this respect, it might have been easier to have the calculation sessions in English too—language just doesn't matter. Ken writes down everything the lecturer puts on the whiteboard. He thinks it's easier when you see stuff on the whiteboard, so there needs to be a well-structured whiteboard. If this isn't the case, he needs to spend a lot of time thinking about his writing and he might miss something. In the lectures, Ken understands a lot directly, but there are other things that he needs to do calculations with before he can understand. When doing calculations he works with other students in a group that they formed themselves. This way you can help each other when you get stuck. In the group they read the English problem and then speak Swedish to solve it. Ken realizes that he spends different amounts of time working outside class depending on the course content—this course isn't too bad so he spends about 2hrs per day outside class, but he feels he should do a little more really. The amount of time you need to work with stuff isn't really that informative—you need to work with things until you understand them. Ken never reads work before the lecture—so he doesn't really know what a lecture will be about when he goes in.

Leo

Leo is studying in the engineering programme. He didn't like physics at lower secondary school, but he liked it at high school. He studied for the International Baccalaureate (IB) and all subjects except Swedish were taught in English. The reason he liked physics at this level was not because he was taught in English, but because of the teacher—he made it fun. Leo studied literature for a year before starting this programme—he likes that even more than physics, but “You have to think about the future”. Leo really likes the

mathematical parts of the programme—he feels he is good at maths and he really enjoys it. He doesn't feel that learning through English is a problem, he has good receptive skills, but speaking is more difficult, he feels he has lost some of the fluency he had when he was doing the IB. Leo chose the IB programme because he saw it as a challenge. He had good grades in secondary school, so there was pressure on him to do something that was more difficult. He feels he would have got better grades if he had gone to a regular school, but he doesn't regret the choice. The reason Leo thinks he would have got better grades in a regular high school is not because of being taught in English, rather he felt that the material covered in the IB programme was more difficult than that covered in the Swedish system. One surprising consequence of his IB experience is that he still takes notes in English—even when he is taught in Swedish! This isn't as difficult as it sounds—he reads the chapter before the lecture, so he knows what will be discussed and so he just translates as he goes along. Even so, in exams Leo answers in Swedish. Leo uses problem-solving as a means to understanding the material. He doesn't go to problem-solving sessions—he would rather try to figure things out for himself. This means he doesn't work with other students in study groups. If he ever gets really stuck he might go to ask the teacher, but he would much rather 'play' with the problem himself until he manages to work it out. In lectures, Leo feels that he can usually follow the lecturer's line of reasoning, but if he doesn't follow he wouldn't feel comfortable to ask a question. "I'm the quiet type". He works around 2-3 hours a day outside class, but feels he really should do a lot more. Interestingly, if the books had been in Swedish, Leo says he would have quit the course—he doesn't think that Swedish textbooks have real credibility, Swedish signals simpler, more summarized knowledge.

Mia

Mia is studying in the engineering programme. She has always liked physics and says she finds it easy and interesting. It's not *as* easy anymore, because things are on a much higher level than in high school. Mia also thinks maths is easy, and she enjoys solving problems. She hasn't been taught in English before, so this is the first course where there have been some English lectures. There have been English books all the way through of course. Mia also likes English—she read more English and maths than the basic requirement at high school, because she thought that this would help her in the future. She doesn't think that she has any problems learning in English—it just helps her improve her English skills, and that's important for the future. Mia finds the physics terms are easier when there is a match between the book and the lecture. In the future Mia is not sure what she will do, but since she likes maths and physics it will probably be something related to these. Mia goes to all timetabled lectures and for her it is important to link these lec-

tures to the book and then to try the problem sets. The book on this course is good and explains things from a basic level. Outside class, Mia solves problems together with other students—“It’s good because it makes you study rather than watching TV!” In these groups the language used is Swedish. Mia thinks that she also needs to work on her own to understand things. Her amount of work outside class depends on the content—she does less work now than in say, mechanics. Mia can usually follow the lecturer’s train of thought and she usually takes notes in a mixture of Swedish and English—“it doesn’t affect *what* you write, just how.” In Swedish, Mia believes that things are slightly different because she knows the terms from high school—they have a history for her. Sometimes she asks questions in lectures, but it usually feels better to leave it to the end, or to ask one of her classmates. She’s not sure, but perhaps she is less inclined to ask questions when she is taught in English.

Nick

After high school Nick worked for some years—he quit his job to do this programme “I wanted to do something totally different”. First he had to study a number of adult education courses, and then the introductory year before he could qualify for entrance. Nick has always been interested in physics, but he doesn’t find it easy. The adult education courses were easy. He has always liked maths, and always found it easy, but he didn’t understand the maths they did this term in an earlier course—he didn’t have enough prior knowledge. Nick thinks he has always been bad at English, he finds it very difficult to speak. He has never been taught in English before—he was terrified when he heard that this course would be in English. “Well, there always has to be a first time—and this was a good time”. Things are more difficult in English, but it’s not overwhelming. Nick feels he really needs to concentrate in lectures in English. He doesn’t know every word the teacher says and sometimes he needs to go home and look things up, so he has to do extra work after lectures. Nick has always wanted to study and now he got the chance. He likes the programme profile of engineering and economics. Nick goes to all the lectures, and most of the problem-solving sessions, but he doesn’t use the website—he would rather use a pen and paper. For Nick, the book is by far the most important thing in the course—he reads it and does the problems. The book is better than the lectures because you can always stop and look up a word. In the lectures, Nick takes notes in English. He doesn’t think he spends too much time working outside class. The work he does is solving problems sometimes on his own, and sometimes with a group. In the group work they always speak Swedish. Nick finds it much more difficult to learn in English—in fact, if he knew he wouldn’t need English in the future, he would have no problem having everything in Swedish. Nick thinks it’s probably better to have lectures in English if the

book is in English—that way you don't need to involve two languages in your learning. At the moment he needs to look up English words almost every day. Nick usually asks questions after the lecture when he can ask questions in Swedish.

Oskar

Oskar is studying in the engineering programme. He started to be interested in maths and physics at high school—mainly because he found them easy. When he finished high school, he didn't really know what he wanted to do. He chose this programme, but he didn't even really know what the programme was about when he started—he just hopes it will lead to a decent job. Oskar is interested in English, and took the Cambridge Certificate examination during high school. He has never been taught in English before. Oskar likes being taught in English “You have to reflect on what has been said, so it helps keep your attention”. He thinks it's better to have English when the course texts are in English. Having said that, he would have liked a course in technical English to start with. Sometimes words come up in English that Oskar doesn't understand. As far as the mathematics for this course is concerned, it isn't so difficult, in fact, it would have been enough with high-school maths for this course. Oskar goes to all the lectures, but he misses the problem-solving sessions. He spends different amounts of time on the course at different points, doing much more near the exams. Oskar thinks he probably does too little work. When asked about how much work he should do, Oskar explains that there is no definitive amount—perhaps it should be like a full-time job, but really it's about doing enough to understand. Oskar learns physics by reading the book and doing calculations together with other students. The group speaks Swedish when they meet to solve problems. Oskar rarely understands during the lectures, he uses the lecture to mechanically write things down and then works with the notes in his own time later. He takes notes in the same language as the lecture is given. Oskar says that he is unsure about the course content at the moment—he needs to spend time working with it. Spontaneously, he thinks that “It looks like there are a lot of equations that you need to memorize”. Oskar never asks questions in lectures—he concentrates on writing things down. If he did ask a question it would be in English.

Pam

Pam is studying in the engineering programme. She has been taught in English before—she spent one year of high school in the USA. English has never been a problem for Pam, but she did find reading maths and physics in English difficult at first. After her time in the USA, Pam started thinking in English—initially she found it difficult to do maths she had read in the USA

when she came to do it in Swedish. Pam has always liked maths—she needs to work hard at it, but she thinks it is interesting. Physics is more difficult. “If you understand maths, you understand it, but physics is complicated”. Pam has no fixed plans for the future, but thinks that the programme could be useful for lots of jobs, so it gives her lots of options. Perhaps she’d like to be an engineer like her father—it’s an interesting job. Usually Pam understands parts of the lecture directly, but she always goes through her notes directly after the lecture—working her way through everything and connecting it to the book. Pam thinks it’s much more important that a teacher structures everything for the students at the right level—the teaching language is not relevant in comparison to the teacher’s pedagogy. Pam finds it difficult to solve physics problems. “We sit together and try to figure out what the problem is asking and then we try to solve the problem on our own”. In the group, the students discuss the problems in Swedish “It’s good. You get it both ways”. Sometimes the group uses English words in their Swedish discussions. Pam experiences no problems with learning in English—“It’s better in English when the book is in English”. Pam goes to almost everything that is timetabled on the course, and she uses the book a lot—it’s a good book. In lectures, Pam writes down everything, she uses mostly English, but sometimes writes a few notes for herself in Swedish. Pam works every weekday and all weekend. You need to be disciplined, “If you miss a day that’s eight hours you’ve lost!” Pam hardly ever asks a question in lectures, she usually goes to the lecturer after she has had some time to work with the material. She has no problem answering questions in lectures—she’s quite prepared to “chance it” and has no problem with answering in English.

Roy

Roy had quite good grades in maths and physics at high school, so he decided he wanted to read physics. He chose this programme because he has relatives in this town. He finds the course more fun than at high school. This is the first course he has had with lectures in English. He thinks it’s good to have lectures in English because it matches with the book. In earlier courses, Roy didn’t read the book—he just translated exercises and worked through them. Now he reads the book at home—it’s a good book. He feels that in Swedish he gets so much more for free, it goes in straightaway. He found that being taught in English got easier with time. Roy suggests that now there is not much difference in learning when he is taught in English. It’s better to use the language that the teacher is most comfortable with. Roy works with other students to solve physics problems—they write the answers in English, but discuss the solution in Swedish. Roy would like to work in the area of theoretical physics when he finishes this programme—if he’s good enough that is. He goes to everything that is timetabled on the course—he’s afraid he’ll miss something important if he stays away. Roy doesn’t ask

questions in class, but he might ask after class—but then he would use Swedish.

Sue

Sue sees herself as an average student, she's had no problems so far—it's all gone pretty well. She feels that maths and physics became more fun the more she learned. Maths is easier than physics though—physics has so much other 'stuff' involved. For example, it's difficult to visualize an electron and what it will do. Sue feels comfortable with English—she has always had good English grades. She also lived in London for 6 months. Although she has never been taught in English before, Sue thinks that the differences between maths and physics are greater than the differences between the same content in English or in Swedish. Sue goes to everything timetabled on the course. She takes notes in both languages, but finds it difficult to translate and simultaneously write notes. It's better when the teacher writes on the board, then Sue can use the language of the lecture instead of translating. "You can often piece together what was said from your notes if the teacher writes on the board". Sue wants to take a year studying abroad, so she feels it's good to have this course taught in English. Sue mostly works alone—she tried working in a group but found it difficult.

Tom

Tom studied the introductory year before starting this programme. He has previously studied music at university level before changing to science. Tom feels he does more work for this course than the previous courses in the programme. Tom likes English, he listens to a lot of films in English and he reads English books. He prefers English terms because they are more useful for the future. Tom uses the text book for this course more than in previous courses. The other courses have had English textbooks, but the lectures have been in Swedish. This is the first time Tom has been taught in English. He says it felt strange at first to have lectures in English, but now he thinks it's natural. He thinks there is no real difference between learning in English or in Swedish— just the odd confusing word, for example, *derive*—is it 'de-ri-vera' or 'härledda'? In lectures, Tom takes notes in English and writes problem solutions in English, but he uses Swedish when working with others in the group. He doesn't ask questions in lectures. He is uncertain about what he wants to do in the future. Tom goes to everything timetabled on the course. Interestingly, Tom needed a higher volume when watching the video of the lecture in English—this is something he commented on himself.

Victor

Victor is studying in the engineering programme. Before coming to university, he worked at a petrol station. First, he read history for a year before changing to this programme. Victor has never been taught in English before, but he feels that there is no difference in the learning experience. He's not sure what he wants to do in the future, but there are a lot of alternatives with this programme. Victor goes to everything timetabled on the course. He uses the *Mastering Physics* website and he also reads the book a lot. He thinks it's a good book, "It's very simple and explains well". Victor finds the lectures simple to follow—in physics the words are almost the same. It would have been different if he had been reading history though! In lectures, Victor takes notes in English and annotates them in Swedish. He doesn't ask questions in lectures, whichever language is used. He works for about 4-5 hours everyday after classes and one day at the weekend. Victor works in a group with 4-5 other students solving problems. The language used in the group is Swedish. Victor thinks that there might be a few physics words that he uses that aren't really Swedish.

Will

Will was unsure what programme to study at university but this seems like it was a good choice. He has not been taught in English before, but he doesn't think it causes problems. "It's a bit easier in Swedish, but really good to have English". In the past all his course books have been in English. Will's short-term goal is to pass the exam. Long-term, he doesn't know what he wants to do, he's not really thought further than next year. Will goes to lectures and labs, but no problem-solving sessions. He thinks the book is quite good—it explains in detail. In lectures, Will takes notes in English, but he only copies down what is written on the board. Will loses the thread of lectures quite often, so he doesn't understand much in the lectures. He works alone outside lectures, problem-solving and reading the book. Will doesn't ask questions in lectures. He has had mixed results on exams, he puts this down to his own laziness—"It's better to have hand-in tasks".

Zack

This is the third time that Zack has read this course. Previously, he has swapped around a bit—he read computing at another large university. He's now getting money from the *Job Centre* to get enough credits in physics so that he can become a teacher. Zack fails every exam and then passes on the third or fourth attempt. So far he has read a full two years of courses, but has only passed half of them. He wants to help others who have difficulties with reading and writing. This is Zack's first course in English. Zack thinks that

there's a big difference when learning in English because it can be difficult to understand teachers' accents. Sometimes it's difficult to translate words into Swedish—the written language is a problem for him. It's difficult to get down what is written. “Why do teachers use slides instead of writing? Is it a lack of confidence from them? It gives you less time to write things down”. Zack thinks that overhead slides would be fine, if he could get everything given to him on paper—then he could just sit back and listen.

6. Results and discussion

6.1. Introduction

The previous chapter detailed the courses from which data has been collected for the three cases and gave profiles of the individual informants. In this chapter the combined results from these three cases are presented and illustrated with examples. Since there are three main areas of interest (language, bilingual scientific literacy and disciplinary discourse), it was decided to present the results from each of these areas, together with the related discussion. This is done in order to help the reader see the relationship between results and conclusions without having to move from chapter to chapter. These results will be coupled to the relevant research questions in chapter 7.

6.2. Results and discussion in terms of learning and language

6.2.1. Language is seen as unimportant

The most striking aspect of the combined findings of the three studies is that when asked directly, the students say they feel that there is very little difference in their learning when taught in English rather than in Swedish. This is something that is common for all the students interviewed 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.

(Airey & Linder, 2006:555)

This result is similar to that 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 over-

whelming majority of students interviewed in the case 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 being 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.

(Airey & Linder, 2006:555)

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

6.2.2. 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.

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.

(Airey & Linder, 2006:555)

That the traditional reluctance to ask questions is exacerbated when lectures are in English is all the more worrying in the light of 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.

(Airey & Linder, 2006:556)

When observing this particular lecturer's sessions it was found that a number of students, though silent in the lecture, came forward at the end of each session to ask questions.

6.2.3. Answering questions

The students in the three case studies describe how they tend to answer fewer questions when lectures are given 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.

(Airey & Linder, 2006:556)

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, it can be expected that the 'shared space of learning' (Tsui, 2004) will also be correspondingly reduced.

6.2.4. 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 on 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)

6.2.5. Work outside class

For students who take notes, their understanding of 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 6.2.6.).

- 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!

(Airey & Linder, 2006:556-557)

This should not be interpreted as a suggestion that when the students attend lectures in Swedish they do not need to do work outside class. Rather, as shown in section 6.2.4, the students in the three studies indicate that when they take notes in a lecture given in Swedish they are better able to simultaneously follow the thread of that lecture than they are when taking notes in a lecture given in English. Consequently, when the students take notes in a lecture given in English, they find they typically find themselves doing more work outside class than when the lectures are given in Swedish.

6.2.6. Reading before the lecture

In some cases students had read through the relevant chapters before the English language lecture and, without exception, these students are those who claim 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.

(Airey & Linder, 2006:557)

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.

(Airey & Linder, 2006:557)

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 three case studies only mention reading before class as a strategy they adopt when they are lectured in English.

6.2.7. Multi-representational support

In one of the videoed lectures, the lecturer followed the 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' is appreciated by all the students 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.

(Airey & Linder, 2006:557)

So, one useful lecturing strategy when teaching in a second language 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 it's 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 it can be seen that when lecturing in a second language, writing extensively on the board appears to help students. It may be speculated that other forms of support such as handouts, overhead slides, demonstrations, computer simulations, etc. would also help.

6.2.8. Summary of results and recommendations for teaching

The results reported here provide a good illustration of the ways in which second-language lecturing is experienced by Swedish physics undergraduates. The main conclusion with respect to research question one 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 three case studies 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 address 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.

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, pedagogical decisions need to be based 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 work 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 three case studies 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 as the language changes, lectures may no longer 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.
- *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.

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 this section to help students to cope with the shift in language.

6.2.9. Relevance for other teaching situations

The extent to which these results can be generalized to other groups of students within Sweden and to other countries where the English language ability of both students and lecturers varies, is an open question. Applying the concept of moderatum generalization presented in section 3.2.3. it can, however, be speculated 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 part of the thesis set out to answer research question 1, and hence, to inform physics lecturers about what might be problematic when their students are taught in a second language. In this respect, the work has been successful, and physics lecturers should be able to transpose these findings to their own specific lecturing situations, using the recommendations to devise strategies to mitigate any possible problems. Although there will always be questions about the generalizability of this kind of work, 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.

6.3. Results and discussion in terms scientific literacy

6.3.1. Implied scientific literacy

In section 4.4.3. It was pointed out that it is uncommon for course syllabuses to specify educational outcomes in terms of the semiotic resources that may be needed for attaining scientific literacy. Research question 2 was therefore formulated, suggesting that it would be interesting to examine the *implied* goals, with respect to the suggested components of scientific literacy, that form part of the ‘hidden curriculum’ of natural science degree courses. This research question was addressed through an audit of a sample of 30 physics syllabuses (Airey & Linder, 2008).

First, an audit of the teaching language and the language of the course texts, as detailed in the syllabuses was carried out. Unfortunately, ten of the course syllabuses failed to detail the required literature, thus effectively reducing the number of useable syllabuses to twenty for this aspect. Of the twenty undergraduate course syllabuses that did specify texts, only four appeared to have exclusively Swedish course literature. Sixteen courses had at least some literature in English, with six of these having only English texts.

When it comes to the teaching language, things were somewhat different. Of the thirty courses, only two were taught exclusively in English; the majority, twenty-three were taught in Swedish. This information is summarized in Table 6.1.

Table 6.1. Language use in 30 undergraduate physics courses as specified in the syllabus.

English texts Only	Mixed texts	Swedish texts Only	Taught in English	Taught in English or Swedish	Taught in Swedish
6	10	4	2	5	23

Note: Of the 30 syllabuses, 10 gave no guidance on literature, these have therefore been excluded from the left hand column detailing the language of course texts.

It is interesting to note that five syllabuses indicated that “*If so required, the course will be given in English.*” One can wonder about the type of bilingual scientific literacy that course developers have in mind when a course can spontaneously change teaching language in this way.

Next, for each syllabus the course content was analyzed in terms of the practice (and hence the control) that could be seen to be implied in the representations, tools and activities of science. Table 6.2. presents the results of

the analysis of the control of semiotic resources other than language implied, in the 30 syllabuses that were examined.

Table 6.2. *Implied control of semiotic resources other than language*

	VISION I		VISION II	
	Interpretive	Generative	Interpretive	Generative
Mathematics	High	High	Low	Low
Graphs	High	High	Low	Low
Diagrams	High	High	Low	Low
Tables	High	High	Low	Low
Tools	High	High	Low	Low
Activities	High	High	Low	Low

Here, with respect to Roberts’ (2007) two visions of scientific literacy, it can be seen that the activities on the 30 courses imply high levels of interpretive and generative control within the discipline (Vision I), but the implication is that there is little use of these semiotic resources with respect to the problems of everyday life (Vision II). This suggests that either lecturers do not see it as their job to foster Vision II scientific literacy, or that they believe that Vision I literacy automatically leads to Vision II literacy.

6.3.2. Implied bilingual scientific literacy

An analysis of the same 30 syllabuses with respect to the concept of bilingual scientific literacy is presented in Table 6.3. Here again, the implication is that a Vision II perspective is most likely absent. However, a new pattern emerges. Within the discipline (Vision I), there is now no longer a uniformly high level of practice. Control of spoken disciplinary English and Swedish does not appear to be encouraged. This lack of expressed focus on oral skills is, in fact, a common finding in science education—even without a dual-language approach (Lemke, 1990).

Table 6.3. *Implied control of linguistic semiotic resources (language)*

	VISION I		VISION II	
	English	Swedish	English	Swedish
Reading	High	Medium	Low	Low
Listening	Medium	High	Low	Low
Writing	Medium	Medium	Low	Low
Speaking	Low	Low	Low	Low

Table 6.3. also illustrates that the higher levels of implied control appear to be in *interpretive* rather than *generative* forms, i.e., higher in reading in English and listening in Swedish. The results also raise questions for reading,

listening and writing. In these forms there is only *some practice* in one or both languages.

6.3.3. Spoken bilingual scientific literacy

Since control of spoken language was identified in the previous section as the least developed within university science (Vision I) it was natural that this particular resource should be the subject of further study. This led to the formulation of research question 3. The selection of the student descriptions of disciplinary concepts for this in-depth, cross-case study, and the methods used to analyze the descriptions are described in sections 4.4.5. and 4.4.6. respectively.

Table 6.4. summarizes the data from analysis of student descriptions in English and Swedish of the concepts they met in their lectures.

6.3.4. Code-switching in disciplinary descriptions in English

The first point that should be highlighted from the data in Table 6.4. is that two students (Hope & Nick) find it almost impossible to speak about disciplinary concepts in English. English descriptions are also a problem for Victor, who code-switches extensively to Swedish disciplinary vocabulary. These students are all in their first year of study, and have not been taught in English before. Interestingly, these three students encountered few problems when talking about their background in English at the start of their interviews, and thus it is concluded that it is precisely scientific literacy in English which is lacking. In the example below, Victor does not have access to the disciplinary words: number, squared, and imaginary:

I didn't understand why it wasn't a real ...**er vad ska jag saga? Tal**—er only when you **har det upphöjd till två**. But she said it was an **imeg...imag ett sånt där tal**.

Such code-switching was not unusual when first-year students described physics concepts in English, and it was noticeable that their lexical gaps in disciplinary English were sometimes likely to cause a breakdown in communication. For example, the student in the interview excerpt below uses the false friend⁸ *feather* instead of the word *spring*:

Yeah, yeah. I think it's a **feather**, that's ... it's going from potential energy to kinetic energy and if you combine, yeah, that with the **feather** constant you get this [...]

⁸ A false friend is a word in a second language that resembles a word in a student's first language, but that has a different meaning in the second language. In this case, Swedish has one word, *fjäder* that means both feather and spring.

In comparison, the second-year students (case study 1) rarely code-switch in either language.

* code-switching where the student immediately repairs using the correct code

Table 6.4. Summary of results of the analysis of student descriptions of concepts met in lectures

NAME	Lecture language	Interview in English					Interview in Swedish				
		WPM	SPS	MLR	Involuntary code-switching	Disciplinary	WPM	SPS	MLR	Involuntary code-switching	Disciplinary
Case study 1	Andy	76	2.0	6.1	one switch but in metalanguage	3	141	3.7	8.7	nil	3
	Ben	127	1.3	5.7	nil	2 to 3	118	2.9	5.7	nil	2
Case study 2	Cole	144	3.7	8.6	nil	3 to 4	132	3.1	6.7	nil	3 to 4
	Dave	136	3.0	5.8	nil	3 to 4	139	3.4	6.3	one switch level 1	2 to 3
	Eva	115	2.2	1.9	nil	2	143	3.4	8.9	nil	3
		81	1.8	4.5	one switch level 1	2 to 3	246	6.2	8.5	nil	0
Case study 3	Fred	75	1.8	3.4	one switch level 1	2 to 3	121	2.9	6.7	nil	2 to 3
	Gary	102	2.1	4.9	nil	2	132	3.3	7.1	nil*	2 to 3
	Hope	72	1.7	4.4	one switch but in metalanguage	2 to 3	168	4.0	9.0	nil	2
		88	2.0	4.4	three switches, one at level 2	1 to 2	159	4.1	8.1	nil	2 to 3
		80	1.6	3.8	three switches, two at level 3	1 to 2	147	4.1	12	nil	3
Case study 3	Ian	56	1.3	5.2	one switch level 1	2	108	2.6	7.3	nil	2
	Jon	111	2.3	4.8	one switch level 1	3	60	3.0	7.3	nil	3
	Ken	95	2.0	4.8	nil*	2 to 3	134	3.2	8.1	one switch level 1	2 to 3
	Leo	79	1.9	4.9	nil	3	95	2.6	6.6	nil*	3
	Mia	108	2.4	5.3	nil	3	99	3.0	7.5	nil	3
	Nick	NA	NA	NA	codeswitches throughout level 3	1	85	2.3	6.5	nil	1 to 2
	Oskar	82	2.0	5.5	nil	2 to 3	100	2.6	7.1	nil	2
	Pam	99	2.0	4.1	one switch but in metalanguage	3	145	3.5	5.3	two switches level 1*	3
	Roy	87	1.9	4.2	one switch level 1	3	84	4.3	5.2	nil	3
	Sue	89	1.9	4.5	nil	3	126	3.1	7.1	nil	3
Case study 3	Tom	114	2.5	4.8	nil	3	120	3.1	7.7	one switch level 1	3
	Victor	58	1.3	3.4	four switches, level 1	2	138	3.5	6.3	one switch level 1*	2
	Will				insufficient data		87	2.2	5.5	nil	3
Zack	both			insufficient data					insufficient data		

6.3.5. Code-switching in disciplinary descriptions in Swedish

As might be expected, students code-switch to a much lesser extent in their Swedish descriptions of disciplinary concepts. One pattern that can be seen in the data is that those students who do code-switch in their Swedish descriptions, only do so when English has been used in the teaching of the concept they are describing.

All code-switching in Swedish was considered to be unlikely to cause a breakdown in communication. There are two reasons for this assertion: first, in the main, the lexical gaps were less likely to be central to an understanding of the text. Second, since students are speaking Swedish, it is more than likely that the listener will understand the code-switched word or phrase. Clearly this second assumption about the listener cannot be made when students describe disciplinary concepts in English. Below is an example of this type of first-language code-switching:

Ja, ja den betyder ju, att **the curl of E** då är, är minus derivatorn av B fältet men sen just vad en **curl** är det har man fortfarande inte riktigt fått en så här direkt in, intuitivt, bild av det.

It is argued that the majority of Swedish physics students would hardly notice that code-switching had occurred in this description, with curl being perhaps more likely to be used than the Swedish equivalent (rotation) in student disciplinary descriptions in Swedish.

6.3.6. Disciplinarity

In terms of disciplinarity, second-year students have higher ratings than first-year students, with three of the five students in case study 1 achieving the rating 3-4 for at least one of their descriptions. By comparison, *none* of the first year students achieve this rating for any of their descriptions.

Disregarding the two students who have severe problems with English (Hope, and Nick), there is strong agreement between student disciplinarity ratings in both languages—any difference being within a half a grade point, with the ‘better’ description just as likely to be in English as in Swedish⁹. It is therefore concluded that, *above an initial threshold of competence in disciplinary English, students give descriptions with similar levels of disciplinarity in both English and Swedish, regardless of the language that has been used to teach them*. There is one notable (and initially puzzling) exception to this general rule—Cole gives a much better description in English of a concept that was taught in Swedish. However, closer examination of the full transcript and sound file showed that Cole actually gave expressions of start-

⁹ Note: Dave’s disciplinarity grade of zero in Swedish does not contravene this description—zero denotes a meta description which was unable to be graded for disciplinarity.

ing to understand what the lecturer was trying explain *during the stimulated recall clip* that was shown between the two descriptions—i.e., he learned something in the short period between his two descriptions. This can also be seen in the transcript where, when asked to describe the concept in English after watching a Swedish lecture clip he starts his description with, “Well, as he just said ...”. As explained in section 4.4.5, one of the methodological limitations of this thesis is that students do not describe *exactly* the same concept in both English and Swedish—the descriptions that were planned to be used in this way proved unsuitable for analysis.

6.3.7. Linguistic fluency measures: WPM, SPS and MLR

In keeping with the qualitative nature of this thesis, the quantitative measures WPM, SPS and MLR presented in this section, function purely as an illustration of trends. Hence, no attempt is made to construct any kind of comprehensive statistical analysis. The reason for choosing to use syllables per second (SPS) over the more well known words per minute (WPM) when comparing languages is discussed in section 4.4.4. The WPM values are, however, included in Table 6.4. for readers who may also be interested in this measure. A glance at the comparative values of WPM and SPS for Ben’s descriptions of a concept taught in Swedish should suffice to convince any skeptics that there is indeed a difference in what is measured between these two measures—the English description scores slightly higher than the Swedish description when using WPM, but scores dramatically lower on SPS. Interestingly, this same example serves to highlight the differences between SPS and MLR—the MLR value is, in fact, the same for *both* descriptions. SPS measures the total amount of syllables uttered during a given time, whilst MLR measures how many syllables are said without pausing (phrase length). For Ben’s descriptions then, this suggests that in English the total amount said in a given period of time was much less than in Swedish, but that the amount said *between each pause* was about the same. Therefore there must be much longer pauses in the English description, which was confirmed by listening to the sound file again—in English, Ben uses a large number of filled pauses—‘er’s’ and ‘um’s’, which were deleted before the syllable count (see method of analysis described in Appendix H).

From the point of view of trying to isolate measures of student ability to speak about disciplinary concepts in English and Swedish, the SPS and MLR values appear to give little useful information to help judge the bilingual scientific literacy of students. This is in stark contrast to the claim made by Hincks (2005:116) in her summary of research in this area that “[...] temporal measures provide a reliable estimation of second language ability”. Clearly, above a lower threshold, second language ability and bilingual scientific literacy have little relationship to each other. The only thing that can be said is that these results confirm earlier work which has shown that

speech rate slows down (lower SPS) and phrase length shortens (lower MLR) when using a second language.

As a simple illustration of the trends across the case studies, the mean results of these measures for each case study and the whole cohort of students are shown in Table 6.5.

Table 6.5. *Mean values of linguistic fluency measures for the three case studies*

	Words per Minute (WPM)		Syllables per Second (SPS)		Mean Length of Runs (MLR)	
	English	Swedish	English	Swedish	English	Swedish
Case study 1	90	151	2.5	5.7	5.6	7.7
Case study 2	86	146	1.9	3.7	3.9	7.4
Case study 3	89	100	2.0	3.0	4.7	6.7
All students	89	126	2.2	4.0	4.8	7.2

Using the values presented in Table 6.5. it is found that students spoke on average 45% slower in English. These values represent a much greater reduction than the 23% found by Hincks (2005; 2008) in her work with student presentations. This finding is perhaps in line with what could have been expected. Since the speech events examined in this thesis were not planned presentations, students had to spend time to think about what they are going to say; and, it would seem that more time is needed for this task when the language used is English.

6.3.8. Summary of results with respect to scientific literacy

It was found that physics courses appear to imply low levels of practice in spoken disciplinary English and Swedish. This discovery was followed up by the analysis of students' ability to describe the disciplinary concepts they had met in their lectures in both English and Swedish. Here it is found that, for some students, describing disciplinary concepts in English is very challenging. In this thesis, these students were in their first year, and had not been taught in English before. First-year students code-switch in English more than second-year students, and their lexical gaps are more likely to cause problems in understanding. Students at all levels do code-switch to some extent in Swedish, but only when English has been one of the teaching languages for the concept they are trying to describe.

Second-year students have higher disciplinary ratings for their descriptions than first-year students, however, it appears that above a certain lower threshold of control of disciplinary English, students give descriptions with

similar levels of disciplinarity in both English and in Swedish—regardless of the language in which they were taught.

The linguistic measures SPS and MLR do not provide much guidance with regards to student bilingual scientific literacy, they merely confirm the expectation that students speak more slowly and have shorter phrase lengths when speaking in English.

6.4. Results and discussion in terms of disciplinary discourse

Research question 4 has been answered by the development of the analytical framework described in section 4.5. The examples presented in this section illustrate the use of this analytical framework to answer research questions 5 and 6. 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 semiotic resources of disciplinary discourse that have been characterized as *representations*.

6.4.1. Discursive fluency through repetition

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

[You learn physics] by working with lots of problems—solving problems that’s the way.

And here another student quote (reported earlier in section 6.2.5.) that deals with the same theme:

[...]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! [in Swedish] The penny’s dropped!

(Airey & Linder, 2009:35)

With the growth of constructivist ideas about students making meaning for themselves, the behaviourist 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 is viewed as playing no meaningful role in learning. A similar 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 a student 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 described by students in terms of searching for variation. 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 (see section 4.5.8.).

This interpretation may 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 was new to both groups, the group which had had experience of several positions was found to be better at hitting the target. Marton et al. argue convincingly that the better performance of the second group is due to the variation they experienced by changing positions.

However, 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 work carried out for this thesis 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 three case studies attain *discursive fluency* in the various disciplinary semiotic resources through a process that includes repetition—what Kuhn (1962/1996:47) has likened to “finger exercises” on the piano.

In this characterization, then, gradual familiarization with the way meaning about a particular way of knowing is constituted in a particular semiotic

resource leads to increased discursive fluency in that resource. It is further suggested that discursive fluency is a necessary condition for experiencing the associated facets of a way of knowing through a given semiotic resource. In the following quotes students suggest that they use their discursive fluency (here in mathematical resources) in order to experience facets of the ways of knowing of the physics discipline.

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:

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, 2009:36)

These descriptions may be understood in terms of students using their discursive fluency in mathematical resources 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 resource help these students to structure input in terms of other semiotic resources 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 semiotic resources can be collected and ‘decoded’. Following this analytical framework, such decoding can itself only occur when students have become discursively fluent in these semiotic resources. 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 (see 6.4.2. below). Similar ideas have been discussed by Duval (2002; 2006) who outlines the circumstances in which movement from one mathematical representation to another may either lead to increased student comprehension, or to a discontinuity in the learning process.

6.4.2. When students are not fluent in certain semiotic resources

An illustrative example of a lack of discursive fluency is given below (diagrammatic resource). In this section of a lecture the lecturer drew a diagrammatic representation of a transformer on the board (Figure 6.1) and gave the following oral and written description.

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 whiteboard]

And concretely it looks like this.

[starting to draw Figure 6.1.] 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

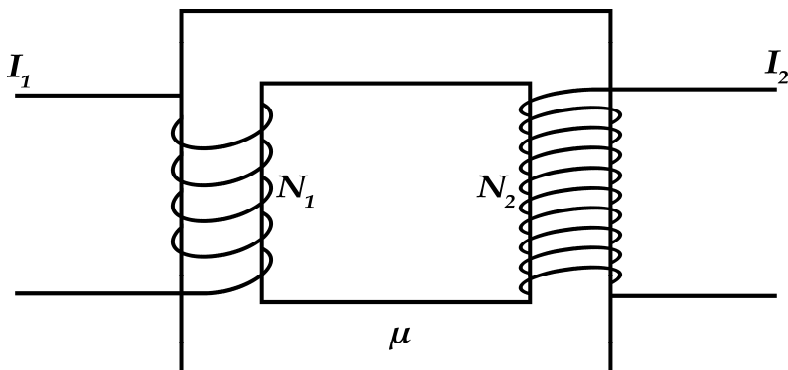


Figure 6.1. Diagrammatic representation of a transformer drawn by the lecturer on the whiteboard

(Airey & Linder, 2009:36)

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

- Interviewer: This is [the lecturer] 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 [on the whiteboard]...
- 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!

(Airey & Linder, 2009:37)

The interpretation here is that this student has not had the necessary holistic learning experience of the facets of the way of knowing ‘described’ by this combination of written and oral text and this particular disciplinary diagrammatic representation of a device for raising/lowering the EMF of an alternating current source. In the language of this thesis, the interviewed student has not become discursively fluent with respect to this disciplinary way of knowing about the transformer vis-à-vis mutual inductance. This student was attending an intermediate-level course dealing with the principles of inductance, yet had not become appropriately proficient in seeing and handling this particular diagrammatic representation and thus little of the necessary appresentation is able to be evoked. Had the student instead answered something like, “The lecturer drew a diagram representing two solenoidal coils wrapped around an iron core so that equal amounts of magnetic flux could pass through each turn” then it could have been inferred that this student was discursively fluent in this semiotic resource. 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 an actual transformer, nor understood why changing voltages, currents and associated electric and magnetic 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 a holistic access to the disciplinary way of knowing.

This piece of student transcript is a good illustration of Northedge’s (2002) claim that some meanings cannot be construed from outside the discourse of the discipline. All the other students in case study 1 appeared to relate the diagram to a shared disciplinary way of knowing. As discussed earlier in section 4.5.7, in phenomenological terms, the various facets of the way of knowing were appresent for them. Logically, however, there must also have been some stage when the diagram did not evoke 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—they have become fluent in the discourse of the discipline. It is therefore suggested that students will need to become fluent in a given semiotic resource of disciplinary discourse before they are able to experience the facets of the particular disciplinary way of knowing that that resource affords.

6.4.3. Necessary but not sufficient: discourse imitation

If it is accepted 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 semiotic resource automatically lead to a student experiencing the associated facets of a disciplinary way of knowing? Engagement with the data from the three case studies suggests that discursive

sive fluency is a *necessary but not sufficient condition*—that is students may learn to use a semiotic resource appropriately, but still not experience the associated facets of a way of knowing. The term discourse imitation is now introduced to characterize discursive fluency without a corresponding experience of the associated facets of a disciplinary way of knowing.

The 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 contemporary teaching of academic writing (Clark, 1951; Mintock, 1995; Rider, 1990). The notion can also be seen to be discussed by Bakhtin (1953/1986), who uses the term *ventriloquation*. This term has been characterized by Knapp (2006:7) as “[...] the voicing of or use of [...] someone else’s words without a full underlying understanding of the meaning”. 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 component of the undergraduate learning experience and can be enacted with respect to any of the semiotic resources that collectively form the disciplinary discourse of university science.

Below are examples of discourse imitation—instances where students are fluent in one or more semiotic resources of the 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 disciplinary 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.
- (Airey & Linder, 2009:38)

It is possible to convincingly argue from the above transcript that the student is discursively fluent in the mathematical and oral semiotic resources with respect to this particular way of knowing. Here, strong supporting evidence for diSessa's (1993) 'slogans' can be seen in the words "conservative vector field". The student knows the expression and uses it appropriately, but the description carries little, if any, holistic meaning or appresentation. It is clear that the student has not experienced the way of knowing this phrase represents. Here, the lecturer was using this idea to provide a conceptual link between the electrostatic case (magnetic field constant)—that he presumed was already well understood—and the case of the varying magnetic field that he intended exploring as his object of learning. In the terms of this thesis, the student's description exhibits discourse imitation. The student can calculate answers using the curl of E formulation (in fact this student had been one of the more successful participants on the degree course up to that point, and self-reports finding the mathematics needed for physics 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 semiotic resource 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 self-consciously] 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 [to understand something].

(Airey & Linder, 2009:39)

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 that this mathematical resource represents is still not available to the student.

6.4.4. Translation between semiotic resources

Iterations through the interview data suggest that discursive fluency in some of the semiotic resources 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*.

(Airey & Linder, 2009:39)

This student's suggestion that only mathematics can describe quantum physics is strikingly similar to a description offered elsewhere by an American physics professor:

The problem is you're trying to shoehorn a phenomenon into ordinary everyday English language, and I think the problem is with the language, not with the phenomenon. So, if you ask me to explain it in English, I think English has limitations which make it impossible to give a satisfactory explanation in English. But, I don't have to understand it in English. I mean, I think I sort of know what's going on. At least I have realized the limitations in English and, it doesn't bother me."

(Brookes & Etkina, 2007:3-4)

These descriptions are taken as confirmation that the various semiotic resources 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 semiotic resources. Certainly, as the student suggests, the disciplinary way of knowing the world which is called quantum physics is best represented through a higher 'proportion' of mathematics in relation to oral and written language than, say, Newtonian mechanics.

It is suggested that the student is struggling with the appresentation aspect and consequently is attempting to translate the meaning in a mathematical

resource to some kind of meaning in oral (line 2) and visual (line 4) resources. Following Stern, Aprea, & Ebner (2003) and Duval (2002; 2006) such re-representation of meaning can be seen as an important part of learning because such translation between resources offers the possibility of opening up further facets of a disciplinary way of knowing that a learner was previously unaware of, or unable to fruitfully access. 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.

(Airey & Linder, 2009:39)

This is a good illustration of the way in which the student recognizes in moving from written and oral semiotic resources—reading about and listening to descriptions of a way of knowing—to a mathematical semiotic resource—'calculating'—that there is a mismatch' between her own way of knowing and that of the discipline. The student realizes that she is not fluent in the mathematical resources with respect to this disciplinary way of knowing, and that certain facets of the way of knowing are therefore unavailable to her. Thus it is suggested that students who have not appropriately experienced a disciplinary way of knowing may have the possibility for such an appropriate experience opened up for them by translation between semiotic resources.

Similarly, since each resource both has and opens up different possibilities for meaning-making it therefore seems reasonable to argue, following Marton & Tsui (2004), that from a variation point of view, a *multi-modal* approach to teaching will enhance the possibility of appropriate learning. For example, here is a student describing the usefulness of such multi-modality 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, 2009:40)

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

6.4.5. Critical constellations of semiotic resources

From the point of view of disciplinary discourse, it may be said that *no one semiotic resource 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 resource alone.¹⁰ That is not to say that mono-modal discourse may not be useful within the scientific community. Once students have discursive fluency across semiotic resources, the presentation of a few short phrases, a mathematical formula, or a simple diagram, functions as a sort of disciplinary shorthand that facilitates powerful meaning sharing—those facets of a way of knowing which are not present in the immediate semiotic resource 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 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 disciplinary semiotic resources*. Once a way of knowing has been experienced, it can be activated across several other disciplinary resources, but first one needs fluency in a critical constellation of semiotic resources.

Naturally, it is not suggested that providing students with access to a certain constellation of disciplinary semiotic resources is sufficient in itself to guarantee a desired learning outcome—far from it. A great deal of research has pointed to the importance of other factors beyond difficulties that students have dealing with the semiotic resources that a discipline offers for the teaching and learning of its ways of knowing. Here examples that need to be considered in descriptions of science learning include attributes such as gen-

¹⁰ This not meant to suggest 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 resources of English or Swedish.

der and power relations (Conefrey, 1997; Linder & Marshall, 1998; Thomas, 1990), student epistemology (Hammer, 1995), culture (Brown, 2004), group dynamics (Bianchini, 1997), approaches to learning (Marton & Säljö, 1976; Svensson, 1976, 1977, 1984), etc. Thus, much of the interview data presented in this thesis could be gainfully interpreted from any or all of these perspectives. However, it is argued that, irrespective of these student-related factors, certain disciplinary ways of knowing may be *impossible to appropriately constitute* without discursive fluency in a critical combination of disciplinary semiotic resources.

From this multi-modal 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 (c.f. the discussion of interpretive and generative control in section 4.4.1). Givry & Roth (2006) have described how student meaning making with semiotic resources may not initially have a stable sense but can change over a short period of time, even within the same context. In this respect, 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 multi-modal student discourse can be seen in Stern, Aprea, & Ebner (2003) and Kozma, Chin, Russell, & Marx (2000). Thus, it is suggested that the role of the teacher should be one of guiding students away from the use of variable, context-dependent semiotic resources, to the use of the standard, disciplinary discourse for each disciplinary way of knowing within a given context. Hammer, Elby, Scherr & Redish (2005) can be seen to have arrived at a similar conclusion although from a quite different starting point. Experience suggests that the supporting of students’ own meaning making within disciplinary discourse is typically not a common practice in university science education. When present, 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 demonstrates the use of mathematical semiotic resources.

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 typically are in the social sciences and humanities.

These assertions are reformulated in this thesis to suggest that students need to be given the opportunity in a supporting environment to ‘discourse’ in science, in order to gain the necessary fluency. That is, students need op-

portunities to practice using a range of disciplinary semiotic resources with respect to the various objects of learning that their program is made up of. The students in the three case studies repeatedly indicated that a large segment of their learning occurs when ‘discoursing’ with each other using what could be recognized as being various semiotic resources. This is similar to the findings of Svensson & Högfors (1988). Unfortunately, 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 fluent user of disciplinary discourse is often under-exploited in university science. In their teaching, many science lecturers appear to at best reconstitute the representations, tools and activities of science in language terms, or at worst even take them for granted.

One way of thinking about this problem is to see science learning as metaphorically analogous to learning a foreign language. The easiest way to learn a foreign language is to travel to a country where the language is spoken and then stay there for a while, interacting with native speakers. Similarly, the easiest way to learn science is through *doing* science together with scientists (c.f. Lave & Wenger, 1991). 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.

6.4.6. More about discourse imitation

In section 6.4.3. it was argued that students may use disciplinary discourse appropriately but still fail to holistically experience a disciplinary way of knowing. If such discourse imitation continues for any length of time without an experience of the corresponding facets of a disciplinary way of knowing, it is argued that students may set out on an imitation-revelation learning trajectory. On this trajectory students may experience the disciplinary way of knowing in a sudden “Eureka!” moment or revelation. In such cases, the discourse in which a student has become fluent is suddenly and spontaneously linked to the disciplinary ways of knowing that it represents.

Although the data from the three case studies does not directly exemplify this, Ahlberg (2004) has 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. In the terms of this thesis, these early student experiences can be interpreted 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. However, it is suggested that usually 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, experience suggests that learners will, in the normal course of events, find it difficult to point out precisely when discursive fluency has led to them to experience a particular disciplinary way of knowing.

Part of the analysis of the data from the three case studies brought to the fore the notion that the route to learning a disciplinary discourse involves at least some element of discourse imitation—that is students appear to initially achieve discursive fluency without holistically experiencing the associated disciplinary ways of knowing. If this is indeed the case, then lecturers need to be reflective about student learning not only when students show that their understanding is lacking in some aspect(s), but also when students seemingly do understand appropriately through the provision of 'correct' answers. Lecturers need to be as sure as they can be that their students are playing the same 'language game' (Wittgenstein, 1958) as the rest of the discipline. Wickman & Östman (2002) discuss how Wittgenstein's language games can be operationalized, using the idea of lingering gaps in discourse. An experienced and insightful lecturer, who has come to know students as learners will notice these gaps and see them as a cue for further efforts to promote holistic and appropriate understanding (Prosser & Trigwell, 1999).

It is now well established that assessment plays an important role in influencing the approach—deep or surface—that students adopt for parts of their learning (Fransson, 1977; Hakstian, 1971; Marton & Säljö, 1976; Newble & Jaeger, 1983; Peters, 1982; Scoulier & Prosser, 1994). If disciplinary ways of knowing can only be experienced through discursive fluency in a critical constellation of disciplinary semiotic resources, then it is suggested that the design of assessment which takes into account these resources will help shift students towards a deeper approach to learning (and hence minimize prolonged discourse imitation).

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 appropriately experiencing the ways of knowing of the discipline. Furthermore, since disciplinary discourse is multi-modal, examinations using mainly mathematical disciplinary resources may encourage prolonged discourse imitation (and a surface approach to learning), particularly at introductory levels. Why should a student pay attention to all those other semiotic resources if the perception is that only fluency in mathematical resources is formally graded? For physics, the mono-modal mathematics case was well critiqued by Hewitt (1983) in his 1982 Millikan Award Lecture as follows:

Why is it common for students to avoid basic physics and instead take biology? Biology is much more complicated than physics. Physics is so simple, in fact, that it's easily expressed in mathematical form. But that's the problem for most people; because it *can* be expressed mathematically, *it is*. And for most people, mathematics is a foreign language. The reason more students elect biology is because it's common knowledge that biology is taught qualitatively while physics is taught quantitatively. *Physics is easy to teach mathematically, but we make a mistake by then assuming it is easy to learn mathematically.*

(Hewitt, 1983:305 emphasis added)

Today, over a quarter of a century later, many in the physics teaching community have hardly progressed at all from this position. The extensive work carried out in higher education, has principally been centered on difficulties that students have in learning through particular semiotic resources (see Redish, 2003 for an excellent collation of this work). Despite the existence of research which explores the possibilities for enhancing learning by combining semiotic resources (see literature review section 2.2.4.), many courses are still examined from a purely mathematical perspective.

6.4.7. Critical constellations in other disciplines

Clearly the proportions and combinations of semiotic resources are radically different when examining ways of knowing in disciplines other than university science. As detailed in section 2.4.5. this thesis builds on Fairclough's (1995) ideas to suggest that each discipline has its own specific order of discourse or disciplinary 'grammar'. So, whilst there may only be a limited number of semiotic resources that contribute to discursive fluency in a discipline, each discipline uses and develops the 'grammar' of these resources differently. For example, art history would use very different resources than economics. One could expect art history to have a much more developed use of visual resources, using a much more complex visual grammar or order of discourse for those particular resources than economics. Even when disciplines appear to use a semiotic resource in similar ways this can be misleading. For an example, suppose political science students and physics students were independently asked to interpret the following statement: "The work done by a conservative force is zero". Although both sets of students receive the same input in exactly the same semiotic resource, it is argued that political science students would relate this to a way of knowing centered around liberal/conservative political rhetoric, whilst physics students would relate this to the work on an object by a force being independent of the path taken by the object. The meanings carried by the components 'work done' and 'conservative force' would have nothing in common beyond their superficial word-sounds.

Disciplinary ways of knowing can be more or less complex and/or more or less abstract. In general, the more semiotic resources a discipline uses, the higher the complexity and abstraction of the disciplinary way of knowing they describe. It is tempting to suggest that a discipline like physics which uses a wide variety of semiotic resources is more complex than say English literature which uses much fewer resources. However, as was posited earlier in this section, disciplines develop their orders of discourse in different ways. To say that English literature is less complex than physics since it uses fewer semiotic resources would be to overlook the specialized growth in the use of oral and written resources that has occurred in the discipline of English literature. In this respect physics discourse could be viewed as only functioning at a very basic level within these oral and written resources. So, a more complex learning task would require either more semiotic resources for appropriate constitution or a more highly developed use of a few semiotic resources (more complex order of discourse). However, if a discipline does have a large number of semiotic resources, then students will need to become fluent in all of them. Moreover, following Lemke (1998:7), students will need to “orchestrate movement” between these resources in order to more fully represent a disciplinary way of knowing. Thus, it *could* be argued that the more semiotic resources, the more difficult it is to become discursively fluent in that discipline—simply because students might not see the need to develop the full complement of resources and hence be satisfied with fluency in a reduced set.

6.4.8 Fluency or literacy?

In this thesis, two similar concepts have been developed and defined—fluency in disciplinary discourse and bilingual scientific literacy. Both of these concepts have been ‘stretched’ from their initial language focus in order to describe a wider range of meaning. The concept of fluency is developed from analogy with an oral description, whilst the concept of literacy is developed from analogy with written descriptions (Norris & Phillips, 2003). In effect, then, the two concepts are very similar, and it may be possible to unite these ideas in future work.

6.4.9. Summary of results with respect to discourse

The application of the discourse analytical framework to the case study data resulted in three theoretical ideas. First, it was suggested that students may initially *imitate* disciplinary discourse, i.e., use disciplinary semiotic resources in line with the disciplinary order of discourse, but without an appropriate holistic experience of the related disciplinary way of knowing. Second, it was proposed that translation between semiotic resources can make apparent this mismatch between the students’ own ways of knowing

and that of the discipline. Finally, it is posited that there is a critical constellation of disciplinary semiotic resources that students need to achieve fluency in *before* they can have the possibility of an appropriate holistic experience of a disciplinary way of knowing.

6.5. Summary

This chapter has presented the combined results of the thesis in terms of language, scientific literacy and discourse. These results are briefly summarized and related to the original research questions in chapter seven.

7. Summary of outcomes

The work presented in this thesis can be seen to fall into three broad themes: language of instruction, scientific literacy and disciplinary discourse. This chapter summarizes the findings and pedagogical recommendations presented in chapter 6 with respect to the six research questions.

7.1. Language of instruction

The first intention of this thesis was to investigate the differences that occur when physics undergraduates are taught in English. In this respect, the first research question for this thesis was as follows:

How do Swedish undergraduates experience the differences between being taught physics in English and in Swedish?

Here there are a number of interesting findings. First, students claimed that there were very few differences between being taught in English or in Swedish—they believed that language played an unimportant role in their learning. Despite this claim, during stimulated recall, a number of important differences between the two teaching situations were identified. When taught in English, the students in the three case studies:

- asked and answered fewer questions.
- reported being less able to follow the lecture and take notes at the same time.

There were a number of strategies employed by students to address these differences:

- Students tended to ask more questions *after* the lecture.
- Some students changed their study habits so that they no longer took notes in class.
- Some students had started to read sections of work before class.
- Others simply used the lecture for mechanical note-taking.

It is also interesting that, for the most part, students were unaware that they had adapted to being taught in English in these ways.

The results of this part of the thesis, led to the following advice to lecturers who teach in English:

- Discuss the fact that there are differences when lectures are in a second language.
- Create more opportunities for students to ask and answer questions.
- Allow time at the end the lecture for students to ask questions and encourage students to use this opportunity.
- Be reflective when introducing new material in lectures.
- Expect students to read material before the lecture.
- Give as much multi-representational support as possible.

7.2. Bilingual scientific literacy

The second research question for this thesis concerned the type of scientific literacy implied by the use of language in the teaching of undergraduate physics:

What type of student competencies with respect to bilingual scientific literacy do undergraduate physics courses appear to imply?

Here, it was found that:

- It is unusual for physics syllabuses to mention the language goals of the course.
- Practice in the control of spoken disciplinary English and Swedish does not appear to be encouraged.

Since language appears to be seen as unproblematic, and is taken for granted in the majority of undergraduate physics syllabuses, it was suggested that all courses should be analyzed in terms of: the Vision (Roberts; 2007), the language (English or Swedish), and the type of control that is desired (interpretive or generative). Figure 7.1. was suggested as a tool to help lecturers think about bilingual scientific literacy in their courses.

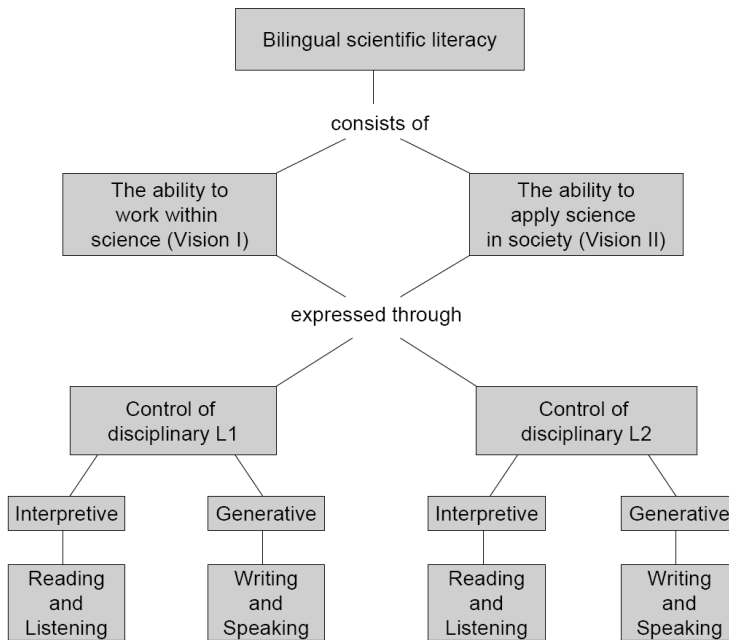


Figure 7.1. *Modelling bilingual scientific literacy within a natural science degree (adapted from Airey & Linder, 2008).*

Having identified spoken English and Swedish as the least developed disciplinary resources, the third research question for this thesis dealt with spoken bilingual scientific literacy:

How does the teaching language affect the bilingual scientific literacy of undergraduate physics students?

Here it was found that some (first year) students found it almost impossible to describe disciplinary concepts in English. As a group, second-year students gave much better descriptions of disciplinary concepts than first-year students.

As regards code-switching in descriptions of disciplinary concepts in English, first-year code-switching was more likely to cause a breakdown in communication than second-year code-switching. For all students, code-switching in descriptions of disciplinary concepts in Swedish only occurred when English had been used in the teaching of the concept. Moreover, it was suggested that this code-switching in Swedish was unlikely to cause a breakdown in communication.

Disregarding the students who had problems with disciplinary descriptions in English, all students gave similarly rated descriptions of disciplinary

concepts in both languages. Thus, it was suggested that *above a lower threshold, the language in which students are taught does not appear to matter.*

7.3. Disciplinary discourse

The initial language focus of this thesis was broadened to include other semiotic resources that were necessary for a satisfactory description of interview data. These resources were brought together in the framework of disciplinary discourse. The fourth research question for this thesis was:

How may learning in university physics be characterized in terms of learning a disciplinary discourse?

Here the analytical framework developed in section 4.5 answers this question as follows:

- The disciplinary discourse of university science is made up of a wide range of semiotic resources.
- Learning in university physics can be characterized in terms of becoming ‘fluent’ in these resources

With learning characterized in terms of fluency, the immediate question became one of how this fluency was attained. Hence, the fifth research question was:

How do students become ‘fluent’ in the collection of semiotic resources that together form the disciplinary discourse of university science?

It was found that students described a repetitive practice element in their learning (working with a large number of problem sets, their notes, the book, etc.). It was suggested that this repetitive practice is the means by which students become fluent in disciplinary discourse.

The sixth and final research question for this thesis was:

How are disciplinary semiotic resources related to an appropriate, holistic experience of a disciplinary concept?

Here it was found that fluency in a given semiotic resource was a necessary (but not sufficient) condition for experiencing the facets of a disciplinary way of knowing that that resource allowed access to. When students were not fluent, it was found that they may *imitate* the disciplinary discourse. It

was suggested that an element of discourse imitation may therefore be a natural stage on the way to students experiencing a disciplinary way of knowing.

It was noted that a single semiotic resource can never be fully representative of a disciplinary way of knowing. Thus, *translation* between semiotic resources can help students notice new aspects of a disciplinary way of knowing. At this point, discrepancies between the student's way of knowing and that of the discipline may become apparent.

The final finding of this thesis was that *only certain critical constellations of disciplinary semiotic resources may be able to afford access to disciplinary ways of knowing.*

The following pedagogical observations were made:

- Students need opportunities to practice 'discoursing' (i.e. using the representations, tools and activities of the discipline) as an integral part of their science education.
- The assessment criteria for university science courses should reflect the multi-modal nature of disciplinary knowledge, i.e., assessment should be authentic.
- The specialist knowledge of lecturers as experts in using disciplinary discourse may often be under-exploited in university science courses.
- To improve the possibilities for learning, lecturers need to come to better understand the specific constellations of semiotic resources necessary for a full representation of each individual disciplinary way of knowing.

8. Future research

This thesis took its starting point from the work of Klaassen (2001). Her study of engineering students in the Netherlands suggested that, over a period of a year, students somehow adapted to being taught in English. This thesis confirms Klaassen's findings and furthers our knowledge in this area by identifying some of the ways in which students adapt their study habits to cope with a change of teaching language. Naturally, during the course of this work a number of new questions have arisen.

First, this thesis points out that some first-year students do have great difficulties describing disciplinary concepts in English. It is therefore suggested that future research should focus closely on the *early stages* when students are first taught in English in university education—following students and documenting adaptation processes. A related, short-term, longitudinal study should answer the question of whether such students do, in fact, adapt, or whether the absence of such students in the second-year may be due to student attrition due to the teaching language.

The second question deals with speaking rate. One of the findings in this thesis was that students speak much more slowly when describing disciplinary concepts in English, however, the disciplinary content of these descriptions was much the same in both languages. An extension of this work would be to examine *lecturer* speaking rates. Do lecturers also speak more slowly when they lecture in English, and, if so, is more time needed to teach a course when it is taught in English? Or, put another way, is there a risk that time constraints mean that lecturers may actually 'cover' less material when they teach a lecture series in English rather than in Swedish?

A further question relates to scientific literacy and the training of future science teachers. What is the relationship between the English-language, discipline-based scientific literacy that trainee teachers develop in undergraduate courses taught in English, and the Swedish-language scientific literacy needed for teaching in schools, which is often framed within an everyday perspective?

Next, one of the main contributions of this thesis is the bringing together of disciplinary semiotic resources into the single analytical framework of disciplinary discourse. However, as pointed out in section 6.4, the data gathered for this thesis 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, a study of student interaction with the wide range of semiotic resources available in the physics laboratory would be a natural extension of the work presented in this thesis. It is suggested that in such environments a disciplinary discourse approach would have a distinct potential for extending our understanding of student learning.

Finally, (and most importantly), the claim is made in this thesis that there is a critical constellation of disciplinary semiotic resources that are necessary for an appropriate holistic experience of any given disciplinary concept. Research should therefore be carried out into *which* resources are necessary for the effective teaching and learning of given disciplinary concepts, particularly in a university science environment such as physics.

9. Summary in Swedish

Naturvetenskap, språk och ämneskompetens

Fallstudier av lärande på engelska och svenska inom högskolefysik

9.1. Bakgrund

I skrivande stund förbereder sig europeiska högskolor och universitet för en stor tillströmning utbytesstudenter. Den största anledningen till detta är den nyligen fastslagna Bolognadeklarationen som är tänkt att vara fullt genomförd 2010 (Bologna Process, 2007). Avsikten med denna deklaration är att likrikta den högre utbildningen i Europa och därmed möjliggöra en större rörelsefrihet för studenterna i de 46 medlemsländer som deltar i processen. Som ett led i dessa förberedelser har många högskolor och universitet beslutat att använda sig av engelska som undervisningsspråk i olika kurser. Detta gäller i synnerhet de nordiska länderna. Ett antal färskta studier rörande engelska som undervisningsspråk visar att endast Nederländerna erbjuder fler platser på engelskspråkiga kurser än de nordiska universiteten (Maiworm & Wächter, 2002; Wächter & Maiworm, 2008). Under hösten 2007 förväntades exempelvis hälften av alla svenska masterutbildningar använda sig av engelska som undervisningsspråk (Högskoleverket, 2007). Även på grundnivå undervisas idag många kurser i Sverige endast på engelska. Detta är särskilt vanligt i kurser i naturvetenskap, teknik och medicin där större delen av kurslitteraturen sedan länge är på engelska och där engelskan fått en allt mer central roll i egenskap av naturvetenskapens *lingua franca* (Ammon, 2001; Falk, 2001a; Gunnarsson & Öhman, 1997).

Även om bytet av undervisningsspråk ofta välkomnats av lärare och studenter är det naturligtvis viktigt att undersöka hur det påverkar lärandet. Det är dock först på senare år man har börjat göra detta. Faktum är att det finns väldigt lite forskning kring hur en sådan förändring påverkar ämneslärandet. Met och Lorenz (1997), liksom Duff (1997), menar att begränsade kunskaper i undervisningsspråket kan göra det svårare för studenten att tillägna sig abstrakta ämnesbegrepp. Här kan man notera att relationen mellan språk och ämne är synnerligen problematisk och komplex—även när undervisning sker på studenternas modersmål. Som Östman (1998) har påpekat är det ämnesrelaterade språkbruket abstrakt och hör samman med särskilda kommunikativa

traditioner och antaganden. Säljö (2000) ser saken på ett liknande sätt och menar att studenternas problem egentligen består i en svårighet i att hantera och förstå synnerligen specialiserade former av kommunikation som inte används i vardagliga situationer.

Eftersom ett antal forskare på detta sätt pekar på ett både centralt och komplext förhållande mellan språk och ämneslärande skulle man kunna förvänta sig en uppsjö av forskning kring ämnet—forskning som i synnerhet fokuserar på engelskan som undervisningsspråk. Dessvärre finns det mycket litet nordisk forskning som diskuterar och belyser övergången till engelska som undervisningsspråk inom den högre utbildningen. Ett antal internationella och svenska studier har dokumenterat utbredningen av *användandet* av engelska och en hel del studier har avhandlat effekterna för *språklärande* av ämnesundervisning på engelska. Däremot är forskning som berör kopplingen mellan *ämneslärande* och språkval mycket begränsad och har mestadels bestått i försök att finna statistiska korrelationer mellan undervisningsspråk och ämnesprestationer på nationella prov och dylikt. Resultaten av dessa studier är svårtolkade då det mest slående draget oftast har varit likheterna mellan forsknings- och kontrollgrupperna. Det finns dock några internationella studier från Hong Kong, Sydafrika, Nya Zeeland och Nederländerna som pekar på att det kan finnas negativa konsekvenser för ämneslärande när undervisningen inte sker på studenternas modersmål. Den mest omfattande av dessa studier, utförd i Nederländerna (Klaassen, 2001) visar att den negativa effekten på ämneslärande försvann efter ett år. Klaassen drar slutsatsen att de ingenjörstudenter som deltog i hennes studie hade anpassat sig till språkomställningen och föreslår en uppföljande studie där man belyser de mekanismer som gjorde denna anpassning möjlig. Denna avhandling har Klaassens arbete som utgångspunkt. Avhandlingen är också den första svenska undersökningen av hur valet av undervisningsspråk påverkar ämneslärande på högskolenivå.

9.2. Syfte

Syftet med avhandlingen är att undersöka undervisningen i fysik på högskolenivå. Det arbete som redovisas här har sitt ursprung i ett intresse för de två språk som används i undervisningen av högskolefysik—engelska och svenska. Hur påverkas fysiklärande när lektionerna ges på olika språk? Under den tid då data samlades och analyserades utvidgades först forskningsfrågan till att omfatta tre ”språk”: engelska, svenska och matematik, och därefter till mer övergripande frågor rörande *tvåspråkig ämneskompetens* (på engelska: *bilingual scientific literacy*) samt om huruvida fysikkunskaper representeras av *fysikämnets diskurs*.

De forskningsfrågor som avhandlingen tar upp och försöker besvara är följande:

1. Hur upplever svenska studenter skillnaderna mellan fysiklektioner som ges på engelska respektive svenska?
2. Vilka underförstådda attityder till den tvåspråkiga ämneskompetensen står att finna i universitetskurser i naturvetenskap?
3. Hur påverkas fysikstudenters muntliga, tvåspråkiga ämneskompetens av undervisningsspråket?
4. I vilken mån kan lärandet i högskolefysik beskrivas och förklaras som ett närmande till en *ämnesdiskurs*?
5. Hur beskriver studenterna det sätt på vilket de lär sig att tolka och använda de olika semiotiska resurser¹¹ som tillsammans bildar en ämnesdiskurs?
6. På vilket sätt kan ämnesspecifika, semiotiska resurser relateras till lärandet av olika ämnesbegrepp?

9.3. Metod

I ett försök att undvika några av de problem som drabbat tidigare undersökningar har denna studie dokumenterat studenters *erfarenheter och lärandemönster* när de undervisas på svenska respektive engelska. Denna dokumentering möjliggjordes genom videoinspelning av lektioner och med hjälp av intervjuer med studenter på fem kurser vid två svenska högskolor. Varje student var närvarande vid två lektioner, en på engelska och en på svenska, vilka både utgjorde en del av deras utbildningsprogram. Vid intervjuerna tillämpades stimulerad hågkomst (stimulated recall) där valda delar av videoinspelningarna av lektionerna visades upp för studenterna varvid studenterna fick berätta hur de gjorde, vad de tänkte just då och hur de upplevde det material som avhandlades. Studenternas beskrivningar av sina erfarenheter av undervisningsmaterialet samlades in på både svenska och engelska och därmed fanns möjlighet att både undersöka hur studenter förstår, beskriver och förklarar fysiska fenomen på båda språken och att söka kopplingar mellan dessa kompetenser och undervisningsspråket.

¹¹ En ämnesdiskurs består i ett antal s.k. *semiotiska resurser* t.ex. talspråk, skriftspråk, matematik, grafiska framställningar, diagram, tekniska redskap och arbetssätt.

9.4. Resultat och diskussion

9.4.1. Fysiklektioner på engelska och svenska

1. Hur upplever svenska studenter skillnaderna mellan fysiklektioner som ges på engelska respektive svenska?

Huvudslutsatsen av denna del av undersökningen är att det finns ett antal skillnader i sättet som svenska fysikstudenter upplever lektioner när de ges på svenska respektive engelska—men att studenterna för det mesta inte själva uppmärksammar dessa skillnader. När undervisningen skedde på engelska ställde och besvarade studenterna i denna studie färre frågor och de berättade också hur det var svårare för dem att följa lektionens 'röda tråd' samtidigt som de antecknade. Studenterna anpassade sig till dessa förhållanden genom att ställa frågor efter lektionen. De förändrade också sina studievänor så att de: 1) inte längre antecknade under själva lektionen, 2) läste igenom studiematerialet före lektionen, eller, 3) i sämsta fall—använde lektionen för mekanisk avskrivning som (kanske) bearbetades efter lektionstillfället.

Studien utmynnar i följande pedagogiska förslag som syftar till att minska de negativa effekter som kan uppstå när undervisning äger rum på engelska:

- Diskutera språkproblemen

Studenterna i studien uttryckte ofta tacksamhet över möjligheten att diskutera undervisningsspråket under intervjuerna. Studenter blir bättre rustade i att hantera språkbytet om de har förståelse för de problem som kan uppstå när undervisningen sker på engelska och när de har tänkt igenom sitt eget förhållningssätt. Dessutom finns det särskilda strategier som studenter och lärare kan använda sig av för att öka tillgängligheten när lektioner äger rum på engelska (läs vidare).

- Uppmuntra smågruppsdiskussioner

Tre orsaker till sämre fråge- och svarsfrekvens när lektioner ges på engelska verkar vara 1) osäkerhet om man har förstått frågan rätt, 2) rädsla för att visa sin okunnighet och 3) rädsla för att tala engelska. Som lärare kan man råda bot på dessa problem genom korta diskussioner i mindre grupper eller i par. Dessa s.k. bikupor tillåter studenterna att kontrollera sin förståelse och generera nya frågor i ett mer skyddat forum (Bligh, 1998). Studenterna känner sig därmed mindre utsatta, eftersom det är *gruppen* och inte individen som svarar på lärarens frågor. Varje grupp väljer en person som ska lägga fram de gemensamma idéerna. De studenter som inte tycker om att tala engelska kommer givetvis fortfarande att undvika detta, men de kommer ändå att ha utbyte med läraren *genom gruppen*.

- Avsätt tid för frågor efter lektionen

Att som lärare göra sig tillgänglig för frågor vid lektionens slut tillåter studenterna att diskutera problem på ett mindre utsatt sätt. Förmodligen är ett bra tips att sluta lektionen tidigt så att lärare och studenter inte behöver rusa iväg. Här kan det vara bra om studenterna även får chansen att ställa sina frågor på svenska.

- Presentera nytt material med hjälp av ett lektionsunderlag

Det klassiska sättet att introducera nytt material är genom föreläsning. Undersökningen pekar på att studenterna kan få svårt att följa lektionens röda tråd samtidigt som de antecknar när kursen ges på engelska. Om nya begrepp behandlas under en lektion kan det vara bra att dela ut ett lektionsunderlag som studenterna kan följa med i och där de kan lägga till sina egna, korta förklaringar under lektionens gång.

- Uppmuntra studenterna att läsa på före lektionen

Det kan vara bra att få studenterna att läsa ett visst avsnitt före undervisnings tillfället; lektionen får då en slags bekräftande och förtydligande karaktär. Man kan välja en bok eller framställa ett eget kompendium som man sedan följer under lektionen.

- Använd flera presentationssätt

Lärare bör stödja sina muntliga framställningar med andra typer av presentationer som overheadbilder, lektionsunderlag, demonstrationer, datasimuleringar. Det är viktigt att dessa olika moment verkligen gynnar lektionens syfte—att använda sig av ett antal olika medier utan tydliga skäl blir bara förvirrande för studenterna. På samma sätt blir det extra viktigt med en logisk uppbyggnad av allt som skrivs på tavlan. Man kan säga att undervisningen på engelska överlag kräver att läraren är extra väl förberedd och har en mycket tydlig struktur på lektionen.

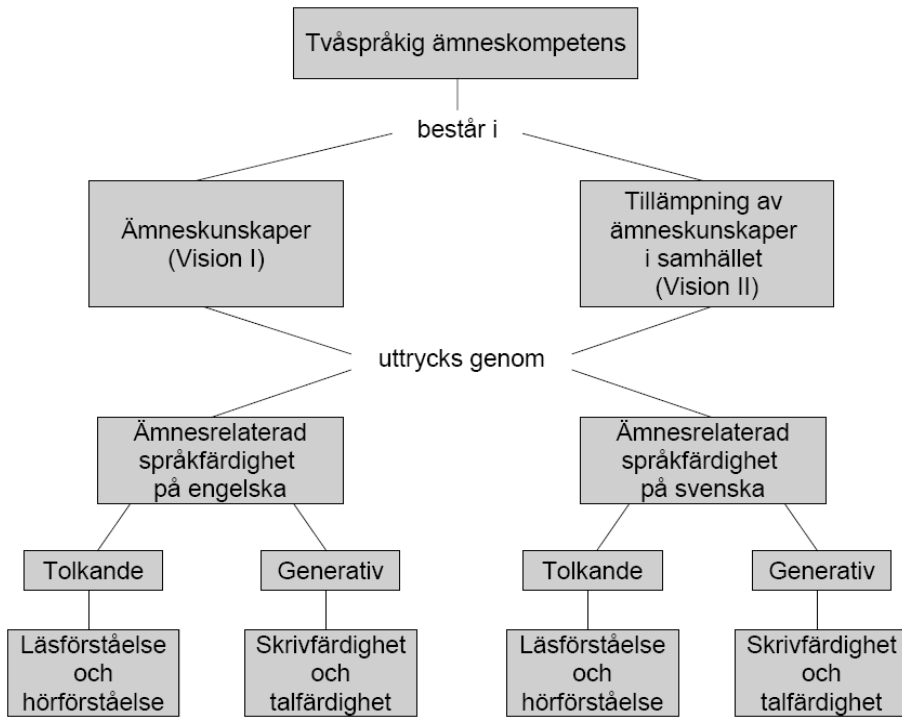
9.4.2. Tvåspråkig ämneskompetens (bilingual scientific literacy)

2. Vilka underförstådda attityder till den tvåspråkiga ämneskompetensen står att finna i universitetskurser i naturvetenskap?

Varför ägnar våra studenter tre till fyra år åt sin grundutbildning? Ett svar på denna fråga—det svar som läggs fram i denna avhandling—är att vi vill producera ämneskompetenta studenter. Den engelska termen ”science literacy”, som begreppet ämneskompetens bygger på, myntades av Hurd (1958), men

sedan dess har man inte enats om vad termen faktiskt betyder (Laugksch, 2000). Denna term skulle kunna översättas som ”naturvetenskaplig litteracitet”, men i denna sammanfattning föredras det närbesläktade och på svenska mer gångbara begreppet ”ämneskompetens”. Frågan är sålunda vad som menas med ämneskompetens? Roberts (2007) har här bidragit till förståelsen av detta genom att lägga fram två olika *visioner* av vad ämneskompetens faktiskt består i: Vision I handlar om att förstå och hantera innehållet i ämnet som sådant och Vision II rör förståelsen för hur ämnet kan tillämpas, i synnerhet i samband med vardagliga situationer. Roberts menar vidare att då man talar om ämneskompetens menar man egentligen en kombination av Vision I och Vision II. Man skulle kunna säga att den typ av ämneskompetens som en högskoleutbildning söker förmedla kan placeras någonstans på den tänkta linje som sammanbinder dessa två visioner. I denna avhandling definieras därför ämneskompetens som både förmågan att *arbeta inom ämnet* och förmågan att *tillämpa ämnet* i det dagliga livet.

Om man tänker sig att målet med högskolestudier är att frambringa ämneskompetenta studenter, i enlighet med denna definition, vilken natur har då denna ämneskompetens i förhållande till språket? Här är det lämpligt att stipulera ett nytt begrepp, *tvåspråkig ämneskompetens*. Med Roberts två visioner i åtanke används detta begrepp för att kunna beskriva de språkspecifika ämneskompetenser som fostras inom en typisk grundkurs inom den högre utbildningen. Här kan man notera att tvåspråkig ämneskompetens också kan indelas i *tolkande* (lyssnande och läsande) och *generativa* (talande och skrivande) komponenter. Därför är det viktigt att varje kursplan för högskolan tydligt beskriver den sammansättning av tvåspråkig ämneskompetens som eftersträvas. Detta låter sig göras genom en kombination av tre faktorer: visionen (I och II), språket (engelska och svenska) och typen av ämneskompetens (tolkande och generativ), se Figur 9.1.



Figur 9.1. Modell för beskrivning av tvåspråkig ämneskompetens

I denna avhandling föreslås att varje kurs på högskole- eller universitetsnivå bör analyseras utifrån detta språkperspektiv. Kursens lärandemål bör inte bara nämna de ämneskunskaper som man vill att studenterna tillgodogör sig, utan även de språkkompetenser som hör samman med dessa kunskaper. När man bestämt detta blir nästa steg att slå fast vilken typ av undervisning man tror kan hjälpa studenterna nå dessa mål.

Eftersom det är ovanligt med naturvetenskapliga kursplaner som specifikt tar upp språkkompetenser, genomfördes en mindre studie av 30 kursplaner för att illustrera de *underförstådda* attityder till ämneskompetens i allmänhet och tvåspråkig ämneskompetens i synnerhet som universitetskurser i naturvetenskap tycks innehålla. Här noterades att i jämförelse med andra ämnes-specifika semiotiska resurser, t.ex. matematik eller laborationsutrustning, tycks de lingvistiska resurserna vara sämre utvecklade, och av dessa är den muntliga färdigheten i både engelska och svenska mest eftersatt. Denna företeelse har diskuterats av Lemke (1990) som föreslagit att studenter borde få chansen att "tala naturvetenskap", samt Tobias (1986), menar att kvaliteten på undervisningen av naturvetenskap skulle höjas om studenter uppmuntrade att "bolla runt idéer lite" som de ofta får göra inom de samhällsvetenskapliga och humanistiska ämnena. I avhandlingen understryks dessa tankar

genom påståendet att utvecklingen av muntlig färdighet i båda språken skulle kunna vara en viktig faktor då studenten tillägnar sig sin ämneskompetens.

Eftersom muntlig engelska och svenska identifierades som det kanske mest eftersatta området, fokuserades den följande forskningsfrågan på detta problemområde:

3. Hur påverkas fysikstudenters muntliga, tvåspråkiga ämneskompetens av undervisningsspråket?

Den viktigaste frågan när man funderar kring bedömningen av tvåspråkig ämneskompetens rör validitet. Hur mäter man en students förmåga att tala om sitt ämne och hur ser en giltig eller tillräcklig kompetens ut? Inom lingvistik finns ett antal användbara metoder för att uppskatta olika grader av talfärdighet. De flesta av dessa mätmetoder förutsätter att det finns en korrelation mellan talförmåga och talets hastighet—detta för att en högre talhastighet anses indikera att kunskapen i fråga har automatiserats (Anderson, 1982). Hincks (2005) menar att man vid jämförelse av olika språk bör mäta talhastighet i stavelser per sekund (SPS)—istället för ord per minut (WPM)—då ordlängd kan variera mycket mellan olika språk. Andra studier har visat att det statistiskt viktigaste måttet av talförmåga är mängden tal mellan pauser (Kormos & Dénes, 2004; Towell et al., 1996). I detta fall räknar man frasers medellängd i antalet stavelser. Detta mått kallas för MLR (mean length of runs) i forskningen.

När man har två olika språk till sitt förfogande kan begrepp som saknar en exakt motsvarighet i det ena språket ersättas av kodväxling (då man alltså använder sig av ett ord eller fras från det andra språket). Nyttan av kodväxling för lärandet har påvisats av ett stort antal forskare från flera olika bakgrunder. Man menar allmänt att användandet av två språk i undervisningen skapar bättre möjligheter för diskussion kring och bildandet av kunskap (Se till exempel, Fakudze & Rollnick, 2008; Liebscher & Dailey-O’Caine, 2005; Moreno et al., 2002; Üstünel & Seedhouse, 2005). I denna avhandling används begreppet *ofrivillig kodväxling* för att beskriva en situation där kodväxling uppstår i en enspråkig omgivning. I intervjuerna instruerades studenterna att endast använda ett språk för att beskriva en viss situation. All den kodväxling som förekom bedömdes därför vara ofrivillig, vilket indikerade att studentens språk saknade en lexikal motsvarighet till ordet eller frasen ifråga.

Slutligen kan man konstatera att för att någon skall anses vara ämneskompetent, måste det som sägs vara begripligt från ett *ämnesperspektiv*—i detta fall fysikens. Det studenterna säger måste alltså ha ett ämnesinnehåll. Här är det viktigt att notera att studenternas metabeskrivningar rörande deras oförmåga att förstå inte nödvändigtvis tillhandahåller mycket information om ämneskompetensen som sådan, även om vissa beskrivningar hamnar högt på SPS- eller MLR-skalorna. Därför är det viktigt att bedöma ”ämnes-

mässigheten” i det som sagts. Följande skala användes då studenternas beskrivningar bedömdes i förhållande till deras ämnesmässighet:

Betyg	Beteckning	Beskrivning
1	Svag:	Studenten har uppenbarligen stora problem när han eller hon talar om ämnesbegrepp på detta språk.
2	Medel:	Studenten använder vissa ämnesbegrepp på ett riktigt sätt, men har antingen tydliga ämnes specifika lexikala luckor eller använder andra begrepp på ett felaktigt sätt.
3	God:	Studenten använder ämnesbegrepp på ett riktigt sätt i passagen, men utvecklar inte idéer till fullo.
4	Utmärkt:	Expertförklaring.

Sammanfattningsvis undersöker alltså denna avhandling möjligheten att triangulera tvåspråkig ämneskompetens med hjälp av talhastighet (SPS, MLR), ofrivillig kodväxling och en bedömning av ämnesmässigheten i det som sagts. I enlighet med denna metod jämfördes studenternas beskrivningar av närliggande ämnesbegrepp på båda språken. De texter som analyserats har valts ut från de tidigare intervjuerna genom en undersökning av de begreppsbeskrivningar som fanns att tillgå på båda språken. Resultaten av denna undersökning beskrivs nedan.

Det första som bör noteras är att två studenter upplevde att det nästan var omöjligt att tala om ämnesspecifika begrepp på engelska—de kodväxlar i en så hög grad att det i deras beskrivningar finns nästan lika mycket svenska som engelska. Dessa två förstaårsstudenter hade inte fått någon undervisning på engelska tidigare. Intressant nog hade dessa studenter inga större problem att tala om sin bakgrund på engelska under intervjuernas inledning, vilket visar att det är precis engelskspråkig ämneskompetens som de saknar. Som grupp kodväxlar förstaårsstudenterna mycket oftare än andraårsstudenterna.

Som man kunde förvänta sig kodväxlar alla studenter mycket mer sällan under sina svenska beskrivningar av sina ämnesspecifika begrepp. Ett mönster som kan urskiljas är att de studenter som faktiskt kodväxlar i sina svenska beskrivningar endast gör detta i de fall då engelska använts för att undervisa det begrepp som de beskriver. Det sågs som osannolikt att denna kodväxling på svenska skulle leda till ett sammanbrott i kommunikationen. Det finns två anledningar till detta påstående: inledningsvis var de lexikala luckor som gav

upphov till kodväxlingen till engelska sällan av central betydelse för förståelse av texten. För det andra, eftersom studenterna talar svenska, är det troligare att den som lyssnar förstår det kodväxlade ordet eller frasen på engelska. Detta andra antagande angående den som lyssnar kan givetvis inte göras när studenter beskriver ämnesrelaterade begrepp på engelska.

Vad gäller ämnesmässigheten rankades andraårsstudenterna högre än förstaårsstudenterna. Tre av de fem studenterna i fallstudie 1 fick betyget 3-4 för åtminstone en av sina beskrivningar. Detta kan jämföras med förstaårsstudenterna där ingen fick detta betyg för någon av sina beskrivningar.

Om man bortser från de två studenter som hade stora problem med sin engelska finns det en stark samstämmighet mellan studenternas ämnesmässighetsbetyg i de två språken—skillnaden höll sig inom en halv betygsenhet och den ”bättre” av de två beskrivningarna kunde lika gärna vara på engelska som på svenska. Det är uppenbarligen så att *när studenterna når över en viss tröskel vad gäller engelskspråkig ämneskompetens kan de producera likvärdiga beskrivningar av sitt ämne på både engelska och svenska, oavsett vilket språk de undervisats på.*

De lingvistiska måtten SPS och MLR visar sig inte vara speciellt användbara då man vill beskriva studenternas tvåspråkiga ämneskompetens. Detta skiljer sig från Hincks (2005:116) summering av tidigare forskning inom detta område där hon påstår att “[...] temporal measures provide a reliable estimation of second language ability”. Det är uppenbarligen så att när man nått över en lägre tröskel har andraspråkskompetens och tvåspråkig ämneskompetens lite med varandra att göra. Det enda man kan fastställa är att dessa resultat bekräftar tidigare forskning som visar att talhastigheten går ner (lägre SPS) och att frasernas längd kortas ner (lägre MLR) när man använder ett andraspråk. Studenterna i de tre fallstudierna talar i genomsnitt 45 procent saktare i sina ämnesrelaterade beskrivningar på engelska än då de använder svenska.

9.4.3. Fysikämnets diskurs

4. I vilken mån kan lärandet i högskolefysik beskrivas och förklaras som ett närmande till en *ämnesdiskurs*?

Under datainsamlingen uppmärksammades att lärande av fysikkunskap baseras på mycket mer än bara språk. Kunskapen läggs fram med hjälp av ett antal s.k. *semiotiska resurser* t.ex. matematik, grafiska framställningar, diagram, tekniska redskap och arbetsätt. I avhandlingen likställs därför begreppet ämnesdiskurs med en kombination av *representationer, fysiska redskap* och *aktiviteter*. Dessa relationer illustreras i Figur 9.2.



Figur 9.2. Relationen mellan ämnesdiskursen och dess semiotiska resurser

Det är förmodligen så att studenterna måste tillgodogöra sig dessa komponenter av ämnesdiskursen innan de kan tillägna sig de ämnesbegrepp som representeras.

Nästa frågan är då hur studenterna uppnår denna färdighet.

5. Hur beskriver studenterna det sätt på vilket de lär sig att tolka och använda de olika semiotiska resurser som tillsammans bildar en ämnesdiskurs?

Alla studenter i studien beskriver hur *repetitiv övning* spelar en viktig roll i deras växande förståelse av fysikämnet. I avhandlingen fastslås att denna repetitiva övning kan vara ett sätt för studenterna att bekanta sig med hur ämnesbegrepp presenteras inom en viss semiotisk resurs. Att känna till hur olika semiotiska resurser används inom ämnet för att presentera ämnesbegrepp är ett nödvändigt men icke tillräckligt villkor för att studenterna ska kunna tillägna sig ämnesbegreppen. I detta sammanhang verkar det som om *efterhärmandet av ämnesdiskursen* delvis är en naturlig fas i denna bekantskapsprocess. Lärare bör med andra ord vara uppmärksamma även när studenter ger de ”rätta” svaren—kanske härmar studenten bara ämnesdiskursen

i ett bekant sammanhang? Om så är fallet kommer studenten att stöta på problem när hon eller han till slut blir tvungen att använda sina kunskaper i nya situationer.

Den sista forskningsfrågan handlar om det sätt som ämnesdiskursen hänger ihop med ämnesbegreppen.

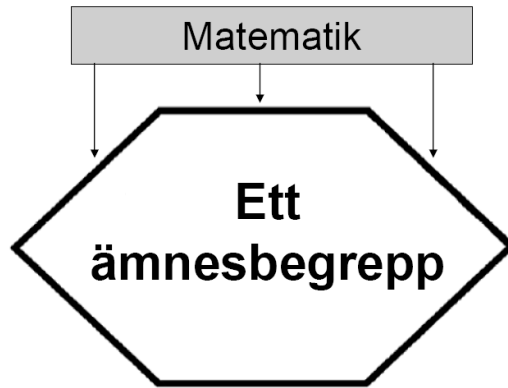
6. På vilket sätt relateras ämnesspecifika, semiotiska resurser till lärandet av olika ämnesbegrepp?

DiSessa (2004:296) menar att vetenskapsmän utformar representationer och att “[...] the invention of representations constitutes a fundamentally important class of advances”. Nya representationer gör det möjligt för vetenskapsmän att betrakta ämneskunskaper på nya sätt. Från ett ämnesdiskursperspektiv kan man säga att man genom de semiotiska resurser som tillhör en ämnesdiskurs kan närma sig ett ämnesbegrepp på olika sätt. På så sätt förmår varje semiotisk resurs avslöja specifika aspekter av ett ämnesbegrepp. Med aspekt menas här de attribut som hör till ett särskilt ämnesbegrepp och som är nödvändiga för att man skall kunna skapa sig en bredare och mer fullständig upplevelse av ämnesbegreppet. Ett ämnesbegrepp kan därför i allmänhet endast delvis representeras av en semiotisk resurs. Detta förhållande illustreras på ett mycket förenklat och idealiserat sätt i Figur 9.3 till 9.7.



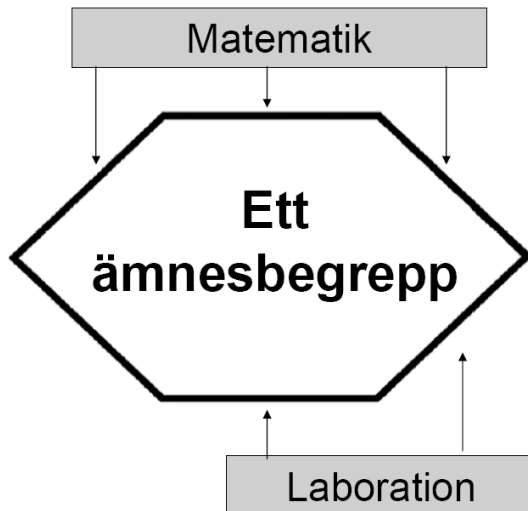
Figur 9.3. *Ett ämnesbegrepp har flera aspekter. Här presenteras en idealiserad representation av ett bestämt ämnesbegrepp med hjälp av en hexagon. Varje sida av hexagonen representerar en aspekt av detta ämnesbegrepp.*

I Figur 9.3 antas ett hypotetiskt ämnesbegrepp ha sex aspekter. Dessa representeras av de sex sidorna av en hexagon. (Notera att ämnesbegrepp har betydligt fler aspekter i verkligheten och att bilden därför egentligen är mycket mer komplex).

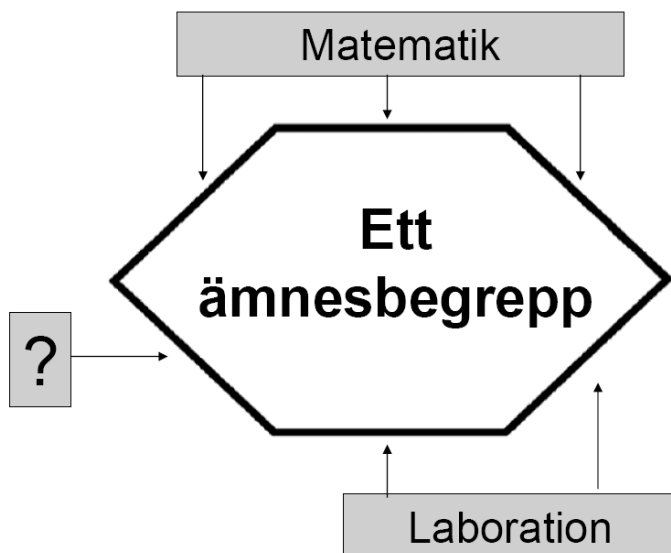


Figur 9.4. Här används matematiska resurser för att potentiellt tillägna sig tre olika aspekter av ämnesbegreppet.

Antag att det är möjligt att representera tre av dessa aspekter med hjälp av matematiska resurser (Figur 9.4), emedan två aspekter kan representeras med hjälp av laborativt arbete (Figur 9.5).

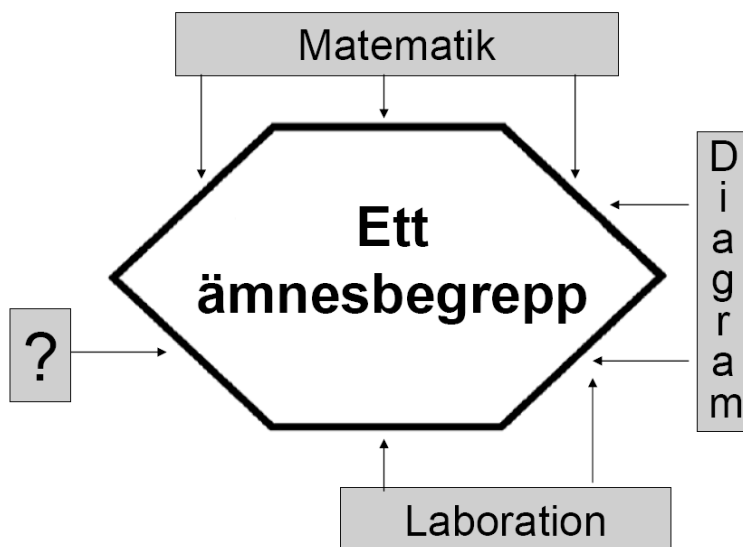


Figur 9.5. Laborativt arbete kan potentiellt göra ytterligare två aspekter av ämnesbegreppet tillgängligt.



Figur 9.6. Det är omöjligt för studenterna att helt tillägna sig ämnesbegreppet utan att få tillgång till den sjätte aspekten. Den resurs som ger tillgång till denna återstående aspekt betecknas med ett frågetecken ovan. Detta belyser den situation som råder på många universitet och högskolor där man har mycket begränsad kunskap rörande den kombination av semiotiska resurser som är nödvändiga om studenterna skall kunna tillgodogöra sig hela ämnesbegreppet.

Den sjätte och sista aspekten, som är nödvändig för en fullständig förståelse av ämnesbegreppet, går endast att närma sig genom andra resurser än matematik eller laborativt arbete. I Figur 9.6 betecknas denna resurs med ett frågetecken vilket indikerar att man har väldigt lite pedagogisk kunskap rörande den kombination av semiotiska resurser som krävs för att utförligt representera olika ämnesbegrepp. Det diagram som återfinns i Figur 9.7 beskriver inte innehållet i den saknade aspekten. Istället tillhandahåller det en länk mellan de matematiska och de laborativa resurserna.



Figur 9.7. I denna sista figur har en diagramresurs lagts till. I detta specifika fall fungerar diagrammet som en länk mellan de matematiska och laborativa resurserna. En fullständig helhetsbild av ämnesbegreppet är fortfarande omöjlig.

Med utgångspunkt i studenternas beskrivningar av deras lärande och den teoretiska modell som presenteras ovan, är ett viktigt resultat av denna studie slutsatsen att en viss bestämd *kombination av ämnesspecifika semiotiska resurser* behövs för att studenterna skall kunna tillägna sig vissa ämnesbegrepp. I detta sammanhang kan *förflyttning* mellan olika semiotiska resurser uppmärksamma studenter på det faktum att deras sätt att uppfatta begreppet inte överensstämmer med det sätt som godtas i ämnet.

Nedan återfinns en summering av denna avhandlings resultat i förhållande till ämnesdiskursen:

- Ämnesdiskursen inom naturvetenskapen på universitetsnivå består av flera semiotiska resurser.
- Ett repetitivt övningsmoment är en nödvändig del av att lära sig naturvetenskap på universitetsnivå.
- Denna repetitiva övning är ett sätt på vilket studenter blir bekanta med den ämnesspecifika diskursen.
- Gedigen bekantskap med hur en viss semiotisk resurs används i beskrivning av ett visst ämnesbegrepp är ett nödvändigt men icke tillräckligt vill-

kor för att en student skall få tillgång till de aspekter av ämnesbegreppet som resursen gör tillgänglig.

- Ett visst mått av diskursefterhärming kan vara ett naturligt steg då studenter närmar sig ett ämnesbegrepp.
- Byten mellan semiotiska resurser kan hjälpa studenter att se aspekter som saknas i deras egen bild av ett ämnesbegrepp.
- Vissa kritiska kombinationer av semiotiska resurser är nödvändiga för att göra ämnesbegreppet fullt tillgängligt.

Pedagogiska förslag

Ämnesdiskursstudien utmynnar i följande pedagogiska förslag:

- Studenter måste få möjlighet att öva användandet av ämnets representationer, fysiska redskap och aktiviteter som en del av deras naturvetenskapliga utbildning.
- Bedömningskriterierna för naturvetenskapliga kurser på universitetsnivå bör spegla det faktum att ämnesbegrepp representeras av flera semiotiska resurser. Bedömningen bör med andra ord vara autentisk.
- Lärarens roll som expert i ämnesdiskursen bör utnyttjas i större utsträckning. Studenter behöver vägledning i användandet av semiotiska resurser och de behöver samtala med läraren om detta. Idag är det inte ovanligt att studenters lärande sker i *ad hoc* studiegrupper med hjälp av andra studenter som själva försöker behärska dessa resurser.
- För att förbättra utbildningsmöjligheterna måste föreläsare lära sig att bättre förstå hur en specifik kombination av semiotiska resurser kan representera varje enskilt ämnesbegrepp till fullo.

9.5. Framtida arbete

Denna avhandling tog sin början i Klaassens (2001) forskning. Hennes studie av ingenjörstudenter i Nederländerna visade att studenterna anpassade sig till att bli undervisade på engelska under en ettårsperiod. Denna avhandling bekräftar Klaassens resultat och ökar förståelsen för denna problematik genom att identifiera några av de sätt på vilka studenter anpassar sina studievänor för att kunna hantera ett språkbyte. Det är naturligt att ett antal nya frågor formats under arbetet på denna avhandling.

Inledningsvis visar denna avhandling att några förstaårselever har stora svårigheter att beskriva ämnesbegrepp på engelska. Det är därför bra om framtida forskning inom detta område noga studerar det inledande skedet då studenter först undervisas på engelska—genom att noga följa studenterna och genom att dokumentera anpassningsprocessen. En närbesläktad, tidsbegränsad longitudinell studie skulle kunna besvara frågan ifall studenter faktiskt anpassar sig, eller om frånvaron av andraårsstudenter som inte behärskar en engelsk ämnesdiskurs beror på att vissa studenter hoppat av.

Den andra frågan har att göra med talhastighet. Ett av resultaten av denna avhandling är upptäckten att studenter talar mycket långsammare när de beskriver ämnesbegrepp på engelska, även om ämnesmässigheten var i stort sett identisk mellan de två språken. En intressant studie skulle vara att undersöka *föreläsarnas* talhastighet. Talar föreläsare också långsammare när de föreläser på engelska och, om så är fallet, behöver man mer tid till sitt förfogande när man undervisar på engelska? Eller, från ett annat perspektiv, finns det en risk att tidsbegränsningen leder till att föreläsare faktiskt inte hinner täcka ett lika stort material när de undervisar på engelska istället för på svenska?

En annan fråga har att göra med ämneskompetens och utbildningen av framtida lärare i naturvetenskap. Vad är förhållandet mellan den engelskspråkiga "Vision I"—ämneskompetensen som lärarstudenter tillägnar sig under sin grundutbildning och den svenskspråkiga ämneskompetensen som krävs för undervisning i skolorna, en undervisning som ofta inramas av ett vardagsperspektiv (Vision II)?

Vidare är ett av denna avhandlings viktigaste bidrag att den samlar ett antal semiotiska resurser inom ämnesdiskursens analytiska ramverk. Samtidigt, vilket påpekas i sektion 6.4, illustrerar de data som samlats i denna avhandling först och främst representationsaspekten av den ämnesspecifika diskursen. Det vore därför av intresse att använda det föreslagna ramverket på kontexter där den fysiska redskaps- och aktivitetsaspekten får utgöra fokus. På så sätt vore en studie där studenternas interaktion med den stora mängd semiotiska resurser som återfinns i fysiklaboratoriet en naturlig förlängning av det arbete som presenterats i denna avhandling. Det är mycket möjligt att en analys av ämnesdiskursen i sådana miljöer skulle kunna bidra till vår förståelse av studenternas lärande.

Slutligen, och detta är av största vikt, visar denna avhandling att det finns en kritisk kombination av ämnesspecifika semiotiska resurser som är nödvändiga för en helhetsförståelse av ett ämnesbegrepp. Forskning borde därför inriktas på *vilka* resurser som är nödvändiga för effektiv undervisning och lärande av ett ämnesbegrepp.

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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 case 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 case study 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
$\nabla \times \mathbf{E} = 0$ $\nabla \cdot \mathbf{D} = \rho$	$\nabla \cdot \mathbf{B} = 0$ $\nabla \times \mathbf{H} = \mathbf{J}$
$\mathbf{D} = \epsilon \mathbf{E}$	$\mathbf{H} = \frac{1}{\mu} \mathbf{B}$

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?

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

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

What do you understand by curl?

Clip C

SWEDISH 5:00 → “easily convince yourself not consistent”

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

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 inläringen? Varför?

Kunde du se hur detta hängde ihop med resten av lektionen?

Kursen?

Svenska

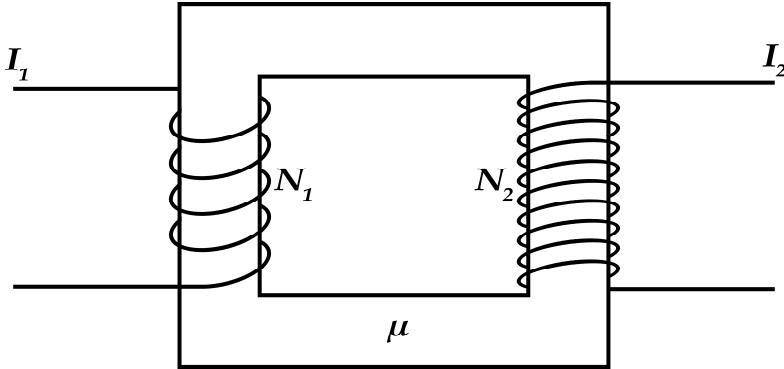
Länge sedan jag gjorde det här. Skulle du kunna sammanfatta vad det är som man har kommit fram till här?

Vad är innebörden av detta?

Han säger att konstanten är minus ett kan du berätta varför?

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)



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 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 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

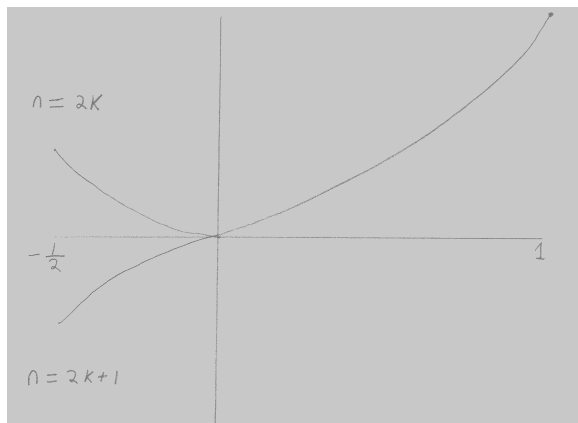
Can you say how you think this section fits into the rest of the lecture?

the course?

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

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

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



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
 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)

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 $\sum_{n \geq 1} M_n$ is convergent and $|f_n(x)| \leq M_n$ ($\forall x \in J$, $(\forall) n \geq 1$) then the series $\sum_{n \geq 1} f_n$ 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 inläringen? 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 $f_n \xrightarrow{u} f \iff a_n \rightarrow 0$.

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?

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

Appendix C: Sample student interview transcript case study 1

Interviewer: Yes, as I said earlier, I'm going to try to do some of this in English, but you can also speak Swedish.

Student: Mmh, yeah.

Interviewer: Erm, in this study that I'm doing, erm, I'm really interested in students' experiences of learning.

Student: Okay.

Interviewer: In the past, people have looked at erm, English and Swedish as a medium for teaching, but all they've done is look at the input...

Student: Okay.

Interviewer: ...and then the output, you know the exam results, and said "Well, there's no difference". Erm, but I'm a little more interested in what goes on within that system—especially since we've got this idea with erm, I don't know if you know about this Bologna process and so on that there's gonna be more and more English...

Student: Yeah!

Interviewer: ... in programs and so on. Erm so the most important thing for me is—you know—that there's no right or wrong answers—and it's not going anywhere as far as that's concerned—it's just really to try to find out, erm, what people are thinking and doing and so on, in class.

Erm, perhaps you could tell me a little bit about yourself, er, your background... have you learnt, had courses in English before?

Student: Er, well, I've had some courses—two five point courses in English. I think, well it's different, but I think it's almost better to sometimes have the courses in English.

Interviewer: Yeah, why's that?

Student: Especially if it's, er, the teachers are... especially with mathematics here there are many teachers from, like Russia and, er, and former Eastern Europe, and most of them actually speaks, speak better English than Swedish. We had one, one course with, er... and he tried to speak Swedish all the time but he, we... I think he didn't know what he was saying and we didn't understand what he was trying to tell us. That's one reason, but also, well there's two sides of it because all the literature is in English, so we read in English and then, it's, it's, linked better in some way, because the, the thing about this is when, er, we don't get any of the concepts and nothing in Swedish we don't know what, really what, what all these is called in Swedish.

- Interviewer: So you're saying that there might be a problem if you had to, to go and talk with other Swedes about...
- Student: Yeah, 'cos when we sit and you just do calculations we just, er you almost start to speak, to speak English because, I write, when I, I also write everything in English when I, when I do calculations for myself because, it's... it's the only way [Laughing] In the end and it's...
- Interviewer: Erm, if you think about you learning physics, 'cos we've got several things here going on, but, we've got physics and mathematics and then we've got English and Swedish and so on...
- Student: Yeah...
- Interviewer: Erm, How, how do you view yourself as a learner of physics? Have you, in the past, have you been, er, has it been quite easy for you or...
- Student: Er... well I don't, well I think it's been—well it's not easy for anyone—[laughs] It's not extremely hard. I think I got, got... it's quite easy for me compared to some other... well it feels that way. It's very hard to compare how other—because it's related to how much time you spent on it and I spend quite much time on my studies...[pause] Yeah.
- Interviewer: But, if you think about the past, then, erm, you've done reasonably well in the past in physics?
- Student: Yeah, Yeah.
- Interviewer: Mmh, what about maths? Is, is that the same or is there a difference between the way that you are in maths and the way that you are in physics?
- Student: No, it's about, about the same.
- Interviewer: So you've always done reasonably well in maths?
- Student: Yeah. Yeah, probably that's why it's not so hard for me with the physics, because I, the math is quite easy for me I think.
- Interviewer: Erm, what about English and Swedish, and so on? I mean you're speaking English quite freely now.
- Student: Yeah.
- Interviewer: But what do you feel about your skills in English?
- Student: Erm, Well, we... I don't use it every day so, but I'm not... I don't worry about it because, well I think I know as much... I can always explain what I'm trying to say, it's not directly but I, I think that most of the time people in the end understand what I'm saying, so, er...
- Interviewer: So you've already said that you think that in some cases it might be good to actually learn in English if the Swedish of the lecturer wasn't so good...
- Student: No. Yeah.

Interviewer: ...but do you think there are any other reasons I mean, I mean I'm just thinking about when you get exchange students and the course is in English...

Student: Yes of course...

Interviewer: Do you have any feeling about that?

Student: No, because I, I don't have any problem with un... Understanding English is no problem, so, so I don't care if... but I know that some other people think it's sometimes bad, if they have trouble with understanding the English they get kind of confused...

Interviewer: In school, in languages, did you, did you just do English or have you done other languages?

Student: Er, French, but I'm, I don't know, it's not the easiest language especially for Swedes I think.

Interviewer: I was talking to your maths lecturer and he was saying that he would prefer to teach you in French.

Student: Okay, Oh! [laughs]

Interviewer: [laughing] So what do you think about that?

Student: [still laughing] No. I don't think that's a very good idea!

Interviewer: Erm, okay, what I'd like to do is to, to talk a little bit about each course...

Student: Yep.

Interviewer: ...and then for each course I want to show you a few video clips, just, just small bits, to get you a feel of what was going on then...

Student: Yeah,

Interviewer: ...and then we can talk about that.
Erm, we start off with the electromagnetics course... um ... er... could you tell me something about what you think the aims of this course are—or what they are for you?

Student: Well, er, I think it's...we already talked with [the teacher] last week about the aims of this course, er, and I think—well of course to learn some electromagnetics, but it's also like some kind of introduction to, to theoretical physics, 'cos its, er, yeah it's a very theoretical course, and, er, so I think it's two aims actually, er, from [the teacher's] point of view I got this impression anyway and it's, it's the same for me I think, it's ... it's very good because it's very hard to connect the mathematics with the physics, 'cos all of the physics courses have been not very much mathematical parts of it—more like concepts and so on, you know, in mechanics it's not very much, it's not very hard mathematics, so that's well, that's one, one big, well something that I've learned this far anyway is to really make this connec-

- tion and to see that, well, this is this mathematical idea I can use here and ...
- Interviewer: Connecting...?
- Student: Yeah, connecting these two.
- Interviewer: And then, so, you also mentioned something there about a long-term goal, that is some sort of introduction to theoretical physics.
- Student: Yeah, yeah I think well [the teacher] was talking about that and I think that's a good idea to... because he's a, well I understand a very good theoretical physicist, so it's very interesting to see his point of view and his way of thinking.
- Interviewer: As far as, sort of, long-term, do you think that you might be interested in doing something like that or...?
- Student: Well, I don't know. Well I'm, I'm more into that field than, er, experimental physics. I don't really like doing a lot of experiments and stuff and I, well, I like mathematics so it's, but I don't know, I don't know what I'm want to do in a few years, it's quite early in my education...
- Interviewer: If we think about then, the, the erm, things that you actually do in this course, you've got lectures and labs and problem-solving sessions and so on, erm ... er, to what extent do you go to all—do you go to all of those or some of them...?
- Student: Yeah, I—all of them.
- Interviewer: So all the problem-solving and so on?
- Student: Yeah.
- Interviewer: And what about, erm, the materials and so on? I mean, you've got this book...
- Student: Yep.
- Interviewer: ... erm, er, do you, do you use this a lot then?
- Student: Yeah I, I use it a lot, well I think the, the theoretical parts are very good in this book. The problems, all of them are quite hard so it's not like when you start to do a thing, well okay, it may be like this, it's... they change everything and if you turn this upside down and do this the other way, then what will happen [laughs]. But it's good, good and you just solve two problems in an afternoon, but you learned a lot in these two problems—not very good for your ego, but it's ... [laughs] I don't know.
- Interviewer: So you do quite a bit of, of work with this outside of class then...?
- Student: Yeah. yeah
- Interviewer: ...and it seems as though that links in to some of the sessions in the class as well. Is that right, that you come along with something in the problem-solving...

Student: Yeah, yeah it's... Well each student gets some bonus points for the exam if we can solve problems and present them to, to our classmates it's always—these few points can be the difference, so its... [laughs].

Interviewer: So do you, do you think that you might have a problem passing the course?

Student: No, but you never know, what will happen.

Interviewer: It's always good to have?

Student: Yes, it's always good to have.

Interviewer: Erm, there are some other things as well, 'cos I saw that [the teacher] had put out things on the web, there's like a, a wordlist as well.

Student: Yeah!

Interviewer: Have you used that at all?

Student: No, I haven't really looked at it yet because, er, I tried to find it but then there was something wrong with his page and then I [laughs] I haven't tried again.

Interviewer: Erm, do you think that there was anything that erm, that you lacked when you started this course er, or have you been given pretty much what you needed as you went along?

Student: Er, no, it was not very, not a big part it's, it's more like I said it's the way we use mathematics in physics differs a bit from the way you learn it in mathematics so it's, you have to get past this barrier before you... I mean, we always do a lot of things and you say well this is this area of math and then we go to a mathematician and he says " This is wrong! You can't do like this." [laughs] "This is not true."

Interviewer: Is that to do with special cases, that physicists use special cases where mathematicians want ...

Student: I don't know.

Interviewer: It was just a thought. Erm, This course is taught in English, erm, do you see any, any special problems with that?

Student: No, I don't, no.

Interviewer: Do you do anything special to cope with the language or just take it as it comes?

Student: No, I don't. No, I don't have actually any problem because, well perhaps there is one word in every second chapter that you have to look up but the—it's just to do it...

Interviewer: But then you, but there's some sort of element of "Oh I don't know what that word is?" But then that might even occur in Swedish?

Student: Yeah. I mean I would guess... no I don't think it's more often in the English. Not for me anyway.

- Interviewer: Erm, when you're in lectures and erm, there's some sort of derivation or something going on...
- Student: Yeah...
- Interviewer: ... erm, do you feel that you can usually follow what's going on or is this something that you do afterwards that you catch up?
- Student: Sometimes it's a little too fast. In this course I try to read everything before the lecture—then it's easier to follow and I've seen everything before and then it is just to ... of course then there's a lot of questions everywhere, but then can spend the time in the lecture by straightening them out so it's...
- Interviewer: So, erm... Because the teacher follows very closely this book...
- Student: Yep.
- Interviewer: ...erm, do you think that's good or bad or...?
- Student: Well, well I think it's good for ... Well you learn this material better this way but the bad part is that you only get things presented one way. Sometimes it's good to get another point of view as well in the long term, because...
- Interviewer: So you mean that the more variation... it would help you to understand better?
- Student: Yeah, perhaps—well not perhaps to understand the, this part, but maybe when we encounter things from this subject somewhere else it's, it's more possible that we can see, okay, this is what he's talking about because you've seen it in different ways. But also it can be easier to understand if you don't get the idea in the book and the teacher gives you another idea, of course it's, sometimes it's easier.
- Interviewer: I'm just thinking, you mentioned that sometimes you, it goes a little bit too fast, erm what do you do then? Do you do anything outside class er...?
- Student: Yeah. Yeah well, well I try to, try to if, if some sometimes it's just details you miss and then it just goes away, you forget about it, but the big parts I try to catch up and read again and, I'm, usually sit on the afternoon and do some calculations together. Me and another guy, so then we talk about, discuss things and try...
- Interviewer: So you work in a, a in a pair so to speak with mathematical problems.
- Student: Yeah, problems for this course.
- Interviewer: Is that because these are difficult so then it needs quite a bit of perspective from...
- Student: Yeah, I think so. 'Cos I've tried to sit on my own in the beginning because sometimes I think that's good because I can think in another way but this was... Well it's very good to have someone to discuss things with.

Interviewer: And do you speak English or Swedish then?
Student: Oh, then we speak Swedish, yeah
Interviewer: With lots of English words thrown in?
Student: Yeah! Yeah of course! [laughs].
Interviewer: Okay, we'll take a look at some clips from this particular course, erm and then I'm just going to show you very small pieces...
Student: Yep
Interviewer: ...and then we'll, we'll see what you made of them, you can tell me a little bit about what you were doing at his stage, if you can remember and what you were thinking and so on. So let's have a see here...

Video Transcript: Clip 1

And now what we're going to do is, erm, if we try to modify our equations such as, er, to that include time dependence, the time dependence in different situations. And then you will see that the modification that, er, we have made, er, indeed is sufficient to describe all electrical phenomena at the same time.

Interviewer: Okay, so just a little bit there, erm. So that was right at the beginning...
Student: Yeah.
Interviewer: ...er, erm can you tell me what you were thinking at this stage?
Student: Er, well at this stage I since I read this chapter in the book so I know where he was going so it was I...
Interviewer: So this was fairly clear for you?
Student: Yeah, I think his goal was to get us to think what could we do, but since I already know what should be done [laughs] it's a little bit hard to be at that stage. So I thought that it was a shame that I'd read it, because it's would have been good to, to make me to think about this for myself, that's what I was thinking about. [laughs].
Interviewer: But as far as what you were feeling about this stage you were feeling what? Confident? or...
Student: Mhh. Yeah. Well I didn't feel very much at all actually [Laughs] It was early so I was tired!
Interviewer: So, you could almost say "Now he's going to say this."
Student: Yeah. Almost, yeah.
Interviewer: Erm so, could you tell me a little bit about how this fits in with the rest of the lecture—just very, very, briefly.
Student: Er, How it fits in, how it corresponds to the way he usually...
Interviewer: No, I meant, er that, er this is some sort of starting point, yeah?

- Student: Yeah!
- Interviewer: Er so you had a good feeling of where it was going then?
- Student: Yeah! Because, I'm sorry I don't really understand your question.
- Interviewer: Mmh, yeah, he's put these, put these up [points to the equations]
- Student: Yeah...
- Interviewer: Erm, I'm going to show you where he was going in a minute, but I'm just wondering if you can tell me...
- Student: Yeah, he's where he's going?
- Interviewer: Yeah.
- Student: He's on his way to, er, introducing the, replacing the zero with the minus derivative of the B field, with respect to t. I think.
- Interviewer: Okay, and for you this was very much a clear thing that was going on?
- Student: Yeah.
- Interviewer: Okay we'll take a look at the next bit here...

Video Transcript: Clip 2

Erm, the second remark is that the equations that we will end up with will look more complicated than the ones we have now, but first of all they are not MUCH more complicated, since we do a minimal modification—we just modify erm, these as slightly as possible at all to include time dependence, but then er, er, apart from that I would say that er they become also more beautiful—I think that these equations are actually quite beautiful, er but making them a bit more complicated they become even more beautiful, er, because er, so far these are just er two equations and two other equations of similar type, but they are not related. And we will see that the modifications will relate them, but they will not just relate them arbitrarily, in that case the whole computational power would be reduced, but they modify them precisely in such a way that all the computational power that they have is kept and in addition we can apply them now to many other problems as well.

- Interviewer: Okay, so here he's talking about things being er, erm, beautiful...
- Student: Yep.
- Interviewer: ...did you have an understanding of what he meant by that?
- Student: Yeah! well I, Yes. Well that's one thing... well I think he's talking about the beauty of describing very much of the world we're living in in just four basic equations. And that's—I think

that's what he was talking about the beauty of just ... so that it looks quite simple but it's not - well it is simple in a way but it's not simple to use them and to make anything... make the calculations can be hard, but yeah...

Interviewer: So this very condensed thing can be something quite complex...

Student: Yeah, yeah. It's just a lot. These four equations and its...

Interviewer: I'm just thinking... can you tell me a little bit about what your understanding of these is then—and this isn't a test of course [laughs]

Student: [Laughing] These equations, erm well the first equation—the curl of the electric field...

Interviewer: Yeah just talk about that, 'cos that's the one he's going to change yeah?

Student: Yeah, well what he says right now is basically is that the E field is a conservative field—even though a mathematician wouldn't say that [laughs]... but er, yeah which allows us to create a potential and, er... yeah, also it says that, yeah, a line integral, yeah, describing the work for example is independent of, independent of time, in this, when you've got the zero there.

Interviewer: Okay that's fine, it's just to get a short description like that is really interesting for me on a, on a language level.

Student: Yeah.

Interviewer: So here. Were you doing anything special?

Student: No, just listening.

Interviewer: You're just listening, 'cos you're with him, you're not having to take any notes or anything...

Student: No, it's no. I'm not—I'm not one of those people who likes to sit and write all the time, because, sometimes it's good to write, but when someone is just talking I have a hard time to take notes, because then I can't listen, so it's...

Interviewer: Okay, let's take another section...

Video Transcript: Clip 3

...so there should just be a number here and it turns out that this number should be minus one. This is our new equation, and we will then start from this equation and then derive what is known as Faraday's Law. So the first modification that we will do today is that we will add minus 'dee bee by dee tee' on the right-hand side of this equation. Erm, as you can easily convince yourself, er, this system of four equations that we have developed now is not consistent, but, for the moment we

will ignore this fact and later on we will repair, er this (inaudible)...

- Interviewer: Okej, då är det dags för lite svenska, det är kanske lättare, jag vet inte, men erm, nu har du erm, nu har han kommit fram till det som du förutspådde, så att säga, erm, är det fortfarande så att du, du bara lyssnar åh er, eller vad gör du nu?
- Student: Erm, jag har nog skrivit en del, jag brukar, jag brukar skriva ner det han skriver, precis, tar lite anteckningar och så där...
- Interviewer: Fast det finns i boken...?
- Student: Ah, i alla fall när han med teori, när han gör exempel åh så där brukar jag inte göra det för, uh, då går det ofta rätt fort också så man hinner inte... men jag tycker det är skönt att skriva vissa såna grejer, härledningarna åh så där går bra, så man skriver, det, det går in en annan—en väg till liksom...
- Interviewer: Aha, så att görandet på nåt sätt...?
- Student: Ah, det tror jag—Ah
- Interviewer: Er, men du kände att du, du hängde med här...?
- Student: Ja, jo för det mesta...
- Interviewer: Erm, var det några saker här som, som erm, som hjälpte dig med inläringen som du skulle säga, du säger att "Jag har boken, jag följer den sen så har jag också en annan väg att jag skriver ner..." Var det några andra saker som erm, nånting som här i den här situation att...
- Student: Nej, nej...
- Interviewer: Men i för sig du, du kanske har en känsla av att, du hade redan lärt dig det här, åh att det var mer att gå över det igen uh...?
- Student: Ja, erm... [tittar närmare på skärmen]
- Interviewer: Ja, det är lite svårt att se exakt vad...
- Student: Jo, kommer inte på exakt vaddå...
- Interviewer: Men det var just att han har just satt in det där...
- Student: Jo, det var det ju—sen så exakt varför just minus den derivatorn det är ju ett kapitel för sig så som man (inaudible) och det är lite synd [laughs]. Men erm, det stämmer så är...
- Interviewer: Erm om vi gör samma som vi gjorde nyligen på engelska då erm, kan du bara berätta vad den här betyder då?
- Student: Jo...
- Interviewer: För nu har an lagt till den där, men det är...
- Student: Ja, ja den betyder ju, att ah, the curl of E då är, är minus derivatorn av B fältet men erm, ah... sen just vad en curl är det har man fortfarande inte riktigt fått en så här direkt in, intuitivt, bild av det...
- Interviewer: Det är nånting man gör med...
- Student: Ah, javisst, åh man har fått lite diffusa förklaringar fast det är...

- Interviewer: Man känner att man kommer åt det närmare och närmare men man inte riktigt...?
- Student: Ah, jo. Nej, det är inte så där glasklart som en vanlig derivator liksom—det är okej det förstår man vad det är för nånting, men här är det lite mer...
- Interviewer: Vi pratade om erm, minustecken där erm, erm, kan du berätta lite om vad du tänker när det gäller just den där minus tecken? [pause] Du sa att det var ett helt kapitel för sig, och nu vill jag inte höra ett helt kapitel men, um...
- Student: Nä men som när han presenterar det här så, så sa han att vi måste modifiera dom här och sen så ... ah, sen så ah, just det, ah, alltså i princip sa han bara så här "Att så här blir det" men inte... men inte varför—jag tror också att han sa det just att det, att det är nånting man jobbat med länge då men att sen kom man fram till det här.
- Interviewer: Så han, han hoppar över några, eller några ganska långa steg...
- Student: Aah, jo...
- Interviewer: ... åh bara säger att det är lättare att ni bara acceptera att det är minus än försöka förstå...
- Student: Ah, åh det är lite, i just den här kursen så går man igenom nästan alla härledningarna och allting liksom så det är lite, det är lite frustrerande så där att man får ett—likförbaskat då får man ett hopp där åh...[laughs] men det får man väl acceptera det där.
- Interviewer: Okay erm, then we'll go back to English again, it's gonna be a little bit confusing like that, but erm, I'd like to show you one piece from, from at the end of the course...
- Student: Yep...
- Interviewer: ...where he was talking about transformers...
- Student: Yep.

Video Transcript: Clip 4

And now we will look at section 7.2.2 [in the textbook] which is about transformers. A transformer is just a device for transforming, that means changing the value of er , either currents or voltages. And concretely it looks like this. [starting to draw the diagram of the transformer] You have some metallic core which, will, has some permeability, μ . And as you will see it will be interesting to take ferromagnets that means 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 some current I_1 er , 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

- Interviewer: Yeah, we'll stop there. How did you feel about this? Is it, erm, I mean the teacher erm, sort of mentioned that, that—he took this slightly out of sequence...
- Student: Yeah.
- Interviewer: ... from the book and mentioned that it was a slightly different thing...
- Student: Yeah.
- Interviewer: Erm, did you, did you feel you had an understanding for why he did it this way?
- Student: Er. Yeah I think it's, er, because er, this is more, more like an application of the theory, so perhaps that was, yeah, what he wanted to, yeah, first he deals with the theory part and then he makes some kind of application of this. This is something that we have seen before, er, since high school er you do little labs and you use transformers and coils and stuff...
- Interviewer: So what did you think about the degree of difficulty here... compared to what you had in the last clip?
- Student: Well I think that this part was er, actually more, this is more, for me it was more—I don't know why, but more... it's not—it wasn't as easy as the other part I think, I don't know why but... because erm when we just deal with the mathematical expressions it's just this, yeah we've got one thing to concentrate on, but now we've got the physical situation and we have to see...
- Interviewer: That together?
- Student: Yeah together, and then we've got this thing here and we use this equation, and we, so it's—and also at the end of the lecture you get a little bit tired and so it's harder to, to connect [laughs] everything.
- Interviewer: So you, you were saying then that you felt that this fitted into the rest of the course in the sense that it's, there's more an application...
- Student: Yeah!
- Interviewer: ...whereas the rest of the course is more, more mathematical...
- Student: Yeah.
- Interviewer: ...and this is both mathematics and physics?
- Student: Yeah, of course there is a lot of applications, but it's... I don't think that, that's not the main idea that we should know what a transformer is and how we use this and what we... the main course is the main ideas that we shall know the theory.
- Interviewer: I thought it was interesting 'cos you said well, okay, you know, this is something you've seen before in high school and so on, that at the same time you found it more difficult...
- Student: Yeah, erm, yeah!

- Interviewer: But maybe that's surprising to you too?
- Student: Yeah, I, erm when I was saying it I actually was surprised as I was saying this, but erm—well of course we've seen it and we've used it but we didn't have, haven't made the, the explanation that we did now, what is going on actually, it's more like—it's just that we have seen it but it's...
- Interviewer: Okay, then I'm gonna leave this course and then look at the mathematics course, but er, before we leave this, er, is there anything else that, er, you think that I should say as far as, er— or that you could say as far as er, language is concerned or the mathematics and so on, 'cos we've got the Swedish, the English and the mathematics which are...
- Student: Yeah, No I don't think so...
- Interviewer: ...and you also have a diagram here, but that was something that you understood straight away, that—what that was, it keyed into something from the past.
- Student: The diagram, yeah, yeah, yeah it wasn't much, any problem to understand what this was.
- Interviewer: It's very clear
- Student: Yeah. Yeah that's right.
- Interviewer: Okay then we'll go on and look at the, next course. Erm, so what I want to do first is erm, is, erm, ask some specifics about that course, like we did about the physics course and then we'll look at a few clips from that.
- Student: Yeah, right.
- Interviewer: Erm, If you think about er this course you talked about the aims being erm, erm, to move you towards theoretical physics is one of the aims. Erm what do you see as the aims of the mathematics course then?
- Student: Well, the aims of this course should be just what I was talking about before, to make a connection between mathematics and physics, but that's not what he's doing—so that's a problem.
- Interviewer: Erm, if you think about that then, how does this course fit in with your sort of long-term goals, your degree and so on, the, the mathematics course this is...
- Student: Erm, it's very hard to say right now because I think that er, well, well, like I said, I think the goal is that we shall use the mathematics we have done before and, in um, to some extent, er, apply them to physical situations and so on, because uh a very large part of this course is actually repetition, we have studied it before but now it's coming once again.
- Interviewer: In which situation did you study this maths before?
- Student: It's in the calculus courses
- Interviewer: Okay...

- Student: Mostly. And also a bit in linear algebra. Er, so this... Yeah that's something that I think we would need in one way to, to make it easier to start with the physics, but he's making this course strictly mathematical and it's, it's actually one step away from physics, rather than one step towards physics—But, in the long term I think that's good because erm I've learned a lot. Oh—the first lectures I didn't understand anything, he was writing but it was just notations, notations, notations but er, now I've learned that, that part and I think perhaps that is very good in the future to know these things so... It's always harder when you're in an education to say this is, “I don't need this”, because er maybe I will need it, maybe I will be able to use it.
- Interviewer: That's interesting, you mentioned there the notation, at the beginning you felt... er at the beginning of the course you said something about feeling quite, quite lost with the notation...
- Student: Yeah.
- Interviewer: ...how, how did you get around that?
- Student: Erm. Well I was... yeah you saw the, the, his handouts from every lecture. Well I just read them and after a while I, you, you understand what he means. It's not very, it's not, nothing strange, it's just that we've never used it before so it's...
- Interviewer: So are you saying that the actual notation, the symbols were the problem?
- Student: Yeah! That was the problem yeah.
- Interviewer: Not so much the ideas?
- Student: In the beginning it was nothing new, it was just, he just he, I—you got the feeling that he was making it very, very more complicated than it had to be.
- Interviewer: Aha. So when you got into it, at first you understood nothing but then you looked at it and you thought “But that's what we've already done!”
- Student: Yeah, so—and I still don't think that his way of, of notation is very good because he's sometimes got very long expressions and stuff so it's, but it's good to know what, what—because I think it's very, I believe it's very standard notations, it's very... So if you want to read mathematical literature and physical literature then perhaps it's very good to have...
- Interviewer: To have learnt that notation?
- Student: Yep. I mean it's a language, so it's ...
- Interviewer: Erm, so one of the things that you felt that you lacked at the beginning was the, just the notation, er, but the actual content and the mathematical knowledge you felt like you had, erm perhaps even more than enough is that right at the beginning? Because you'd done these things before.

- Student: Yeah we'd done it before so it's, and if you read the, er what's it called? 'kursplaner' [syllabus] ...
- Interviewer: Yeah
- Student: ...er, er this course is supposed to take all the important parts of mathematics that we have studied and er put them in a physical context. Er, yeah, repetition so we actually manage all of it so er, so it, it shall not be very much new stuff some stuff like...
- Interviewer: So a kind of recycling course...
- Student: Yeah!
- Interviewer: ...with a little bit new added on?
- Student: Yeah, some er, some things are new so er... So I wasn't surprised that we—not everything is new, it's not a surprise to me, it's more like, the way it was presented feels a bit more strange sometimes.
- Interviewer: What do you think about er, erm the same questions as I asked before, er—the materials, er initially, you were told about this book...
- Student: Yeah.
- Interviewer: ...but then the lecturer started giving out handouts like this...
- Student: Yeah.
- Interviewer: ...and there's also another book, er that he said was, was more suitable...
- Student: Yeah
- Interviewer: ...er, did you get this other book, or this [original] book or do you just stick to the notes?
- Student: Well I bought that book but then I got it ex, exchanged so I've got the other book now er so I use both I, I read what he says, his handouts and er, what else—I mean these are very, in very condensed form—it's just like five or six pages and er, maybe in the book, this book it's like forty or fifty pages [laughs]—the same subject, so... erm sometimes you really don't have the time to read all those pages because it's hard to know which part you can skip so [laughs] so then it's very good and I, I always read this [the handout] quite carefully. And the book is more like reference, where you check out, check up things—okay, this I really don't understand and I look at the book.
- Interviewer: Are you saying when you look at the book that you, you sometimes don't have a, an understanding—because *everything's* there you don't have an understanding of which are the important pieces?
- Student: No, 'cos it's... There's a much, very much text and er, examples, examples, examples and er...
- Interviewer: And so, these notes point out for you in a sense...
- Student: Yeah...

- Interviewer: ...what the, what the main thing's gonna be?
- Student: Yes, but on the other or the other—this book is more applied to physics, it's more it's applications.
- Interviewer: Okay. Oh yeah, of course, 'cos you were saying that this is quite mathematical. Erm, as far as the things that you do, you've got lectures and these problem-solving sessions, er, er, to what extent do you go to those?
- Student: Well, maybe like—to the lectures, I go to all of them and the problem-solving sessions, maybe half... 50% something like that.
- Interviewer: But in the other course you go erm, quite often...
- Student: Yeah, Yeah—because in er in the er, electromagnetics course it's more like a lecture, it's just that we solve problems and yeah, we try to solve the problems ourselves before and then [the teacher] solves them. But in the mathematics course it's more like we, we're just sitting and doing our own calculations and we can ask him, and that's not a—for me it's not a good situation.
- Interviewer: So it's more like he's there as a resource?
- Student: Yeah. And I just got distracted and it's ...
- Interviewer: 'cos I guess you could go to him anyway?
- Student: Yeah, yeah he always says the next day anyway so its...
- Interviewer: You already talked about er, working quite a bit with the book, do you read the book before or after—oh, and these things as well [Handouts]
- Student: That's afterwards for this course almost all the time—because it's a little hard to before the lectures I don't really know—because it's okay it's in this chapter but we don't know which parts...
- Interviewer: And of course you haven't got these [handouts] because he's, he's making them as he's going along.
- Student: Yeah. Today it was good because we got them the same got them the same day. Sometimes it's a week, late so it's... [laughs]
- Interviewer: So that would change er, er as well, the things that you did in the lecture quite, quite seriously, I assume, because if you've got this in front of you...
- Student: Yeah, it would have been more easy. Yeah it's always yeah it's very much—yeah, those days we have got them it's it's ...
- Interviewer: You just make a few notes on them?
- Student: Make a few notes on them, Yeah.
- Interviewer: Okay. Erm, same question as with the other course, er, do you feel that you can usually follow what is going on? You said at

- the beginning it was quite difficult because of the notation. Do you feel you can follow or do you have to catch up?
- Student: Yeah. Well, today it was it was not a problem, perhaps some small parts, but on the whole it's not, perhaps some small parts but on the whole it's not because this, we have done before er, we had some lectures on tensors for example and that, that was completely new and then I don't, I don't think any one of us followed at all—so it was [laughs] not me at least...
- Interviewer: With that, the, the tensors stuff, what did you do—have you done anything after that, or is it just lying there as a, as something that you're gonna have to have a ...
- Student: Yeah, well, No. Well, I read these handouts very careful, because, and I know that it's an important concept in physics so now I think I've got some kind of abstract idea of what it really is, [laughs], but er I still haven't seen any er, no, almost none, applications.
- Interviewer: This is like you were saying about curl but worse?
- Student: Yeah, a lot worse! But I, I know mathematically very well what it is, I just don't know how I can use it.
- Interviewer: What it means in the world?
- Student: No.
- Interviewer: Okay, erm then I think we can take a look at some clips from this. Okay so here's the, the start of the lecture from today.

Video Transcript: Clip 5

[Students entering the room and taking their seats, opening bags etc. Simultaneously lecturer starts lecture by talking whilst writing on the board]

$X(n)$ kallas för konvergent. Så [inaudible] det finns ett reell tal, a , så att $X(n)$ går mot a . Problemet är nu att vi har nu fått ett frågetecken hit, frågetecken är: "Vad betyder detta?" Detta måste defineras. Så $X(n)$ går mot a . Detta är vår första viktiga definition. För varje epsilon positiv det finns ett moment, en epsilon—det betyder ett naturligt tal, så att för varje naturligt tal större än epsilon avståndet från $X(n)$ till a är mindre än epsilon.

- Interviewer: We'll stop there. Okay. So he came in and er, [snaps fingers] just started with this. Erm, er can you tell me what you were thinking at that stage?
- Student: Er, yeah, well, this was er, actually a bit repetition from the last lecture...
- Interviewer: Okay.

- Student: ...Because it was on, on er, series without the, er, sequences and series of er, numbers. Yeah, so this was, yeah, I think he was going to link this to the functions.
- Interviewer: Okay, so you automatically had a feeling that "Okay, this is what he said last time, so now he's going on from there."
- Student: Yeah.
- Interviewer: Okay. Strangely enough I didn't have that feeling [laughs] Because I wasn't there!
- Student: [laughing] Of course...
- Interviewer: So it's good that he knows his students well enough, cos I was like "What? Why?" [laughing] Good, it's not as bad as I thought it was...
- Student: Nowhere near! [laughing]
- Interviewer: Erm, okay, so at this stage you were thinking, okay this is, this is what he had last time and now he's going to link on...
- Student: Yeah.
- Interviewer: Erm, did you feel like you understood where you were and so on?
- Student: Yeah, this far it was...
- Interviewer: Erm, and you had a good feeling of how this fits in...
- Student: Yeah.
- Interviewer: Erm, okay we'll play another piece...

Video Transcript: Clip 6

[...]Jen familj av följder av reella tal. Nämligen för varje x , vi får en följd av reella tal. Grubbla på det—det är inte komplicerat. Därför att när vi sysslar med följder det finns två variabler. En variabel som är variabel i x och en variabel som mer... erm— följderna betyder naturligt tal, så det finns en variabel x och det finns en variabel naturligt tal. Vi har ett mycket bra till exempel: Titta här: Vi tar som intervall av $jz\ddot{o}$ [pointing to J] intervallen är minus en halv till ett, och varje $f(n)$ är x uphöjd till n . Vi kan till och med rita om vi vill. [börjar rita diagrammet] Minus en halv, ett... minus en halv här också, det beror på x . Ja, för n det kan vara så i fall att n är jämn, eller hur? Annars för n är lika med $2k$. När den är udda, udda tal—för udda tal, grafen är så för udda tal och när n växer naturligtvis denna punkt närmar sig noll. Så grafen är så för n lika med $2k$ och så för n lika med $2k$ plus ett.

- Interviewer: Okay, we can stop there I think. Okay same sort of questions again, erm did you, erm, what were you thinking at this stage?

Student: Er, well I don't know I don't remember that well er, it was about er, can I [taking the handout]...

Interviewer: Er yeah, I should have marked out which piece it was.

Student: It was in the, on the first page. Yeah, okay I think so. Yes, well yeah, yeah, well this is also, yeah I was thinking about because this was a series of functions it's not a new, it's not a new concept.

Interviewer: So this is again something...

Student: ...Yeah, but, but that I, I forgot actually because in the beginning I thought well, well this is something new, but then when we got to this point I aha! we've actually, I've actually done this...

Interviewer: Was that the notation again or the...

Student: Yeah, yeah I think so, and also because before it was actually not defined as a series or a sequence of a function—it's more like a function with a variable or, or sequence with, with er, erm, yeah ...variable x so it will... I didn't think of it as functions, but now, now so it was, yeah.

Interviewer: And what were you doing at this stage? Did you write anything down...

Student: No I was just er..

Interviewer: 'Cos you could follow this..

Student: I could follow it, yeah,

Interviewer: ...because it was very small on here [video screen] but of course you had this in front of you [handout]

Student: Yes so it was possible to follow.

Interviewer: And erm, this diagram that he drew...

Student: Yeah

Interviewer: ... erm what did this mean for you?

Student: Er, well that was quite good, because I, it's, it's easier to see sometimes what it's about and what happens to this erm polynomial...

Interviewer: Can you explain what he meant here then? Erm it's not a test...

Student: No well, yeah, of course, you have an odd er, n odd then we will be like this...

Interviewer: Okay so this is for n , odd, and this is for erm...

Student: even...

Interviewer: erm, if it's an even number

Student: Yeah. So that's what he was trying to say.

Interviewer: And then you felt like you could follow, that, that actually helped you in your...

Student: Yeah, yeah I think so, and even what will happen when n is getting bigger and approaches infinity so...

Interviewer: So do you feel that you were with him here in this explanation?

- Student: Yeah in this part yeah.
- Interviewer: And you said that this was not something new, but at the same time it was maybe a way of looking at it...
- Student: Yeah! Yes...
- Interviewer: Did you feel like you were learning something then?
- Student: Yeah, I mean we have all these definitions and theorems and stuff it's all, all this is new. So the concept is not new, but er the theory's actually new because...
- Interviewer: So, so maybe if I understand you correctly, your, you started to see this maybe in a slightly different way...
- Student: Yeah
- Interviewer: ...than you've seen it before.
- Student: Yeah.
- Interviewer: Erm, maybe the way that a mathematician sees it rather than a physicist?
- Student: Yeah.
- Interviewer: Or maybe the way that a physicist should see it? I don't know...
- Student: [laughing] Yeah! According to some people yeah! I don't know—ask me again in ten years and I'll give you an answer!
- Interviewer: Can you explain a little bit about how er, this particular thing fits in to the rest of the courses that you're—er, to the rest of this course.
- Student: Well this course is very er, what should I say? it's it's very it's erm, a lot of different parts so it's..
- Interviewer: So this is just just one of many...
- Student: This is just one of ...Yeah.
- Interviewer: But if we think about how this fits in with other things erm, I mean in your degree...
- Student: Then I think this is, I believe it's quite important in physics to er, yeah, look at like things we have studied like Fourier series and stuff, it's a series of functions so... it's, so it's er, I believe it's a big, it's an important concept.
- Interviewer: Okay The we'll take a look at one more, one more scene.

Video transcript: Clip 7

Det betyder att supremum för denna mängd är... kan vara plus oändligheten—den är oändlig, men det finns situationer när—mycket speciella situationer—när denna mängd är ändlig, det vill säga er, det finns en del tal—inte alltid—det finns ett tal en epsilon, så att, n epsilon x är mindre eller lika med n epsilon för alla x i J . I vissa fall det händer så. Om! vi har denna situation—om vi ska ta exempel när det händer så—vi kan välja samma n , n epsilon för alla x oberoende av x och i detta fall

man ser att följderna $f(n)$ konvergerar mot f likformigt—uniformly. När detta tal, dessa tal kan väljas oberoende av x . Det är en mycket, mycket svår matematisk matris. Och denna typ av konvergens var introducerad av Weierstrass artonhundrasjuttio. Så...strålande matematiker...

- Interviewer: Okay we can stop there. Erm, so there he'd gone through quite a bit, I mean, I didn't follow this at all, but I'm thinking that maybe you, you had an idea of what he was talking about here is that...?
- Student: Yeah, I think so, yeah, all the part about this supremum well, that was clear to me. Er this last part about uniform convergence it's er, well, it's not intuitivt.
- Interviewer: Vi kanske ska ta det här på svenska förresten... Du sa att du, du förstod det här med supremum, men, erm, du sa någonting att det var inte intuitivt...
- Student: Nej, alltså, likformigt konvergens var inte intuitivt klart, varför man inte kan välja, då väljer ett—om det finns ett n för alla x varför kan man inte ta den största först?
- Interviewer: Ja, precis...
- Student: ...det är för mig inte självklart, men uppenbarligen så [laughs] så finns det ju, är det ju så och så... ah, så det får man fundera lite över [laughs].
- Interviewer: Så det är någonting du ska, erm, som han sa ”gå och grubbla lite med”?
- Student: Ah... Jo. Jo för det är ofta så i hans föreläsningar, ofta man får grubbla ganska mycket åh sen, sen trillar det ner. Men det finns—kanske det finns en poäng i det också.
- Interviewer: Så du kände också här att erm, på det ena sätt så var det här ganska klart, men det var ju erm ”Men varför just det det?”, ”Han säger så som om det är självklart men det är inte så självklart för mig just nu...”
- Student: Nej! [laughs]
- Interviewer: ”Jag måste gå och tänker innan det...”
- Student: Jo, jo precis. Det är så det är.
- Interviewer: Men, erm, du har en ganska bra känsla själv av vad det är som du inte förstår och vad du måste då gå åh jobba med va?
- Student: Ah, jo, det tror man att man har, men sen ibland är det saker som man tycker man har förstått så börjar man pratar och jobba med det sen och ser sen att det har jag inte alls fattat! [laughs].
- Interviewer: Men för dig, i alla fall du kände att du var med här. Skrev du ner saker här eller var det bara att du följde med eller...

- Student: Nja, delar av det skrev jag ner—kom inte ihåg exakt. Vissa saker står inte tror jag i—inte vad jag kunde se i alla fall, så skrev jag ner den där definitionen av det supremum, men annars då...
- Interviewer: Men er, förresten... Maybe we should switch back to English and take a look at that bit actually...

Video Transcript: Clip 8

Vi kan förklara hela fenomenet med hjälp av ett tal, en följd av reella tal. Problemet är mycket mycket enkelt och här, i princip, åtminstone här, vi måste klara detta därför att vi har en funktion och vi måste hitta ett maximum för funktionen av detta supremum.

[student fråga] Supremum? är det, er, det största värdet...

[lecturer] Vad är supremum?

[student]... det största värdet kan man säga eller..?

[lecturer] Inte alltid. Till exempel när vi har mängden $aah(a)$ är lika med intervallet noll ett, supremum av $aah(a)$ är ett, max av $aah(a)$ existerar inte—inte maximum. När supremum tillhör mängden den kallas för maximum—det finns en skillnad mellan maximum och supremum okej? Här vi syslar med supremum.

- Interviewer: Erm, he had a question there, that obviously he'd been talking about this supremum for quite some time and then somebody said "what's that?" But you, you felt like you had a, a reasonably...
- Student: Er, no, er I, I was asking the question—well I, it's something about some kind of maximum, but er I felt I had to ask because it was coming again and again and again ... yeah but I don't think anyone—not many of us actually knew, had any idea what it was.
- Interviewer: And so this is something that you're gonna have to go and... look in the maths book directly...
- Student: Yeah...
- Interviewer: ...and try to find out what.
- Student: Yes, but now I think I know what it is—I think at least this...
- Interviewer: The second time around?
- Student: Yeah [laughing] this is the second time so, er I think I know enough to use it in this context anyway. Maybe at home I won't check it up right now—too lazy.
- Interviewer: Unless it's on er, tomorrow's lecture as well.
- Student: Yeah. [laughs]

- Interviewer: Okay. Then that was all the, the clips that I'm gonna show you... er so the only thing I'm interested in now is a comparison between these two courses—er obviously they're taught by very different people in very different ways erm, but erm, I'm just thinking, could you compare the experience of learning in these two languages for me?
- Student: Umm. In these courses or ...
- Interviewer: Um, well yeah I mean, well yeah I mean between these two courses is er, gives you something to talk about I guess.
- Student: Ummmm. I don't think well the, the language is not very important I think
- Interviewer: Why's that?
- Student: Well I think it er like I said, understanding English is not a problem for me so I, Actually it's a little better in the electromagnetics course because [the teacher] speaks better English than he speaks Swedish so it's well yeah he is more free in his language than [maths teacher] is in the Swedish so...
- Interviewer: So it er feels like er the governing factor is more the lecturer than your own understanding of English or Swedish?
- Student: Yeah. Yeah. Yep.
- Interviewer: And then there's this third language which is mathematics erm, how do you see those hanging together?
- Student: Erm, Well I ?
- Interviewer: I'm just thinking for example erm, you're learning er maybe a term comes up here that you haven't heard before or some type of notation or something erm, If it's in Swedish er, will you automatically know how to talk about that in English or or vice versa?
- Student: Mmmmmh well to talk about it... For me to talk about it of course it's easier in Swedish than in English but er but the explanation, if someone is explaining something I think in one way English is a better language, it's more... it's a little bit more rich in some way—it's easier to sometimes it's hard someone tries to explain it in English and then in Sweish it's not possible sometimes because...
- Interviewer: I mean well you've done very well here...
- Student: Yeah er, but about the, the teachers I'm thinking about yeah.
- Interviewer: What about the mismatch between the notes and the lecture language because that, that comes up a lot in lot's of different course doesn't it?
- Student: Yeah, er well like I said before it's well it's in one way it's nice to have the same language, because its it corresponds better terms and things at the, the same time it's good to have, to know what things is what something is called in Swed-

- ish.[laughs] So it's, er, so that's the only disadvantage I think with having English.
- Interviewer: If this course had been in English, erm do you think it would have made any difference in any way?
- Student: Well it depends, I don't know. I , I got a feeling that he speaks a little better English—at least he knows what everything is called in English. and he's writing English quite well I think—better that he speaks Swedish anyway I think [laughs] So perhaps it would have been better, but I don't know... he's... because that's, that's the main... the most important thing is that the teacher himself is confident with the, with the language cos otherwise he can't he cannot explain anything because he has to think al the time "okay what's this called? what is this called and so it's [laughs].
- Interviewer: And, er, if you think about the erm you mentioned there that er it's good to have to have both languages erm, do you feel like in the physics degree that there, that there is exposure to both languages erm and do you feel that there's some sort of system behind all of this so that you're ...
- Student: Ummm. No—no I don't think so I don't get that...
- Interviewer: That it that you get more a feeling that the language is just whatever it happens to be.
- Student: Yeah I think so.
- Interviewer: What do you feel about that?
- Student: Um, perhaps it would , would be good to have some, some strategy where to put the English courses—but it's not so important I think. It's better that—well if a teacher prefers to to teach in English then I think it's better to, to use English for this course.
- Interviewer: How would you feel about erm a Swedish teacher teaching in English?
- Student: Er, yeah well we had one course last year were there were actually three teachers but two of them know, know Swedish quite well and one of them actually she's Swedish so umm, but there were some exchange students and I also think that this course is always er, er taught in English. Er cos it's one of the courses in the A- level...
- Interviewer: How did that work out then?
- Student: Err, well it was... Yeah well I think it was okay er, well actually one of the one of the teachers was a PhD student er she was very very bad at speaking English and she... nobody understood anything [laughs] she was erm talking er teaching erm some kind of introduction to the quantum mechanics and the Schrödinger Equation, so it was [laughs] most of us just went

to one of her lectures, then she was on her own so...[laughs] I felt a little bad for her actually so it's [laughs] er because I think it was her first the first teaching experience for her so it's yeah...

Interviewer: Er you think that she learned something?

Student: Yeah [laughs]

Interviewer: So, so but I mean er for you then er if I try to summarize this er the language doesn't make so much difference er, but the language that you receive it make more difference the language that's produced by the lecturer....

Student: Yeah

Interviewer: ... and you think that that's the governing factor for you?

Student: Yeah yeah

Interviewer: ...and then there's this third language here, mathematics and that's pretty much the same in both languages—in English and Swedish, though perhaps not the same in the mathematics department as the physics department.

Student: No, and that's also one thing that we really shall learn here it's mathematics I mean we're not here to learn English but we're here to learn mathematics

Interviewer: Yeah, precisely. And er you mentioned a little bit about that that the idea of learning mathematics the mathematicians way erm at that could be quite useful erm is there any sense that it could be actually counterproductive?

Student: I don't, No I don't think so in the long term. It's never bad to learn anything er, of course it can be a little bit more difficult than we learn in other physics courses because er, yeah like I ... it would have, would have been nice to put the mathematics more in a physical point of view, but er... so we will deal with that later. It's that simple. [laughs]

Interviewer: Okay, well erm, then I've run out of questions...

Student: Yep

Interviewer: ... I've taken quite a lot of your time anyway so erm, but erm is there anything else that you think that you would like to say about these two courses erm, I mean it's not something that...

Student: No!

Interviewer: ... I'm just thinking generally your experience about them.

Student: Well, no I think I've said quite a lot, [laughs] going on and on... [laughs] No I think we've covered the basic...

Interviewer: And if we just think about the... the general sort of happy, clappy thing ... you feel like you're actually learning something in both of these courses?

- Student: Yeah! I think so! Especially in that electromagnetics course this is more well this is I'm not as erm I'm not working as much with this course as... it's, I'm quite lazy...
- Interviewer: So you would say that the the interest and the usefulness of the course, that reflects in the amount of work that you put into it as well?
- Student: Yeah, because it's even though I know that this is perhaps very useful it's hard right now to see why it is useful.
- Interviewer: but here there's very clear links
- Student: Yeah because even in other physics courses it would have been nice to have studied this course before because it it's a different areas you always come to these—like we know from electromagnetics
- Interviewer: Just out of interest, do you think that that's because of the subject or because of the lecturer making links.
- Student: Umm I don't know...
- Interviewer: I mean, would it be If we think about this course the mathematics course...
- Student: Yeah
- Interviewer: ...erm would it be possible to, to teach it in such a way that, that those links were made.
- Student: Yeah! Of course. It would... it should be actually it should be actually teach in that way because er that's that should be the main idea with this course to, to really point out for physicists why, why these mathematics is good but now it's more like a mathematics course and so ...
- Interviewer: Um if [the electromagnetics teacher] had taught this course,
- Student: Yeah it would have been different.
- Interviewer: It would have been different you think.
- Student: Yeah I think so.
- Interviewer: And do you thin that your work on this course would have been different then?
- Student: Ummh... yeah I think so
- Interviewer: And by different we're saying that you would perhaps have done more work?
- Student: It's also, so it's very much that some areas in this course is, we have only got these papers and he's proposed problems here and it's just "prove this and prove this mathematical statement" and well, yeah, of course it's—well in an ideal world every scientist should know everything about.. from three thousand years ago until now, but that's not how things work actually...
- Interviewer: Some sort of renaissance man?

Student: Yeah, yeah. ... so you also have to trust other people sometimes so er I think it's more interesting when you apply mathematics to something than...

Interviewer: So in a sense what you're saying is there's some sort of cultural, erm, crash or...

Student: Yeah

Interviewer: ... difference between the way that a physicist thinks and the way that a mathematician thinks cos a mathematician has to prove to themselves...

Student: yeah yeah...

Interviewer: ...whereas a physicist can accept some things.

Student: Yeah—it corresponds to the, to the reality then it's okay. So that's the difference.

Interviewer: Oh, I think that's a really nice, er, really nice place to end anyway...

Student: Yeah!

Interviewer: Thanks very much! I've got two cinema tickets for you here...

Student: Ooh!

Appendix D: Student interview protocol case study 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



Internal motion (around the c of m)

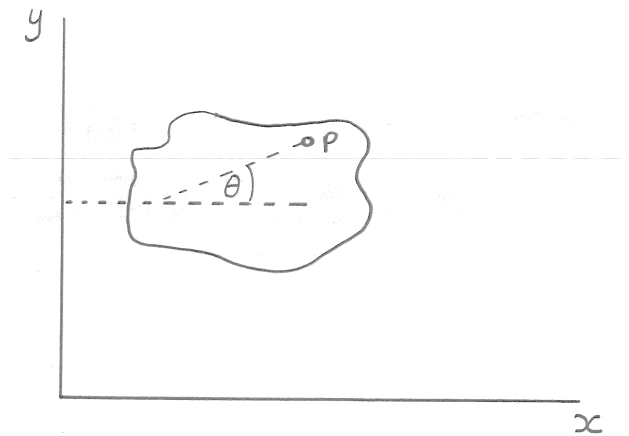
The diagram shows a collection of small grey dots representing particles. A larger, darker grey dot in the center represents the center of mass. A line points from the text 'c of m' to this central dot. The particles are arranged in a roughly circular pattern around the center of mass, illustrating internal motion.

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?

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?

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 inläringen? 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?

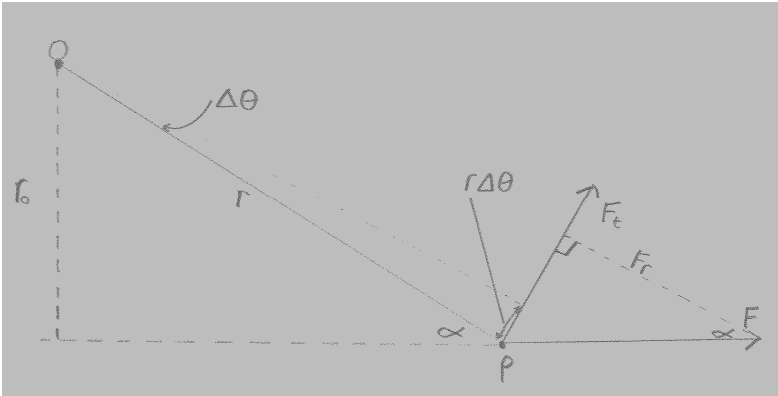
Vad är innebörden av denna jämförelse?

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



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

$$\tau = F_t r \quad \textcircled{1}$$

$$F_t = F \sin\alpha$$

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

$$\tau = F r_0 \quad \textcircled{2}$$

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

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

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?

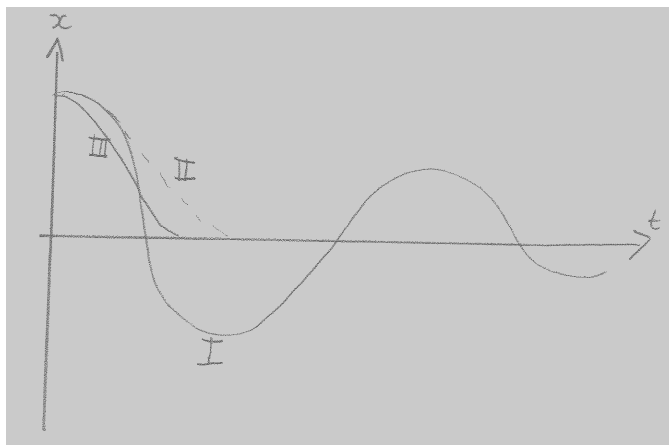
Can you tell me what you understand by this equation?

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?

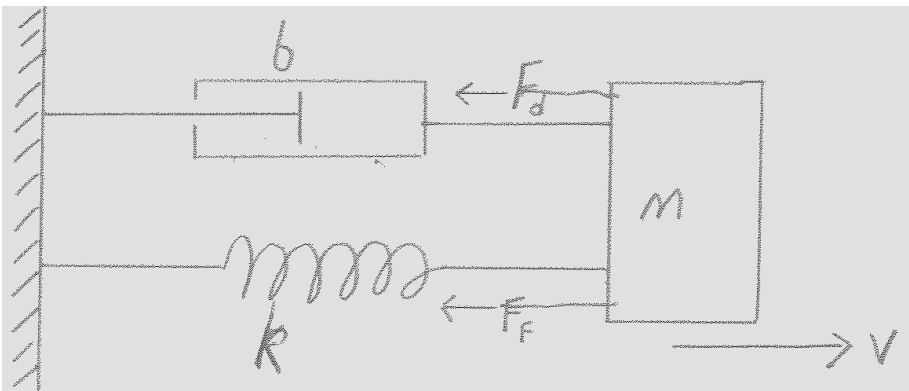
the course?

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?

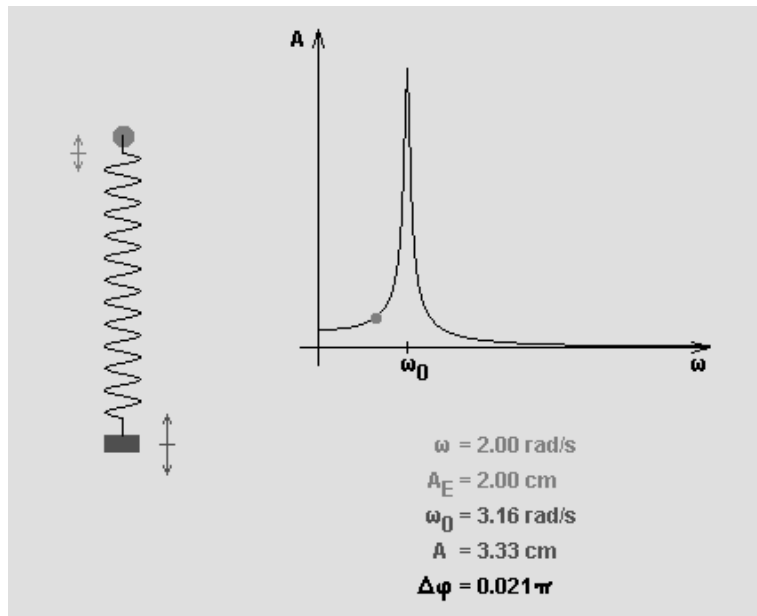
Vad är det svåraste med att försöka förstå det här?
Vilka saker hjälpte till med inläringen? Varför
Kunde du se hur detta hängde ihop med resten av lektionen?
Kursen?

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?

Clip E scene 13 solution to equation → End

	$X_H(t) = A_0 e^{-\gamma t} \cos(\omega_0 t + \delta)$	Homogena ekvationen
	$X_P(t) = B \cos(\omega_d t + \varphi)$	Partikulär lösning
	$X(t) = X_H(t) + X_P(t)$	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
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? Language.
Which do you prefer? Why? Different if 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

Appendix E: Sample student interview transcript case study 2

- Student: So!
- Interviewer: So, we'll just sit here and look at some of the video...
- Student: Yeah, okay.
- Interviewer: ...you probably know what we're gonna do anyway by now, er, and of course, er, I've, erm—remember that I'm recording everything we're saying!
- Student: Ah. Okay!
- Interviewer: ...but that's, er, just so you know—I'm not going to use it in any way except for research.
- Student: Ummh.
- Interviewer: Erm, basically what I'm interested in is, um—well actually the whole group that I work with in Uppsala are interested in looking at students' experiences of learning physics... er, I'm particularly interested in, er, how students, erm, understand maths and what they think about that, but also, erm, because I'm originally a physics teacher, but now I'm an English teacher, I'm also interested in the sort of language aspect...
- Student: Um.
- Interviewer: ...of this, that's why it's quite nice with these two lectures: one in, in English and one in Swedish, and so on.
- Student: Um!
- Interviewer: Erm, up till now, people have just looked at, at sort of exam grades and maybe what the teacher has done and so on...
- Student: Um
- Interviewer: ...they haven't really asked students, what they're thinking and what they're doing in lectures. So our group is trying to fill in that, that piece, if you like...
- Student: Um
- Interviewer: ...so that we, er—what you often find is that everybody's different, but then that you can pick out certain patterns, certain, if you like types of people who think in certain ways and so on. And that's important for a teacher to know...
- Student: Um, Yes!
- Interviewer: ...in order to be able to, to—to actually get, er, a good idea of what their students are thinking. For example I talked to [lecturer 1] before all of this and he said "It would be really interesting to know what these students are thinking—because I've no idea!"
- Student: [laughs]

- Interviewer: So, erm, at, the same time I'm not going to be going to [the lecturers] and saying exactly what people have said and so on, but obviously they're interested in a general idea, but, but my research is, is more, er, I mean basically if there is anything in general I will talk to them about that, but they won't know who said what. At the moment I think they are happy to have got videos of themselves—sort of “Oh, I look like that! and I do things like that!”
- Student: [laughs]
- Interviewer: Erm, I think the most important thing is that, that there are no... it's not a test or anything, and there are no right or wrong answers to this—we're just trying to figure out the way that people think about certain things...
- Student: Um.
- Interviewer: ...and so every answer is just as valid as every other answer, because it's, it's how you think about these things.
- Student: Yes.
- Interviewer: Erm, so to start off with then, er, I'd like to—what I'd like to do is to talk a little bit about, er, your background as far as learning is concerned, and then we'll look at this particular course, er, in, in general. And then we'll look at some specific pieces from both courses...
- Student: Okay.
- Interviewer: ... or, um, from both lectures—on the same course yeah. Er, so, to start off with, erm, er, can you tell me a little bit, about, about your background as far as learning is concerned?
- Student: Ummh. Erm, på engelska eller?
- Interviewer: This you could do in Swedish erm it doesn't matter.
- Student: Erm, jag läste in gymnasiet i Sverige—alltså jag kommer från [another EU country], åh jag har bott i Sverige i sju år och jag har alltså innan jag började här på högskolan läste jag in gymnasiet på komvux för att ta behörigheten sen läste jag ett år kemi på programmet biomedicinskemi och efter det året bytte jag till nanovetenskap.
- Interviewer: Erm, nu har jag mina frågor på engelska så jag blev lite snurrig här...
- Student: Oh, Okej [laughs]
- Interviewer: Men erm, I'm just thinking, as far as er, your background as far as learning physics is concerned erm, just in the past, have you always felt that you've been good at physics?
- Student: Um, not really, erm, erm, I got a good grade in physics when I, erm, at komvux, but I felt I did not really understand things, um, so I was wondering why I got this grade [laughs] actually!
- Interviewer: In, in what sense?—you felt that you didn't understand?

- Student: Er, especially mechanics, erm, maybe it was because, er, I had a lack of math knowledge, um—I don't know. Cos now it's much easier for me to, er understand how things are...
- Interviewer: Work?
- Student: Yeah, how they work.
- Interviewer: Then you mention mathematics and that's obviously one of the things I'm interested in, erm, what's your experience of, of learning maths in the past.
- Student: Er, in the past—easy. Er, not as maths that I studied here in Kalmar was not easy, it was really hard but mest before, at komvux—really easy.
- Interviewer: Okay.
- Student: [laughs]
- Interviewer: So you think that there's some sort of discontinuity there between the komvux and then the maths that you have here?
- Student: Yes, yes, yes, yes, yes it was a real jump like, er, from yes what really was really a big difference.
- Interviewer: Er, just out of interest, have you done anything special to cope with that or was it just...
- Student: Yeah, er, when I...
- Interviewer: ...I'm just thinking you're saying that there's this big jump, how did that feel?
- Student: Oh, well I, I—studied! A lot. I spent a lot of time to understand how, how it works. [laughs] so...
- Interviewer: But, there was..
- Student: Before I, I, I didn't need to spend lots of time to understand the maths, yeah, it was really easy for me before, but er, here, at the university I had to study a lot. Um.
- Interviewer: Erm, what about English then, er ...
- Student: Um... mnja, um Swedish is not my language either so, erm Eng—yes, it's it's okay. I, er,I, I understand in English er, lika bra, er, as well as I understand Swedish, but maybe I have er, it's a little more difficult to speak English for me I think—it's easier for me to speak Swedish, but I understand English as well as I understand Swedish.
- Interviewer: And, and, erm, have you had any learning in the past in English?
- Student: Yes, in [another EU country]. And, er, på komvux. In Sweden på komvux where I, got my er...
- Interviewer: No, I'm thinking about being taught a subject through English rather than...
- Student: No, no, not that. Well, nja, no, not that.
- Interviewer: And er, but then you've obviously, learnt things in Swedish, erm, at komvux and so on...

- Student: Yes. Actually I, I some things, I don't know the words er, in [the student's first language]—I know them in English and in Swedish, maybe in [the lecturer's first language] [laughs] but not in [the student's first language]—it's really fun.
- Interviewer: But, erm, if you think about learning in—now you've learnt some physics in English, you've learnt some physics in Swedish in the past—and now of course—and er, you've also learnt in [the student's first language]...
- Student: Yes I don't actu—I don't have any memory in er, erm, to the, about the physics I learnt in [another EU country]. It's so long time ago cos I'm, I'm thirty five years old and when I went to school in [another EU country] it's like it's, it's a long time ago so I don't remember.
- Interviewer: But, er when you were at school in [another EU country] er how did you see yourself as a learner? Was it easy for you?
- Student: Yes, it was easy as long I was going to school, but I lost interest a little bit. And then I stayed away from school a time and... ah. But it was easy when I was there [laughs]
- Interviewer: What erm, what motivated you to start to go to Komvux and take this course?
- Student: Yeah, erm because when I moved to Sweden—I was living in **** before—and I actually I had no education so I, I've done lots of different jobs but it was working well in, in ****, but it was not working as well when I came to Sweden. So then I was erm I could not choose so much so I get a job at a fabrik so it was really a quite stupid job and I was really bored and after two-and-a-half years I thought I have to do something now I really have to get an education.
- Interviewer: Yes because that's a big thing in Sweden.
- Student: Yes, yes yes.
- Interviewer: You can't do anything.
- Student: No you can't do anything—especially not if you live on the countryside or in a small city. There is nothing so um.
- Interviewer: Erm, when you learn physics—I'm interested in this language thing—er, how did it feel to learn in, in English and then to learn in Swedish?
- Student: Erm. In the beginning I was a little confused, it was not so er, it was not a big thing to learn physics in English it came, it was quite natural, it was not so hard. But then the change from English to Swedish there was a time where I was a little confused so I didn't know how I should write—should I write down in Swedish or in English and then I mixed both languages together like that.
- Interviewer: So, so the notetaking became quite complicated?

Student: Yes,yes. Erm it was erm it was just for two days or something. Then it was okay for me to have it in Swedish again. But er, a short period in between I was kind of confused.

Interviewer: So now when you take notes in class you take notes in Swedish? [in the Swedish lectures]

Student: Yes.

Interviewer: But intially you tried to take them in some sort of mixture or...

Student: Yes, yes.

Interviewer: Erm, we can follow up that because I'm just thinking that erm, er, your book, the book that you have is in English, so, but you're taught in Swedish er, now anyway for [the Swedish teacher's] part. Erm does that cause any problems?

Student: No. I'm used to it because I studied one year chemistry before and its literature was in English and the teaching was in Swedish. It was no problem.

Interviewer: Okay. then let's have a look at this particular course. Erm, when I say this particular course I think that the degree that you've joined up for now this er, "nanovetenskap". What motivated you to choose that?

Student: Um. I'm interested in this 'quant' thing er, I don't know, I yes I'm interested in that. The courses which are coming then like quantfenomen och artificiella atomer, kvantprickar det tror jag.

Interviewer: It sounds really interesting!

Student: Yes.

Interviewer: Okay. As far as long-term er you were saying that when you came to Sweden you had to work in a factory. What would you like to do long-term?

Student: Er in the future? Erm, do some research, find something what I find is interesting and do some research. Um I don't know I hope that it will turn out for the good [laughs].

Interviewer: Erm, but basically this course that you're doing is some sort of vehicle taking you somewhere...

Student: Yes, yes of course

Interviewer: ...so it's very important for you.

Student: Yes, umh.

Interviewer: Um as far as your participation in lectures and so on er, er, do you come to everything...

Student: Yes.

Interviewer: ...Everything?

Student: Yes.

Interviewer: Erm and you've got this book, are there any other materials that you have? Webpages or anything else?

Student: Yes erm, there's a webpage er, from the book, from the writers of the book.

- Interviewer: Ah, okay.
- Student: But I don't use it so much I, I've checked it out but I, I think it's er—I get tired when I'm sitting in front of the computer, but I think it's ok.
- Interviewer: Erm I'm just thinking, when you took notes er, you said that you had some experience of learning in Swedish but obviously learning in Swedish but having a book in English, erm but you take notes now in Swedish but the book is in English...
- Student: Yes.
- Interviewer: ...is there any conflict there, anything that's a problem?
- Student: Well sometimes you have to look up some words—if you don't know the meaning then you have to look them up, but otherwise no, I don't think so. I mean that I, I remember when I er, start studying chemistry last year, that was really difficult it was really difficult to have English literature. But now it's, it's not, it's okay.
- Interviewer: So it's something that you got used to?
- Student: Yes, yes exactly.
- Interviewer: Erm do you do anything special to, to cope with the these two languages?
- Student: No, no [laughs] I don't know.
- Interviewer: Erm, I guess the teachers themselves are interested in you erm getting the terms and the ideas in both languages because obviously the—you're working in Sweden but...
- Student: Yes, I think it's really useful to, to er, know the terms in English I think it's more useful for me to er, understand it in English than to understand it in Swedish so I, I'm interested in learning that in English.
- Interviewer: Erm, as far as understanding is concerned, erm you know, when something's explained to you for the first time or you're reading something to try to, try to figure out what it is, erm, is it easier in English or in Swedish or, or if you could do it in [the student's first language] do you think that that would be...
- Student: I don't know [laughs] Yes, I mean the easiest thing would be in [the student's first language]—I think so. Er but, maybe it's a little more difficult in English than it is in Swedish, but I think it's almost to have it in Swedish is almost the same as having it in [the student's first language]—I think so. It's a little more difficult to have it in English. Yes, because if you have some—if you want to ask a question you have something you want to ask them erm, I don't speak English so well as I speak Swedish so it's easier for me to ask to talk in Swedish and ask things.
- Interviewer: Cos I noticed in [the Swedish teacher's] lectures, there were a lot more questions than in [the English teacher's] lectures is

- that, is that common or is that just, just those two cos I just had two small...
- Student: No. It's common actually. [laughs] Yes. That for sure has to do with the, with the language, that er, people don't—they're a little shy to speak English because they cannot speak English so well. For me it is er, like that.
- Interviewer: So there's a—so you would ask more questions when in the Swedish lecture?
- Student: Yes, yes
- Interviewer: And you would feel more happy to ask questions?
- Student: Yes.
- Interviewer: Okay, erm, If you think about the content—and think first just about [the English teacher's] erm, stuff. What do you think is the most difficult thing to try to understand.
- Student: Um. The most difficult thing er, I don't know. I don't know actually. Everything was equally hard [laughs] The most difficult I don't know.
- Interviewer: Cos you mentioned as well that you thought mechanics was quite, er, quite difficult...
- Student: Yes!
- Interviewer: ...and then this was mechanics.
- Student: Yes. Um, for some reason I um, it's easy for me to understand now, er for some reason—I don't know why I, I, I maybe because I have more math now um, it's different for me to... maybe I think I understand and then I should calculate but 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.
- Interviewer: Erm, and er, in [the Swedish teacher's] section. Er, you've only had a week now, er, is there anything that is particularly difficult there.
- Student: Ummh. Yes. It's erm, he's faster when he's writing—everything is faster sometimes it's hard to er, "hånga med"
- Interviewer: Yeah, yeah just to follow
- Student: ...Follow what's he doing now and..
- Interviewer: Cos I noticed you asked a couple of questions about oh well what's this? Where did you get that term from and so on.
- Student: Yes and then sometimes he writes down some things and he er, sees oh maybe that's wrong and then he takes er, takes away a sign somewhere and change something and you like you're writing, you don't see what he has changed and then oh! What is that?
- Interviewer: So he's found a minus sign that he should have put in somewhere...

- Student: Yes. In [the English teacher's] lessons [the English teacher] was slower so he took more time to explain and we had more time to think what he's doing so... but he took also one week more than he should [laughs] but I think it was good used time anyway [laughs].
- Interviewer: Erm okay, er, do you—you obviously have some, you talked there about calculation erm, do you do that on your own or with other students?
- Student: Er, we used to sit er, we, we used to sit together three four of us er, at least two days a week in the afternoon and I sit at home as well on my own, but often it is like that that maybe I cannot work out a problem on my own but if we are three or four together then everybody can 'bidra med nånting och då klarar vi att lösa uppgiften'
- Interviewer: And erm, How much work do you do outside of the class then?
- Student: Um. A lot! Erm, Yes a lot. How much in hours or?
- Interviewer: About in a week, I mean outside the stuff that's timetabled.
- Student: Outside the schedule?
- Interviewer: Yeah.
- Student: Um I, I normally use almost the whole weekend to read or to study. Mm yes it's I think I have more than a forty hours week. More than that.
- Interviewer: And how much do you think that the teachers expect you to do?
- Student: I think sometimes they don't know how much work we do, how much time we, we put in. Erm, I don't know what they expect—I don't know [laughs].
- Interviewer: Erm, when you work together as a group, which language do you use then?
- Student: Swedish [laughs]
- Interviewer: But even when you were dealing with [the English lecturer's] lecture that was in English and the problems that were in English?
- Student: Yes, okay sometimes we use English there I, um, er, the problem sets which we had every week er, I wrote it in English when we had [the English lecturer] and now I write it in Swedish and so we er, we were concerned with the problems we had so sometimes I, I wrote down something in English, but we talked on Swedish [laughs]
- Interviewer: So, so you were more concentrating on the problem than on the language?
- Student: Yes
- Interviewer: So the language was just not even...
- Student: No.

Interviewer: Okay, then I think we can start to look at some of these bits from these lectures. Basically you'll see the same pattern come up. I start off by showing you a bit of the first, the very first part of the lecture so that you get an idea "Oh, yeah, that one..."

Student: Mmm, okay.

Interviewer: ...and then we'll look at a few specific pieces that I've picked out. So this is the very start of [the English lecturer's] lecture.

Student: Um.

Video Transcript: Clip 1

So, er, erm, the title of this lecture is er, rotations in er, two dimensions and er, er, this is er, a little bit a continuation of last week's lecture remember that last time er, er, we were studying er, systems of n particles and er, we saw that er, in spite of essentially er, the same fundamental Newton's second law was at work, it was very interesting to see how er, things were going when instead of one particle we had many particles. Okay, so examples of this was er, water flowing for example, er, think about the what the molecules are doing. Galaxies whirling about and then we said another example was a solid body like this that can be thought of as a large collection of er, many, many particles. And, er, so what we saw was that in general it's hard to describe completely the behaviour of this er, of these systems, however there was a what we discovered was that there was a specific point, an imaginary point that we define, that we call the centre of mass and is, is defined in terms of the coordinates the vector positions and masses of all the particles making up this system and er, er, this imaginary point was giving us er, somehow, an idea of the overall motion of the system—right? So the centre of mass in the simplest case say is er is a point somewhere in the middle of the system and therefore when it moves er, its velocity, it's acceleration, sort of describes the overall behaviour of this er, of this large collections of particles.

Interviewer: Okay, let's stop there. So this is just to get you sort of to remember, erm. What were you thinking at this stage if you think back...

Student: Oj, well, I think I, I understood what he was talking about.

Interviewer: And what do you think—I mean this is the very start of the lecture—how did you see this relating to the stuff that had gone before and so on?

- Student: Erm, Yes, um, he always started, started he always started the lecture with a review from the one before so it was quite good...
- Interviewer: And so this is what you'd done..
- Student: before, yes.
- Interviewer: And you felt that you had no problem understanding what was going on and so on?
- Student: No
- Interviewer: Okay then then we'll move on because he does something that gets a little bit more interesting...
- Student: Okay

Video Transcript: Clip 2

So when we say that we er, we throw an object like this [throws a whiteboard pen] I've been preparing this all weekend [laughs from the class] er, the body performs a parabolic motion, and what does it mean? Clearly, the body really doesn't do a parabola if we just look at for example er, the two ends of this pen, they are performing a quite complicated motion, but we know that somehow there is something that er, inside that follows a parabola and we found out very clearly what this something is—it is in fact the centre of mass. The centre of mass moves just like if there was one single force acting on it and the mass of this er, fictitious fall is just the overall mass of the system.

- Interviewer: Okay. Erm, okay so here he throws this pen, so what did you think when he was when he was doing that?
- Student: Er, I don't remember what I think—but I understood what he was, what he said that it's just the centre of mass that er, follows this parabolic motion and er, but the whole body is rotating so erm [laughs]
- Interviewer: So, so er, did you feel so you felt that this helped you to understand what he's saying?
- Student: Yes.
- Interviewer: And er, it's still very clear for you what's going on?
- Student: Um, very clear, [ironic] Yeah I think I understand [laughs]
- Interviewer: And of course it's a recap of what, what he's done the time before.
- Student: Umm.
- Interviewer: Erm, er, did you take any notes at this stage?
- Student: Um, no...
- Interviewer: Just because it's what you've done before?

- Student: Um, well I wrote, I think I wrote what he wrote, but not more. Sometimes I write down what the teacher say when I think this is something important.
- Interviewer: But usually you just write down what he...
- Student: Yes usually just what he's writing..
- Interviewer: Okay, then er, we go on and look at a little bit further on.

Video Transcript: Clip 3

*So erm, so how do I describe rotations? of a rigid body? It's a question [interviewed student sighs then laughs]
[Long silence] So I need to describe the position of the body right? So what do I need to do? [long silence] since the body is rigid and I already know that there is a point that does not change because there is a fixed axel rotation what do I need to fix—to just determine completely the position of the body?
[Class member speaks] An angle.
Okay—you are too fast. Yes, so the answer is of course correct. I need to specify the position of another point, right. So I need the green. Let me, and we call it P and how do I specify the position of this point? Well I simply specify an angle, right. So what do I do? I simply, er, draw a line connecting, er, P with er, er, the centre of rotation which I will call O and then I will simply consider the angle defined with respect to say the x-axis.*

- Interviewer: Okay. So erm, I'm just thinking, what did you think at this stage when there's this long silence.
- Student: I thought "Shit, now he wants to have an answer, I hope not from me" [laughs]. Erm, Yes, er, I, I felt quite pressed I think.
- Interviewer: Why do you think there was such a, a sort of long silence?
- Student: Yes, but everyone was afraid that he would come out with a name "Now you have to answer my question" Maybe you have to come to the blackboard and ...
- Interviewer: Has he done that before?
- Student: Yes, yes. Sometimes you have to come to the blackboard and do something there [laughs]—The whiteboard. Erm, yes it was um.
- Interviewer: But did you know what he was...
- Student: No, not really. I think not really no.
- Interviewer: But do you understand now?
- Student: I understand, yes, when, when, now I understand, um. After he had done what he was asking—writing this point P and er, the things then I understood, but when he asked what he should do or how he should do I, I did not know what he meant. Inter-

- viewer: So it's more to do with the way that he asked the question than, than anything else?
- Student: Mmmh, I don't know. No, I didn't know what he wanted us to do and what we should say. I didn't know the, the answer.
- Interviewer: And um. Now I'm just looking at one very small piece, but is that er, something that's happened before in class or...
- Student: Yes. Yes. Um, yes erm, I, when. Sometimes when he explains something or when he will solve a problem, then erm, he wants us to say how he should do and er, we maybe didn't know, so, so nobody answered.
- Interviewer: So you felt that he wanted you to tell him what to do? Er..
- Student: We should tell him what he should write on the blackboard or what he should do. So it would have been easier if he had not asked the question, just showed, er, how it works and then maybe we understand.
- Interviewer: Why do you think he asked the question then?
- Student: Maybe he thinks it's pedagogic I don't know.
- Interviewer: It makes you think?
- Student: Yeah.
- Interviewer: Well it certainly did that!
- Student: I don't know I, um [laughs].
- Interviewer: Erm, but when, when this actually came out..
- Student: Yes.
- Interviewer: ...this was actually something quite easy to understand—the question that he was asking.
- Student: Yes.
- Interviewer: It's just that you didn't know where he was going with the question, what he wanted?
- Student: Er, no not really—exactly.
- Interviewer: Okay, then we'll take a look at the next clip and what he's gonna do is to try to talk about this, this er, table [shows student a copy of the table] I'll show it you here cos you can't see on here. Men här kan vi prata lite svenska.
- Student: Okej.

Video Transcript: Clip 4

And so you see, we start to see some interesting analogy between er, the motion of a particle on a straight line where we have the position and velocity. And er, what we are trying to do here to describe er, rotations of a much complicated system, however confined to rotate say on, in a plane. And you see we start to see some correspondence here correspondence of linear position of a particle, we have angular position, the value of the angle and similarly the velocity which is the rate of

change of the position with respect to time is the rate of change of the angle. In fact, there is a, erm, there is a very strong analogy between er, the motion of a particle in a straight line and the rotation of this in 2D that we will try to exploit as much as possible.

- Interviewer: Okay, er, so he's talking about this relationship between these two. Men nu ska vi titta på det här på svenska, erm, er, vad erm, vad tänkte du här—förstår du vart han skulle?
- Student: Uhm, jo, jag tror jag förstår. Jag tror jag har också läst, er, i boken—tidigare alltså ...
- Interviewer: Så, är det någonting du har gjort erm, förut också?— att du läser innan man kommer på lektionen?
- Student: Ja, jag brukar göra det om jag hinner.
- Interviewer: Så det fungerar bra för dig?
- Student: Javisst, det fungerar mycket bättre än när man inte har läst [laughs] lättare att hänga med, uhm.
- Interviewer: Okej, uhm, kände du att när han utvecklade det här att du lärde dig nånting?
- Student: Jo, jag tror det. [laughs]
- Interviewer: Och hur var det, kunde du ser hur det hängde ihop med resterande?
- Student: Uhm, Ja, uhm.
- Interviewer: Erm, var det nåt som var svårt att förstå med den här analogin som han pratar om?
- Student: Uhm, nu vet jag inte riktigt vad det är alltså...
- Interviewer: Nu tar han fram det här, va [tabellen] så då...
- Student: Nej, jag tyckte egentligen det här var ganska.. okej, den här är lite konstig den här torque grejen, den är lite konstig—och den också, men annars att torquen är analogen till kraften i en dimension det förstår jag och accelerationen ..
- Interviewer: Så det här var ju, för dig väldigt er, klara saker att man har er...
- Student: Alltså väldigt klara det vet jag inte, men er alltså jag förstår ...
- Interviewer: Här skriver han upp allting, men just här för själva kraften och erm, vad kallas det? Rörelse...?
- Student: Rörelsemoment, just det, ahh.
- Interviewer: Ah, just det, det är rörelse... uhm, precis [laughs]. Här skrev han ingenting på den här sidan just i den här lektion va?
- Student: Ah, okej, men den här grejen har jag skrivit. Han har skrivit upp den tre gånger då skrev han det en annan...
- Interviewer: Då var det en återkomst så att säger?
- Student: Ja. Uhm.
- Interviewer: Erm, nu tänkte jag som det här med, erm, vinkel och sen så att man tar vinkeln och sen så andra derivatorn av vinkelen det,

- det verkar var en ganska klart analog där, men erm just den här, [torque equation] vad säger den här till dig?
- Student: Ja. Alltså inte så mycket. Jag har inte tänkt så mycket om dem, jag har nog kört på att jag tar det som det är. Jag har inte försökt reda ut det, utan jag accepterar det bara—att okej så här räknar man ut den, så här får man ut den, och så här får man ut den. Den förstår jag inte riktigt.
- Interviewer: Men du förstår, däremot analogen?
- Student: Ja, absolut, mmh.
- Interviewer: Så det här är någon kraft...?
- Student: Vridkraften, ah, som svarar mot en kraft i en dimension.
- Interviewer: Sen så tänkte jag rent matematisk här va, för erm, om man tänker på just de komponenter som det byggs på erm, de här biter så att säger. Om vi skulle försöka läsa ut vad det kan betyda...
- Student: Ahh
- Interviewer: Men er om vi bara tänker lite logiskt nu, och nu är jag inte så bra på det här heller—det var väldigt länge sen, Men, erm då har man den här vridkraft och sen så säger man att det är lika med ...vad är de här termer då?
- Student: Alltså F_y är kraften i y led, F_x är kraften i x led—alltså krafternas komponenter...
- Interviewer: Ah, just det...
- Student: ...och x och y är erm, ja det, det vet jag inte riktigt erm ...
- Interviewer: Skulle man kunna gissa vad de kunde vara då...
- Student: Alltså det måste vara, det måste vara koordinaterna va?
- Interviewer: Ah just det, någon sorts distans, erm, avstånd...
- Student: Ja en distans, just det—ah just det, mmh
- Interviewer: Någon sorts avstånd eller någonting. Och då skulle vi kanske kunna tänka att det var avstånd till det här, till själva axeln som man...
- Student: Okej, aha, men det tror jag inte. Tror du det eller? Är det så?
- Interviewer: Jag ska inte tro nånting—jag bara intervjuar dig! [laughs]
- Student: Nej, men alltså då kunde man ha betecknat x och y med en index där som betyder att det är avståndet till axeln—jag vet inte.
- Interviewer: Men, på sätt och vis så återkommer vi till den här för han återkommer till det—but in English! [laughs] Okay let's just take a look at where he goes from here. Cos what he talks about is this diagram [shows diagram] er, so he's got the axel here and the point P and then he's got a force going this way and then he's got the tangential component of the force here...
- Student: Okay, men alltså är det en punkt massa här nånstans eller är det, är det någon kropp eller..

- Interviewer: If you remember what he said what he was trying to do was describe the movement of rigid bodies—so something solid.
- Student: Okay
- Interviewer: But there's one axel that is fixed, so the only way it can turn is like this [demonstrates on the diagram].
- Student: Okay, aha, okay, det här axeln?
- Interviewer: Yeah, and then he's taking any point P...
- Student: Yeah okay, mmh...
- Interviewer: ...and then what he was saying is that by describing this point, P—If I describe one of these because it can only turn like this I describe the whole motion.
- Student: Mmh, okay.
- Interviewer: So then he's got this point, P and a distance r to the point P and then he says, okay so let's say that it moves—let's see the change in the angle and then we can start to talk about how the whole thing has moved. And he's got this, force.
- Student: Okay, mmm.
- Interviewer: So let's see where he goes from here.

Video Transcript: Clip 5

So therefore we have now using this er, these three things, we see very interesting characteristics of the torque of course so as I said repeatedly, only the tangential component of the force is important—first comment. Second comment er, you get a larger twisting force if you are far away from the, the origin that is exactly the theory of levers.

- Interviewer: So there he talks about a distance and a force
- Student: Mmm, mmm, mmm.
- Interviewer: Erm, so if the force must be applied at point P to the body—which is fixed at point O and then it can only turn. And then he talked about only the tangential...
- Student: Yes
- Interviewer: ... component of the force being important.
- Student: Yes, mmm.
- Interviewer: Then he comes with this particular equation [points to equation 1]. Mmm what does that mean to you then?
- Student: This equation uhh. Ja alltså the torque alltså jag kan läsa ut vad det, vad det betyder?
- Interviewer: Yeah, yeah.
- Student: Er okay the torque är the tangent, the tangential force times the distance to the point P from the axis.
- Interviewer: So torque must be a force and then a distance which is orthogonal to that—at ninety degrees to that?

Student: Ja, just det mmh...

Interviewer: So he's got the tangential.. and then he's got...so it's a force times a distance—I'm just thinking if we go back to this one [Torque expression from previous clip]

Student: Mmm.

Interviewer: ...here we had the two components of the force and then the two ...

Student: Ahh, okay!

Interviewer: ...things that were actually at, at right angles to them.

Student: Aha!

Interviewer: cos this is y and that's F_x

Student: Aha okay!

Interviewer: But what do I know? I'm just the interviewer. [laughs] But this is fairly clear then that this torque is the something to do with turning and you get it by looking at a force and then something at ninety degrees to that—a distance to the axis from where the force has been applied?

Student: Mmm

Interviewer: But then he works out this one here [points to equation 2] he puts in this angle α and he says the this tangential force is the same as the actual force, times sine α —okay so that's just geometry...

Student: Mmm, mmm, mmm.

Interviewer: ...but erm he's saying that sine αr is the same as this distance here, cos that angle's the same there—he's saying that sine αr gives you this distance. So now he's using the actual force...

Student: Okay, vänta lite er... mmh

Interviewer: Now he's using this actual force instead of the tangential component he's using the whole force...

Student: Yeah, yeah.

Interviewer: But the distance is different.

Student: Jo, jag förstår inte hur det hänger ihop-nej.

Interviewer: But if you look at this force...

Student: Yes

Interviewer: ...and this distance—cos it's always the distance to the origin

Student: Mmm

Interviewer: ...it's the distance that's at ninety degrees.

Student: To the force.

Interviewer: Yeah

Student: the same as before!

Interviewer: Yeah! So actually, what he's saying is that you can use the ... instead of using the tangential force if you use the whole force...

Student: Yes

Interviewer: ...obviously you have to have a smaller distance ...

Student: Aha! Yeah. Okay.

Interviewer: ...so you, you plot back to a virtual point where the force is acting

Student: Mmmh

Interviewer: ...to get the ninety degree...

Student: Yeah, okay.

Interviewer: So I guess there are two ways of doing it...

Student: Okay, mmh.

Interviewer: ...but it's always a force times a distance

Student: Which is also at ninety degrees

Interviewer: Yeah.

Student: Mmh, Okay!

Interviewer: And it's orthogonal from the point where it's applied

Student: To the axis.

Interviewer: Yeah! But here he used the whole force instead of the tangential one

Student: Oh!

Interviewer: ...so he has to plot back

Student: ahh!

Interviewer: to find a ninety degree...

Student: Yep, yeah, yeah!

Interviewer: So in a sense I guess they're both saying the same thing?

Student: Yeah they have to be. It has to be the same I mean...

Interviewer: If you think about then, about this torque uhm, what does it really mean for you?

Student: Erm, well, the force which gets a body to, vad heter det?

Interviewer: Turn, rotate

Student: Turn or rotate.

Interviewer: And then these equations tell us something—that it's a force and a distance

Student: Mmm, yeah [laughs uncontrollably]

Interviewer: [laughing] okay we can we can leave that there and we can go and look at [the Swedish teacher] and what he's got to say. And this is again, just like last time, the start of his lecture.

Video Transcript: Clip 6

Vi fortsätter med våra svängningar, vibrationer och erm, idag ska vi då titta på dämpad svängningsrörelse, dämpad rörelse. Hittills har vi pratat om harmonisk svängningsrörelse—vi har en återförande kraft och vi har alltså ingen energiförlust så att [skriver på tavlan] så, erm, vi har, i den där saken när den håller på, en sinusformad funktion—den svänger alltså upp och

ner. Om vi har en fjäder eller något annat som svänger när en, er, återförande kraft då som ligger, som är proportionell mot avvikelser från jämviktsläge, så vi har ingen energiförlust. Utan energin som vi sa här i början av veckan, det svänger ju hela tiden mellan potentiell och kinetisk energi.

Interviewer: Okay. So actually what he comes up with is this [Energier = $U + K = \frac{1}{2}\kappa A^2 = \text{konstant}$] that the energy is like this. Do you recognize this?

Student: Yep.

Interviewer: So what are these different bits then?

Student: The whole energy is the sum of the potential and the kinetic energy and they're both changing. If the potential energy gets larger, the kinetic energy gets smaller.

Interviewer: And what are these two terms here then?

Student: Er, this is amplitud, svängningens amplitud och den där κ är uhm, fjäderkonstanten, en konstant.

Interviewer: Okay so at this stage this is the very start of the lecture—did you feel that this was this was, er, fairly straightforward?

Student: Yes.

Interviewer: And was this also linking to back to...

Student: Yes because we talked [the English lecturer] talked about that. We talked about energy conservation and er, about er, fjäderkraft, uhm.

Interviewer: Okay, then we're gonna start look at where he starts to talk about these things [points to diagram] actually he doesn't draw these up in this little bit, but this is where he's going with it anyway.

Student: Uhm

Video Transcript: Clip 7

I det verkliga systemet så har vi dämpning va? [ritar diagram] på något sätt. Och ... har jag inga... vad väldigt vad tomt det var härinne! Jag svängde med en pekpinne va' och man kunde göra en pendelrörelse ut av en linjal och man ser att det svänger ett tag men amplituden är väldigt svag och det minskar hela tiden och det beror på friktion av olika slag i materialet, luftmotstånd o så vidare, som gör att den dämpas ut med tiden den där svängningen, så att man kan då prata om tre olika fall—alltså dämpning kan vara olika stark. Antingen är det svag dämpning så att den här amplituden minskar långsamt - energin i systemet en halv gång κ gånger amplituden i kvadrat i det där va? Om amplituden minskar långsamt som med svag dämpning den kan minska snabbare—kraftig dämpning.

Och så har vi ett mellanläge också så vi kan skilja mellan olika fall.

Interviewer: Er, okay. So basically he's talking about this [points to diagram] and saying that there are different... what do these three cases mean for you then?

Student: Umm, ja... alltså vad menar dom för mig? Ahh, okay. Svag dämpning har man alltså—det är det vanliga som man har i naturliga system—och sen kan man påverka systemet här det blir nå'n grej så man får kraftig dämpning istället—alltså tillföra någonting som...

Interviewer: What, what does this mean this erm...

Student: Aha, okay, jo alltså, svängningen hinner inte fullborda hela perioden liksom, den hinner bara göra en halv period så att säga. Okay and in this critical case?

Student: Er, ja... erm, den ligger ju emellan—alltså det är ju en mellan umm, det ligger mellan svag dämpning och kraftig dämpning så den, den här halva perioden pågår lite längre, men kommer ändå att plana ut.

Interviewer: So if there had been a little less damping then...

Student: A little less damp-ning and kraftig dämpning a little more...

Interviewer: Yeah, with this one, if there'd been a little less damping, it would actually start to go past the...

Student: Yes!

Interviewer: ...but this one, I mean it's obviously not going to go past 'cos it's really very strongly damped?

Student: Yeah, mmh

Interviewer: Okay, then I think we'll look at the...this is what he's going to draw up now [shows second diagram]

Video Transcript: Clip 8

[lära ren ritar upp diagrammet] Vi tittar på dämpad, dämpad rörelse—svängning och er, vi tänker oss nu att vi tar den här dämparen här och erm, fäster den då parallellt med fjädern så att säga, då sätter vi dämpad ... också och då har—på det här föremålet nu så har vi nu en fjäderkraft som verkar—vi kan kalla det F , och så dessutom så har vi då en erm, en erm, dämpkraft—så. Och den här kraften den verkar åt det hållet. Om vi nu antar att hastigheten på den där, den är på väg ut och så kan vi dessutom säga att denna sak fördrivs i jämnviktsläge. Uhm, den där beskrivs utav, beskrivs utav arbeten B den här konstanten—och den utav fjäderkonstant. Och nu kan vi se där från Newtons ekvationer att summan ut av dom krafter som verkar på den här massan, den ska vara lika med massan

gångar accelerationen det känner du igen? Förut hade vi bara en fjäder men nu får vi två stycken termer så att vi, vi får helt enkelt erm, sätter in två termer och då har vi först fjädern den var lika med minus κ gånger xm , men så har vi dessutom den här dämpkraften och den var hastigheten och den ska då vara lika med massan gånger accelerationen... så där va? Och då får vi en andra ordningens ekvation igen—differential ekvation, men vi får sån här dämpstermer då...

Student: [interjecting] Men har du tappat ett b här kanske?

Interviewer: Yep!

...och det kan vi hyfsa till så vi känner igen den som en standard form...

Interviewer: [video runs over to the start of the next clip] Oops! I was too busy looking at the missing b!

Student: Yeah [laughs]

Interviewer: Erm, first I thought we could talk about what he's drawn here, what, what are all these different components that you've got here?

Student: Er, should I say?

Interviewer: Yeah, just talk me through what he was trying to do here.

Student: Oh, okay this the mass which is ...ska jag prata på ...

Interviewer: Yeah, in English for this bit, and then we'll take this bit in Swedish.

Student: Erm Massan, erm the mass which is er, er—det är svårt alltså—which is er, fast?

Interviewer: Yeah, connected, yeah.

Student: Connected to, er, to a spring and on here we have erm, dämpnings system which also is connected to the mass.

Interviewer: Okay, and these er, different er values here...?

Student: This is the velocity—of the mass, this is the fjäder, fjäderkraften som verker i motsatt riktning er, ahhg! som er, which er, [laughs] acts in the opposite side to the displacement. This is the spring constant which deter..mines the spring and this is erm, dämp, dämpningskonstant which determs the dämpningssystem [laughs]

Interviewer: Okay—nu, nu tar vi det här på svenska...

Student: Okej

Interviewer: ...jag bara tänkte när du såg allt det här och så gör han det här och så tar han fram all den här matte, vad tänkte du? Hur tänkte du då? Hängde du me'?

Student: Jag tror det [laughs]. Ja, jag tror det...

- Interviewer: Du såg i alla fall att det fattades ett b...
- Student: Jo, alltså jo, jag tror det alltså om man tar—okej jag tänker inte så mycket på b gånger v alltså b gånger hastigheten den är konstant ”b gånger v vad är detta egentligen?”, utan aha, han säger det är alltså den sammanlagda kraften—fjäders kraft minus kraften från den här dämpningssystemet som är lika med den sammanlagda kraft som är lika med massan gånger accelerationen—det förstår jag men jag tänker inte så mycket på ah, varifrån kommer den, vad är det här b gånger, gånger hastigheten utan ahh.
- Interviewer: Men erm, sen så tar han fram en sån här ekvation och så gör han lite så där fiffiga grejor här..
- Student: Ummmh
- Interviewer: ...och sätter in två termer—omega noll och gamma
- Student: Ja.
- Interviewer: Varför tror du han gör det?
- Student: Ja, varför han gör det? Usch! um, för att visa ett annat samband erm, men alltså er, jag förstår inte direkt hur det hänger ihop—nu vet jag inte heller riktigt, jag för...om jag förstår det...erm.
- Interviewer: Han säger att det här är en konstant och det här är en konstant då...
- Student: Umm.
- Interviewer: ...Så han kan kalla dem vad han vill.
- Student: Ja!
- Interviewer: Så det gör han. Och då får han en viss form...
- Student: Umm.
- Interviewer: ...på ekvationen.
- Student: Okej. Ahh just det! Just det och det är ju den där standard formen för en differential er ekvation—andra ordningsdifferential ekvation som man kan lösa ... ah—man kan lösa den i alla fall! [laughs]
- Interviewer: Så han har bara ändrat den så att ser ut som en...
- Student: Ahh, just det, okej ja, sen förstår, nu förstår jag vart det ska gå då—varför han byter ut grejorna—just det.
- Interviewer: Så de här är apropå ingenting egentligen—det är bara för att få det att ser ut så där va?
- Student: Just det.
- Interviewer: Men sen så när han kommer till det här skulle du kunna från matte lösa ut den där?
- Student: Om jag kan lösa den här?
- Interviewer: Ja—ja jag menar inte just nu! [laughs]
- Student: Nej! [laughs] men jag skulle kunna lösa den där om jag satte mig och, ja det måste gå—jo jag tror jag kan det men jag får gå

- tillbaka till mina matteanteckningar och läsa i matteboken och då tror jag att jag...
- Interviewer: För här säger han vad rötterna av det skulle vara egentligen—och då har han dom här så...
- Student: Jo, jag vet, jag kommer ihåg att man kan få tre fall och så där mmh, just det, det kommer jag ihåg.
- Interviewer: Okay, then er, we'll go back to English again...
- Student: Okay
- Interviewer: ...and have a look at this erm, animation that he gave—and this was in German on the screen!
- Student: Yes! Yes, yes.
- Interviewer: It may be actually easier for you then? [laughs]
- Student: [laughing] Yes I was actually really interested in this I, I actually looked at the webpage at home, umm.
- Interviewer: And so you could put in the different values and so on?
- Student: Yes.
- Interviewer: Let's just see what he has to say here.

Video Transcript: Clip 9

Vad är det som händer? Jo, vi ser att den håller på o svänger nu med sin egen frekvens—den håller på o svänger kring sin egen jämviktsläge—och jämviktsläge bestäms ju av att den här åker upp och ner va? Så den här svänger kring den röda linjen—stämmer det? En dämpad svängningsrörelsen som överlagras den här. Men om vi plockar undan det där så ser vi hur det där upphängningen kör—också det ser ut så här va? Och så efterhand så dämpas den här egen frekvensen, och då blir vi, då får vi en frekvens som visar sig vara den samma som den påtvingade frekvensen i efterhand va?—När systemets egenfrekvens har dämpats ut, egensvängningar har dämpats ut... det tar en stund där.

- Interviewer: Okay. Erm, so he showed that thing there? Er, do you think that that helped you to understand?
- Student: Yes.
- Interviewer: And, erm, this er, movement—did you understand what, what he's trying to say here?
- Student: Yeah.
- Interviewer: What's the red bit and what's the blue bit?
- Student: The red bit är den påtvingade är svängningen och den blåa grejen är alltså själva massans egensvängning.
- Interviewer: Yeah, so he talked about it being er, one thing going round, the other so to speak so that this thing does its own frequency, but because this is moving then it's around that...

Student: Yes

Interviewer: ...and that was fairly clear for you I suppose?

Student: Not so clear, but I got a better picture after, after when, after looking.

Interviewer: But after a while something happened? What was, what happens then—cos it doesn't look like this [initial phase] later on.

Student: No. Erm you see, erm, okay, okay so that frequency is larger than the—den påtvingade frekvensen var större än den egna frekvensen så att säger—jo umm.

Interviewer: So this moves, but then after a while the only thing that's...

Student: So from the beginning the frequens of the mass is bigger than the ... erm—än den påtvingade frekvensen eller...

Interviewer: Yeah, the driven frequency

Student: Yeah, mmh, and in the end that will have the same frequens the system has the same frequens and the driven frequens.

Interviewer: So this has a sort of natural—the spring itself has a natural frequency, er, so then it sort of—and that natural frequency is around this red point—but because the point's moving...

Student: Mmh, mmh.

Interviewer: ...then the natural frequency is around the ...

Student: Yes!

Interviewer: That point, but after a while, the natural frequency dies out and you end up with just the, the driven...

Student: Ahh, okay, mmh, mmh.

Interviewer: ...portion of the...

Student: Aha, okay, mmh.

Interviewer: It moves just to the frequency of this rather than the natural frequency of the spring. Now I'm not sure where I am [laughs]

Student: [laughs]

Interviewer: Er, yeah, actually we're here. Erm, let's look at the next part here. What he's gonna do is to look at these two things—we'll see.

Video Transcript: Clip 10

Här är det nog så att x av p är lika med summan av den här, så den här är den homogena lösningen plus partikulära lösningen så, okej? Det känner ni igen nu va? Och vad är det här för nånting? Jo, den här kallar vi som sagt allmänna—den här är—alltså den homogena, kallar vi den i matematikspråk men vad kallar vi den i fysikspråket? När jag började prata om det här? Jo jag sa att det var en transient fas va? I början, som försvinner med tiden [Student: mmh en övergångsfas] och sen har vi en stationär svängning efterhand och den där, den liksom fortsätter—det såg vi ju på animationen också—så att det här är

den homogena och det är på fysikens språket som vi kallar för den transienta delen av lösningen och vi ser att den försvinner ju—den har, den här termen har en exponentiell funktion som gör att den här dör ut med tiden, den transienta, medan den här partikulär lösning—vi kallar den på matematikspråk då par-ti-ku-lär lösning, Annars kallas den för en stationär tillstånd—en stationär lösning.

- Interviewer: Okay so he talked basically about this, erm, what, what do you understand by that? Did you, did you feel like you—when you were at that, in that situation, did you feel like you could follow what he was talking about?
- Student: Umm, ja, it was a little difficult for me to er, make out what is the transient and what is the stationär phase, I thought it would be the other way around...
- Interviewer: The other way around?
- Student: I don't know why, but okay, but from the math that is, is that this equation has a homogeneous and a partikulär solution I, I remember just relate, relating to this little part.
- Interviewer: Um you said there that just spontaneously you thought that these two would be the other way around...
- Student: Yes.
- Interviewer: Erm, but if we think about the animation...
- Student: ...but I had not because I didn't understand er, this animation that's why I thought it was the other way around. Now I understand a little better and now it is quite clear for me that this is the transient and this is the stationary.
- Interviewer: Cos, er, cos this is with er, κ so I suppose this must be something to do with the spring's own frequency?
- Student: No, no, no, this should be an h here—h for homogen!
- Interviewer: Yes! It must be an h, and this is a p, cos otherwise I was thinking that it's very simple...
- Student: No, no, no it's not like that. I thought because transient—trans det är alltid ordet trans betyder ju övergång eller någonting som inte håller i sig—någonting som översätts—transducer till exempel. Och er, stationär det är den som vi står kvar med sen.
- Interviewer: Så det här är övergående?
- Student: Ja precis.
- Interviewer: But then—oh, so you're thinking from the mathematics? Homogeneous would be then the thing that happened afterwards whereas this was something special?
- Student: I don't know how I was thinking. I think I just, just didn't understand the animation correctly.

- Interviewer: But these two parts must be those two phases together, working together, plussing one to the other you get the actual...
- Student: The actual solution.
- Interviewer: Yeah, the way that the thing actually moves.
- Student: Mmmh, yeah.
- Interviewer: Okay. then I've finished really looking at this and I've just got a couple of questions about er, really the comparison between the two learning experiences that you've had. Erm, obviously it's different material and different teachers, erm, but how, how would you compare these two experiences?
- Student: Ummh. Yes, I don't know, I mean...
- Interviewer: I'm thinking more from sort of a language point of view—if it's easier or difficult...
- Student: It's easier, på, på in Swedish. It's easier, yes because it's easier to talk. So you would prefer to be taught in Swedish?
- Student: Yes, yes of course.
- Interviewer: But if you could be taught in [the student's first language]?
- Student: I didn't try it! [laughs] So maybe it would be the best—I don't know.
- Interviewer: Erm, are there things that are better and worse in both languages? I'm just thinking that you're saying that it would be good to be taught in Swedish.
- Student: I mean for understanding, for understanding, I mean otherwise if you think you read an article somewhere everything is in English, so it's good to understand in English—if you don't understand English then I maybe you have to go a course because I don't think you can come somewhere after these four years if you cannot do this in English—I mean what do you want to do?
- Interviewer: So, so there's a balance between, between—for you, if it was in Swedish it would help you to understand easier...
- Student: Yes, yes.
- Interviewer: ...but at the same time you see this long term as an...
- Student: I know I have to...
- Interviewer: There's a need for English?
- Student: Yes, I know I have to do it in English.
- Interviewer: If, erm, if the book and erm, the lectures were in Swedish and everything was in Swedish...?
- Student: This would not be good. Because then you don't get the English part which you really need.
- Interviewer: Um, but then you could maybe think, I guess, the other way as well—er, what if just everything was English and they just said no let's forget about Swedish?

- Student: Yes, okay, but then I would, then I would actually come the point that I would improve my English, my English that much that it wouldn't be so difficult for me anymore—I mean I had to learn Swedish also in the beginning so—I don't know, I mean it is more difficult for the moment, but I know it would be good for me ...
- Interviewer: Would there be any negative sides to that that you could think of?
- Student: That I had a harder time to understand! [laughs]
- Interviewer: Yeah, but I mean more long-term, I mean..
- Student: Aha—no.
- Interviewer: ...surely you would have ...?
- Student: Long-term no, it would not have a negative side because—well I don't think I will live in Sweden all my life and maybe move somewhere where—maybe I move back to [another EU country]—or I move to a country where I can speak English, so it would be better to...
- Interviewer: If we think about then—because obviously I've, I've been interested in, in English and Swedish and this third language—mathematics, erm, er, you, you seem to be saying that English is more important, but in some ways it's easier for you to learn in Swedish and erm, that your understanding of English would be some sort of limit at the beginning—do you think that your understanding of mathematics is a limit to how much physics you can understand?
- Student: I can't understand the question [laughs].
- Interviewer: [laughing] Um, yeah, it's a long question, I'm just thinking erm, you said that er, if everything was in English, erm, initially, at the beginning it would be more difficult but then it would be good in the long term. I'm just thinking about mathematics—erm, if everything is done through mathematics er, would it be the same?
- Student: Ah, Yes.
- Interviewer: If we see mathematics as a language that they're using to explain this erm...
- Student: Okay.
- Interviewer: ...you said that you think that English would be a limit to your understanding—do you think that mathematics is a limit to your understanding of physics too?
- Student: I, er, I can't imagine how it would be to use mathematics like a language—how do you mean?
- Interviewer: But all the descriptions of everything that you have they don't just...

- Student: Uhhg! that would be really really boring! I think. [laughs]
Really boring and not so fun.
- Interviewer: Yeah, you said you spent a lot of time working erm, sort of outside class with, this maths problems and so on...
- Student: Mmmh, okay, because yes, with the math, I remember with the math book we had was in Swedish but it was really hard to understand anyway [laughs]
- Interviewer: Erm, if you think about the way that this course, this course is put together then, er, do you, erm, what do you think about this mixture between English and Swedish? Is it a good thing, or would it be better everything in Swedish or everything in English or...?
- Student: Well, it would be better, well, I don't know, it depends on how you look at it. Yes, I mean normally the people who go this course come from the gymnasium—they're not so old, they have not so much experience and for them it's really, really hard to have a course like that in English. So they maybe lose interest. So it depends on how you look at it. For me, I think that it is good that I had both parts, I don't know ...
- Interviewer: But you're also very highly motivated...
- Student: Yes.
- Interviewer: ...to put work in, to actually deal with that. But are you saying then that in a sense it's good but it creates extra work for you?
- Student: Yes! [laughs]
- Interviewer: So do you think that er, just, just looking at what's gone on so far, do you think that by the end of this er, education that you'll have a reasonably good idea of being able to work with physics in both languages?
- Student: Yes, I think so. It comes, by time, through the books through the literature, but erm, the understanding er, i alla fall, men man lär sig inte att prata man inte pratar [laughs].
- Interviewer: Yeah and of course you didn't do so much speaking in [the English lecturer's] lectures.
- Student: No, [laughs]
- Interviewer: Okay, then, then that's it. We've taken a little longer than I said I would. But I've got a cinema ticket for you here...
- Student: Oh! That's fun [laughs]

Appendix F: Student interview protocol case study 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)

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

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

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?

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 inläringen? 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 säga här?

Var kommer dessa villkor ifrån?

Afternoon (lecture in Swedish)

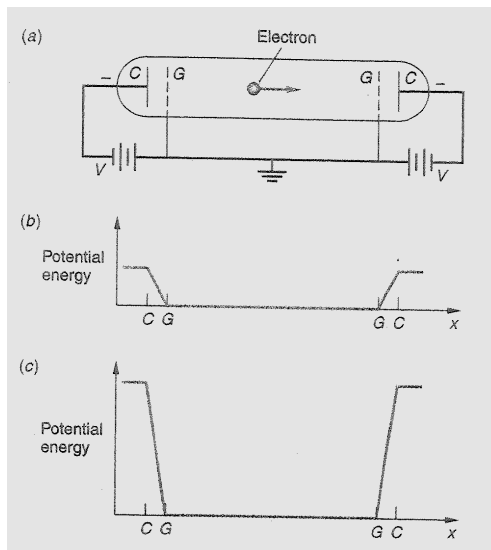
In the afternoon the teacher described a problem-solving strategy for quantum problems

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



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 $V(x)=\infty$ $\psi(x) \equiv 0$

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

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

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

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

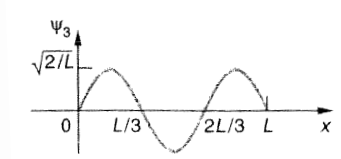
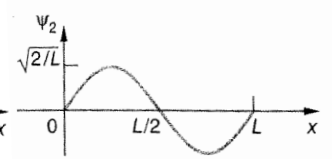
$$\psi(x) = A \sin kx$$

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

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

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

Appendix G: Sample student interview transcript case study 3

Interviewer: Jag spelar in det här, men det är ingenting speciellt med det utan inspelningen kommer bara att användas för forskning, inte dina lärare... Okej, nu ska vi se.—[student's name]?

Student: Ah, just det.

Interviewer: Ja! Okay, we can either do this in English or in Swedish, but some of the things I want to speak about in English—and some of them I'll want to speak Swedish—so some of the things are definitely "oh, no! Now it's this language!"...

Student: [laughs]

Interviewer: ...but erm, I don't know wh, what—it doesn't really matter at the beginning—but most of my questions are in English—well, all my questions are in English, but if you want to answer in Swedish that's not a problem—until I say it's a problem!

Student: Okay [laughs]

Interviewer: [laughing]...but, erm, really all we're trying to do here, as I said in, in er, your class last week is just to er, try to get some data about the way people think about physics, er, and from that, er, to try to make—to see patterns, just like we do in physics or in mathematics—to see patterns, to see things that, that are happening from that data. People have always tried to work with statistics and, you know, how many people pass a course and so on...

Student: Yeah

Interviewer: ...and it's got nothing to do with what's going on—their thought processes...

Student: No.

Interviewer: ...er, so that's what we're trying to get at here. So because of that, erm, the most important thing is that you say what you think—there are no right or wrong answers—so trying to second-guess, you know—"What is it he wants me to say?" is actually just the wrong thing...

Student: Yeah [laughs]

Interviewer: ...cos that would then make it like—it would be like, like being in the lab and then saying "What does my supervisor want the data to look like?" and then just making it up—it wouldn't make any sense at all.

Student: No.

Interviewer: Erm, so the most important thing is you just say what you think—there are no right or wrong answers—there's only your experience of these things—and that's the most important thing for us—to get good solid data where people just say what they

- think. And then from that we may or may not see a pattern—you may be over here and everyone else is here or ...
- Student: [laughs]
- Interviewer: ...it doesn't really matter just as long as you tell me exactly what you think. What I'd like to do today is to talk a little bit about your background just as far as learning physics is concerned, and then to talk about this course—in general—the aim of your, what is it—four years or something like that?
- Student: Yeah.
- Interviewer: So the aim of that, then the aim of this course, and then what you see as the aim of [the teacher's] little bit. And then I want to look at [the teacher's] part—a few clips from that—and er, see what was said and what you understood from what was said.
- Student: Mmh.
- Interviewer: And then I've already got from [the teacher] what [the teacher] wanted to say...
- Student: Okay!
- Interviewer: So, you know, it's also a matching between what the teacher thinks they're doing and what they're actually doing...
- Student: Yeah.
- Interviewer: ...which is also kinda interesting.
- Student: Yeah.
- Interviewer: So there are lots of different things...
So, then if we can start off with you and your—a little bit about your background—and now I'm thinking about, about er, physics maybe and mathematics and English and Swedish. If we think about physics, what's your experience of learning physics up to now—is it something that's been easy for you or...?
- Student: No, I think in mathematics it's more comfortable and more easy for me than physics—I don't know why, but I prefer strict formulas—like a puzzle to make all the pieces fit together. Erm, but I haven't studied so much physics before I came here I did a course in er—I worked as a car mechanic before, so I did that in gymnasiet. And then I studied secondary school—komvux—er, physics there for what they call 'basår' one year where you do all the courses...
- Interviewer: Yeah!
- Student: ...so I still feel that the pieces haven't fit together yet—it's still just a mystery [laughs]
- Interviewer: But, erm, you said that you, you studied car mechanics...
- Student: Yep!
- Interviewer: ...erm, so if we think before that—there must have been some reason that you chose that, erm or chose not to do physics...

Student: Yeah.

Interviewer: ...was, was physics something that you thought was quite difficult or?

Student: Yeah, mmh, but I knew that I had to do the physics to be able to do this course so it was more like forced to do it.

Interviewer: It's something you had to do?

Student: Yeah.

Interviewer: Erm, but you, you mentioned that you were quite interested in mathematics and solving like, little puzzles and...

Student: Yeah!

Interviewer: ...and you see it that way.

Student: Yeah.

Interviewer: ...er, has it always been like that through school—that mathematics has been fun for you?

Student: Yeah, mathematics and language—English and so on... erm but that's the reason that I first started at secondary school, just to try—er, am I going to make this or not? So I took the A-course in, in mathematics and then I realized that this is really fun [laughs] So let's do the “basår”.

Interviewer: Yeah. It's also fun because you can *do* it as well?

Student: Yeah, yeah, yeah—it's a challenge.

Interviewer: And you mentioned there languages as well—erm, how's it been with English and Swedish before you came to university?

Student: Yeah, that's also in secondary school—I studied English and er...

Interviewer: Was that easy for you or...?

Student: Yeah I think so. I do a lot of watching movies in English and the internet and so on, so it comes more naturally.

Interviewer: And what about Swedish—has the, er, the Swedish courses that you've had to do—has that been easy as well?

Student: Yeah—pretty much easy again.

Interviewer: So physics...?

Student: [laughs]

Interviewer: but the other—English and maths and Swedish and so on, um that's not such a problem?

Student: No, no.

Interviewer: Erm, have you learnt subjects—now you're learning in English—have you learnt subjects in English before?

Student: No.

Interviewer: No—so this is the first time?

Student: The first time.

Interviewer: Erm, how do you feel about it?

- Student: No, yeah it's quite difficult when you come to, er, what do you say—special words, technical words and phrases like that—that's quite hard to start with to just come in to right thinking.
- Interviewer: So this word comes along—what do you do then?
- Student: If I read something then I look it up and then okay, oh, then I place it in something bigger then.
- Interviewer: So, erm, you said, you know, physics was—something that was a little bit tough...
- Student: Mmm
- Interviewer: ...erm, does learning physics in English make it even tougher?
- Student: Yeah, yeah absolutely [laughs]
- Interviewer: Absolutely—okay. [laughs] What, what, what things? What is it that makes it difficult?
- Student: Well...
- Interviewer: What do you feel? What is it that's not the same as when it's in Swedish?
- Student: Now you—sometimes you have to think twice, because you don't know the words. And er, it's like—okay I know what she's talking about—what she wants to say, but here's a word and—have I missed something? Er, okay. Then you have to think twice and that, umm—it makes it more difficult.
- Interviewer: When, when you're, when you're learning like that er, er, do you write everything down that [the teacher] writes on the board?
- Student: Yeah. Almost everything, yeah.
- Interviewer: And erm—but that's in English I guess...
- Student: Yeah.
- Interviewer: ...does that make it go slower?
- Student: If you look at my notes it's like that's Swedish and some word in English and then it gets Svengelska. [laughs]
- Interviewer: Erm, okay then, then we'll take a look at this course I think. Erm, er, in general, what are your aims with the doing this engineering education?
- Student: Yeah, to get a better job, erm, more like freedom and er, you can do more advanced stuff—it makes sense—I feel I—like when I worked like a car mechanic I was just a little piece—it doesn't make sense at all. [laughs] So this is my opportunity to do something—what I feel is maybe a bit more challenging.
- Interviewer: Mmmh. So, er, the course that you're doing—the whole education is some sort of vehicle to, to giving you a job that will give you more job satisfaction?
- Student: Yeah, yeah.
- Interviewer: Er, are you going for a specific type of job, or is it just a general idea?

- Student: No, just a general idea. Erm, to get more freedom, when you, what you want to do more erm, vad säger man?—mera valmöjligheter.
- Interviewer: Yeah, you've got more choices.
- Student: Yeah.
- Interviewer: But erm, if we think about what you've experienced of the university course so far—do you think that it, it's giving you what you expected it to give you?
- Student: No. [laughs]
- Interviewer: Oh dear! [laughs]
- Student: No, I think the tempo is too high to er—well I want to learn what I'm reading. I think the tempo is too high for me to, to collect all the data so I, I'm doing er, what I can with the stuff—okay hopefully I will make the tests but I would like if I had to choose—if I had a choice then I would do the same course but in a twice as long time.
- Interviewer: Because your interest is in understanding...
- Student: Yeah I really want to...
- Interviewer: ...not in just getting something at the end of it?
- Student: No, no, no.
- Interviewer: And so the amount of things that you have to do feels like—for you—that there's no way that you could understand it?
- Student: No, no. I can make the tests and hopefully get through it—I have done so far. So... [laughs] but if you ask me questions after this course then I would probably have forgot a lot of things that I wanted to learn in the first place.
- Interviewer: Do you think that the tempo is much different than this, erm, preliminary year that you did?
- Student: Yeah, yeah. But then when I studied in secondary school we had more subjects at the same time—the tempo was not, not er this high—it really wasn't.
- Interviewer: If we think about then, er, the amount of er, work that you have to do for this—you've got labs and lectures and problem-solving sessions...
- Student: Mmmh.
- Interviewer: ...do you go to—what do you go to? Do you go to most of those or all of them or...
- Student: Yeah, all of them.
- Interviewer: Yeah. And, erm, then, how much work do you put in outside the time that's actually timetabled?
- Student: Oh, it's difficult, but I study every day—sometimes you know it gets quite late evenings and I don't feel like I have some sort of spare time—sometimes, yeah I do have yeah but it's...
- Interviewer: But do you think that it's an eight hour day every day?

Student: Oh, yes!

Interviewer: And what about—do you do work at weekends?

Student: Oh, yes! Yes!

Interviewer: Erm, if you think about how much you do—do you think you do enough?

Student: Yeah, I er, can't do more!

Interviewer: You can't do more?

Student: No, that's not a choice.

Interviewer: Okay, if you think about er, what teachers like [the teacher] think—how much do you think they, they want you to do?

Student: Yeah, it's a tricky question. Some times it feels like they think that we know so much more when we come here than what we actually do! So [the teacher] probably thinks I'm not getting any sleep at all—or that I shouldn't get any sleep.

Interviewer: Yeah you should be working all the time! [laughs]

Student: [laughs]

Interviewer: So you feel like all the time they're expecting too much?

Student: Yeah, I should be doing some work—perhaps.

Interviewer: Erm, you've got er, a book for erm, this. How much do you use the book?

Student: Um—quite much actually, well I try. Some books—yeah this book that we have in physics is a really good one. But if I feel that the book isn't good enough then I try to choose different literature—in Swedish perhaps, so that I could make sense of the material. But often I try to read sections before we have the lecture on them and that's a really good way but sometimes it's not time enough to do it.

Interviewer: So, ideally, for you, it would be good to read before...

Student: Yeah.

Interviewer: ...and then have the teacher sort of walk you through it...

Student: Yeah.

Interviewer: ...and then you work afterwards solving the problems?

Student: Yeah that's right.

Interviewer: So those times that you've been able to read—before—has, has that helped you understand...?

Student: Yeah, yeah. Really—cos, yeah, you get, like, a second lecture and then you do it again on your own—I think it's the best way.

Interviewer: When you work with problem-solving, do you work on your own or with other students ...?

Student: Erm, most on my own. But we have some groups we sit together and study a lot.

Interviewer: When you work in these groups, er, those times, which language do you use? cos the book's in English and the lectures have been in English and the problems are in English!

Student: Yeah, no. In Swedish, yeah.
Interviewer: And when you write the problem?
Student: Er, when I write the problem?
Interviewer: Yeah, you know, when you, when you want to answer it.
Student: Oh! Okay, but I answer in Swedish. Yeah.
Interviewer: Er, let's see. Erm, what do you think about the mathematics in just this course, the thing that [the teacher] is doing?
Student: Mmmh, it's not so difficult. It's more the way you're supposed to think in physics er, that's a bit more troubling.
Interviewer: What do you mean by that?
Student: Abstract thinking and sometimes you don't know, okay—is this really right? You talk about small, small things and you can't actually see them, you can't get a grip of them.
Interviewer: So do you think you had enough mathematics to do this particular course?
Student: Yeah, yeah.
Interviewer: Some, some people have mentioned the mechanics course that you've done...
Student: Yeah.
Interviewer: ...er, did you feel you had enough mathematics to be able to do that course?
Student: No, that was more difficult yeah. There was some things that I didn't recognize. But then we studied mathematics and physics parallel to each other and sometimes it felt like the physics were going er, a bit longer, er more forward than the mathematics—and then you haven't got the tools enough to solve the physics problem. That was—yeah, we panicked! [laughs]
Interviewer: Cos I guess if you look at, at erm, mathematics and English and Swedish as the three languages that are giving you this information...
Student: Yeah, yeah, Yeah!
Interviewer: ...you wouldn't say er, start using some language that somebody's never heard before...
Student: No [laughs]That's right!
Interviewer: ...it just wouldn't make sense at all!
Student: No, no that's true!
Interviewer: I mean it doesn't matter even if even if I say to you well the only way to understand this is through German...
Student: Yeah!
Interviewer: ...and then I just start talking German!
Student: Yeah! [laughs] Okay... thank you!
Interviewer: Erm, what do you think about being taught in English?
Student: I think that it's a good way to, probably er, later on when we'll work with this—I'll have to use the English language so I think

- it's good. Of course I think it's—it makes the physics even harder than it is. [laughs] you just have to fit in! [laughs].
- Interviewer: Erm, does it affect your learning—being taught in English then?
- Student: Yeah, I think so—it gets harder. But I still think, well you have to get used to it.
- Interviewer: Mmh, what do you think about being taught then just in Swedish? would it be good if you'd been taught everything in just in Swedish?
- Student: Yeah, it would be more easy for me to learn things, but maybe more hard for me later on when I have to read the books in English. But then I would have the knowledge even before I read the books—yeah I would prefer to do all the teaching in Swedish.
- Interviewer: So you would prefer to have it in Swedish—to understand...
- Student: Yeah, yeah.
- Interviewer: ...and then after that you can use whatever language you like...
- Student: Yeah, yeah—it's true.
- Interviewer: Erm, when you've had courses that have been in Swedish, you've still had an English book—how does that work out?
- Student: Yeah, er, it did work out—yeah, if I had a choice there I would have the book in Swedish too.
- Interviewer: Erm, when you're working with English like this and you've got the book or something that you—something in your notes—how often do you need to look up words?
- Student: Ah, it's not so often. It's often you see a word that you don't recognize and you get it and put it in some context and then you understand it...
- Interviewer: Yeah.
- Student: ...but sometimes even when we sit in these small groups—we see this word "Ahhg what's this? Does anybody know?" "No I don't know"—"Okay we have to check it out—we have to know this word" so...
- Interviewer: If erm—now I'm thinking in general not thinking about one particular language or anything like that—A teacher is writing stuff on the board. To what extent do you follow what's going on then or is it something that you learn by working with it afterwards?
- Student: Mmm, yeah by working with problems—solving problems that's the way.
- Interviewer: So, when you're taking stuff down from the board, is it, is it empty—has it got meaning or...?
- Student: Yeah, it's ...but not so much. Yeah, I get the, the clothes—I can see the pictures and, okay ah, I don't understand how to calcu-

- late this, but I know a little bit of how the big things work so okay. So that gets into my mind and then solving some problems—ah okay! Now I know!
- Interviewer: So it's quite common that when they write stuff on the board that, that later on you have to work through it to...
- Student: Yeah, yeah.
- Interviewer: ...to actually really understand it. Erm, if that's the case though, then can you ask questions if you don't understand?
- Student: No. I don't ask questions. [laughs] Yeah, that's a problem.
- Interviewer: Because if you don't know what it is you don't know [laughs]
- Student: Yeah, what am I supposed to ask here?
- Interviewer: So a lot of, a lot of the work you have to do is after class...
- Student: Yeah.
- Interviewer: ...er, going through trying to nail down exactly what this means and then working through problems to...
- Student: Yeah.
- Interviewer: ...to really understand it. Erm, if the teacher asks a general question to the class, is that something you would answer?
- Student: Mmmh...
- Interviewer: Let's say you know the answer...
- Student: Okay.
- Interviewer: ...let's say you know the answer, erm, would there be a difference if the teacher's teaching in English?
- Student: Yeah, I think so—if it's okay to answer in Swedish, but if it's not then I would probably be quiet.
- Interviewer: So if, erm, in [the teacher's] class then, you would just answer but you would answer in Swedish?
- Student: Yeah.
- Interviewer: ...But if it was somebody who didn't have [the teacher's] competence in Swedish...?
- Student: Yeah, then I probably don't say a word.
- Interviewer: ...and then catch up afterwards?
- Student: Yeah.
- Interviewer: Erm, then we should get to some of these clips here...
- Student: Okay.
- Interviewer: Erm, so what I'm gonna do is I'm gonna show you quite a few clips from the morning and from the afternoon and then, basically, just like I said earlier on, all I'm interested in is your experience of, of what you saw there ...
- Student: Okay.
- Interviewer: ...what, what you actually understand from it—not anything else. And it doesn't matter if you say, "well actually I don't see anything, it's just empty—you know—then that's fine too.
- Student: Okay.

Interviewer: Erm, well it's not fine...[laughs]—you know what I mean!

Student: [laughs]

Interviewer: So this is the very start of the lecture.

Video Transcript: Clip 1

On Monday we talked about electrons, and particles in general, and we saw that particles can have a wave behaviour as well. This duality—a duality between wave and particle that we have seen before also for light. For photons. And er, de Broglie and these other physicists that we mentioned they er, described how these waves in fact could be, and what their properties would be. Like the wave function, er, sorry the wavelength of the wave, and how this is connected to the properties of the particle. Okay so I'll—just to remind you and because we will need it later on, I'll write down this de Broglie formulas—the de Broglie equations.

Interviewer: Okay, and then this is what [the teacher] wrote down there. [shows student equations sheet] I realize that it's difficult to see there, so those are what she wrote down.

Student Okay, Yeah.

Interviewer: Erm, okay, so [the teacher's] at the start of the lecture. What are you thinking at this stage? [the teacher] has just written these down and given that spiel that we've just had there...?

Student: Yeah, well erm it's more like a history lesson and of course I can see the problems to describe the light if it behaves like a wave sometimes or if it's a particle, but it's still, it's nothing that I understand completely, but I can see a picture okay, this is a problem, okay, we're getting somewhere.

Interviewer: So, er, has [the teacher] talked about de Broglie's er, equations before then?

Student: Umm, yeah I think they popped up.

Interviewer: Erm, [the teacher's] speaking in English, but er, does that have any effect on your understanding at this stage?

Student: No, no.

Interviewer: Erm, so do you feel that you're, you're with [the teacher] and how this all fits together or fits into the lecture before—and what's coming have you an idea of what's coming...?

Student: Yeah! Yeah.

Interviewer: Okay, if we look at the equations then, erm, what is it that you see here, do, do, do you actually—how do you understand what these things are trying to say?

Student: Erm, well I see them more like pure mathematics...

Interviewer: Okay

Student: ...like constants okay there we've got Planck's constant, okay. So I can't make sense of I can't see a picture of..

Interviewer: Of, of, yeah—you can't see a physical picture of these things.

Student: No.

Interviewer: But erm , er, but they're relations between different things—what are all the different terms then?

Student: Er, the terms? The wavelength and the frequency and er wave number and er, angular frequency...

Interviewer: Um, what's this h then?

Student: Ahh, yeah, that's Planck's constant.

Interviewer: Cos this is also quite confusing—you've got something called h-bar...

Student: Yeah.

Interviewer: ...you've got h and then h-bar?

Student: Yeah, that's something I've just accepted—okay, I know this divided to 2 pi then it's fine.

Interviewer: So it's just something that's been defined that way?

Student: Yeah.

Interviewer: And, er, er, what's p then?

Student: Erm—what do we call it?—rörelsemängd?

Interviewer: Momentum?

Student: Yeah. I don't know the English word [laughs]

Interviewer: Yeah, that's fine. Erm then we can go and look at where [the teacher] was going with this let's see what comes next:

Video Transcript: Clip 2

The probability is equal to—and we define the square of psi as—mathematically as the complex conjugate times the function itself. And this is also equal to the value of psi squared. Why do we use this complex conjugate—why not just say that it is psi squared? That's because psi is a complex function it's not a real function—it has an imaginary part and a real part—so it's a complex function—it contains this little i. So psi itself the function itself can therefore not be measured because it's only real functions that can be measured we can't measure a value of it. So psi itself you cannot give that a value as such it's a function. But psi squared is real and psi squared can be, can be measured.

Interviewer: Erm, okay let me just show you—that's what [the teacher] wrote up there. Erm what were you thinking about at this stage—did you feel like you could follow [the teacher's] argument?

- Student: Yeah, but it's still difficult. This is more like okay, now we're talking physics, erm humans trying to describe things that aren't there [laughs]
- Interviewer: [laughing] Okay!
- Student: ...now we should try to do, to get a formula out of it.
- Interviewer: What do you think [the teacher] was trying to say here then—with this formula?
- Student: Er, well how to describe something that aren't there [laughs]
- Interviewer: [laughing] Okay, what does the equation mean to you—like we did with the other bits before—What are the separate bits here?
- Student: Erm, to me, this is the part that I don't understand, so, I can see how they turn to make the pieces work by doing this squared and...Yeah, that's it. And [the teacher] was talking about some ima—imaginära?
- Interviewer: Imaginary.
- Student: Okay, then I'm thinking—okay it's quite difficult, so we're doing square? then oh it's fine!
- Interviewer: Why's that?
- Student: To get rid of the er—imaginära delen och negativa.
- Interviewer: Yeah when you square it you end up with minus 1 yeah?
- Student: Yeah.
- Interviewer: Erm, what are these terms then? What's psi for example?
- Student: I'm not sure, er some sort of wave number or something?
- Interviewer: And the P—what do you think that is? Cos this P is equal to psi squared.
- Student: Yeah, no, I don't know.
- Interviewer: Okej då ska vi prata lite svenska. [the teacher] har precis visat en lösning här för klassiska vågor som ljus till exempel, när man har en sån här vågfunktion er, och sen så fortsätter hon så här.

Video Transcript: Clip 3

Let's now go back to our problem of the day—the wave function for particle waves—'cause all this was classical waves that's right, but how about psi? Psi is just another type of pi it's just such a function and what we want is that psi—that there would be sorry, that there would be an equation like this one—a wave equation for psi, er, where psi is a solution of the wave equation and then when we put in psi, in the wave equation we get out something that is typical for electron waves. Okay, so Schrödinger came up with this wave equation it looks like this. The one I wrote here is for one dimension—that means only one dimension in space only x—not y or z.

- Interviewer: Again, it's quite difficult to read on screen but it looks like this [shows Schrödinger equation] Erm, vad tänkte du här? I den här situationen [the teacher] gjorde det här med klassiska vågor och sen så plötsligt dyker den här upp.
- Student: Ah, precis! Ah, då börja jag försöka koppla ihop det, okej om man beskriver den som en vågfunktion då ah, fast den är fortfarande—o sen ser man den där formeln aha, men då är det riktigt klurigt då då ska vi se—det kommer att gå åt några timmar att försöka leta information när jag kommer hem då—kanske—har jag tur så kanske jag förstår det.
- Interviewer: Vad gjorde du just här? Skrev du ner allting eller?
- Student: Ah, jag skrev ner allting.
- Interviewer: Hur kändes det just i det här fallet?
- Student: [laughs] Det är ganska typiskt—för så kan det kännas i för sig att er, Ah, får inte panik, du förstår ingenting nu, men så småningom kanske om du får testa och brottas lite med det kan det komma. Men det är—javisst, det är ett nytt tecken här som jag inte sett förut så det är mycket nytt.
- Interviewer: Så du ser framför dig några timmars arbete och slit?
- Student: Jo bara läsa lite omkring det...
- Interviewer: Så själva efterarbetet ser du direkt framför dig?
- Student: Jo, jajemen! [laughs]
- Interviewer: Tror du om det hade varit levererat på svenska att det skulle ändå... att du skulle ha fullt lika mycket jobb att förstå det?
- Student: Jo, det hade nog fortfarande varit klurigt att förstå—det tror jag.
- Interviewer: I vilket mån känner du att du hänger me' i vad [the teacher] försökte göra här?
- Student: Ah, på väldigt låg nivå, jag väntar ju fortfarande på att förstå överhuvudtaget vad som händer.
- Interviewer: Så just nu när du tittar på det här så ser du en ekvation?
- Student: Ah, precis.
- Interviewer: Men det säger ingenting mer till dig?
- Student: Nej, just det.
- Interviewer: Om vi tittar nu på det här och försöka klura ut lite grann vad, vad det kan vara. Det vill säga trycka lite på hur mycket av det du kan liksom få fram och vad du förstår av det—vad är det som du ser här?
- Student: Ah, jag ser att, okej det är andra derivatorn av första funktionen där och det kan ha med hastighet eller acceleration att göra på något sätt. Mmmh, ah, där har du v också då.
- Interviewer: Och vad är det för nåt?
- Student: Ah, hastighet. Så någon slags utbredningshastighet kanske eller nånting.

- Interviewer: Vad är det här här då? [pekar mot $V(x,t)$]
- Student: Er, ah, det är ju hastighet med avseende på tiden då.
- Interviewer: Sen så det här 'i h bar'?
- Student: Ah, 'i' där vet jag inte. H bar har vi samma då Planck's konstant.
- Interviewer: Så den här biten känner du igen i alla fall?
- Student: Ah, precis.
- Interviewer: Ah just det, vi har psi som det är det som det är derivatorn av också.
- Student: Ah just det.
- Interviewer: Vad tror du psi kan vara då?
- Student: Er, ah våg...funktion?
- Interviewer: Mmmh. Så om du skulle försöka jobba med den här på nåt sätt—du känner att "okej jag fattar inte riktigt vad det är"—hur skulle du gå till väga för att, för att känna ah nu, nu har jag grepp på den här?
- Student: Ah, jag skulle leta efter en bild, det första jag gjorde.
- Interviewer: En bild alltså?
- Student: Ah, nån slags bild som kan förklara—så man ser det rent bildmässigt.
- Interviewer: Du menar någon sorts modell eller...?
- Student: Ah, en modell eller ah, gärna det, man skulle—det som man saknar här i för sig det är att kunna ha en film snutt eller nånting där man har ritat upp en våg som rör sig på nån speciellt sätt alltså—det skulle hjälpa.
- Interviewer: Ah just det—att ser hur, hur den här vågen rör på sig?
- Student: Ah, precis—i förhållande till något annat.
- Interviewer: Okej, då fortsätter vi. Erm, vi kan fortsätta med svenska så låt mig se vad som kommer efter det. Här har hon tagit bort tiden från detta så att man får en förenklad version.
- Student: Ah, okej just det.

Video Transcript: Clip 4

As you see here, it's not possible to, to solve this equation further before knowing what v of x is. The potential energy function—we don't know, it's not given. And for each v of x this will be a different equation. So this describes the equa—the Schrödinger equation for different, different situations. Erm, so erm, if we then find a solution, if we say we will plug in a certain v of x and we find a solution for this then we still need to check a few things—and that is certain conditions that psi of x has to fulfill. And the conditions are as follows: One condition is that solutions of this equation psi of x should be continuous—continuous? it means that they should have a value eve-

rywhere and they shouldn't be any steps or gaps in the function so if I would draw such a function ψ of x that would be a solution of this equation it should be continuous it should not have gaps like this. The second thing is that the function should be single valued also, so what that means is that it can at each point only have one value so a continuous function may be like this [draws a s-shaped loop], but this function would have in this point three values that's not a possible solution of the Schrödinger equation. So only single-valued ψ , functions. Okay? and the third, the third condition is that ψ should not be infinite, it should be always finite—what does that mean? Well, ψ , for example you would have a function that has that looks like this, [draws an exponential curve] and in this point becomes infinite. That's not a possible solution of the Schrödinger equation. It has to be finite. So these are three conditions. Now these conditions don't only have to hold for ψ they also hold for the first derivative of ψ [writes first derivative]. This one should also be continuous, finite and single-valued. And besides there's also one additional condition—and that's the one you already know—it's called a normalization condition and that says that for all solutions ψ of x , the integral, when we integrate ψ squared over dx from minus infinity to plus infinity we have to have the value 1. So there's a lot of conditions ψ has to fulfill in order to be a solution of the Schrödinger equation.

- Interviewer: Okej. Erm, här pratar [the teacher] om olika villkor som den här vågfunktionen måste uppfylla erm, skulle du kunna på något sätt sammanfatta vad de här villkoren är och vad de betyder för dig—vad, vad du tror de här villkoren är?
- Student: Mmmh, jo fast då ser de som rena matematiska funktioner som vi har behandlat tidigare då så på det sättet känner jag igen dem va erm men fortfarande så letar man efter aha, varför är det bara de här då som gör att det är lösningar till hans ekvation då.
- Interviewer: Så du ser inte VARFÖR de här kom...
- Student: Nej!
- Interviewer: ...var de kommer ifrån?
- Student: Nej, precis. Jag bara accepterar detta ja så då är det tre stycken ah, men fortfarande letar hjärnan efter då ...
- Interviewer: Men förstår du vad de här tre stycken är—vad, vad de menar?
- Student: Ah, matematiskt så att man stänger in det i ett intervall till exempel som inte går mot oändligheten så ah det finns bara ett värde på den grafen o då som hon sa att det inte kan gå så jo

- jag känner att jag kan se det framför mig ungefär hur de funkar då.
- Interviewer: Men den där sista integralen som hon hade—vad, vad förstår du med det? Vad är det som det säger?
- Student: Från minus oändligheten till...
- Interviewer: Till plus. Vad den skulle betyda? Då skulle det bli ett.
- Student: Nja, just det. Nej, det är sant, det förstår jag inte.
- Interviewer: På något sätt så verkade [the teacher] tycka att det var självklart att om man integrerar från minus oändligheten
- Student: [laughing] ah just det!
- Interviewer: ...till plus oändligheten så kommer det absolut att vara ett.
- Student: Jo, det är sant. Nej det förstår jag inte.
- Interviewer: Okej, er, vi fortsätter då.
- Student: Synd, annars skulle du kunna förklara det för mig. [laughs]

Video Transcript: Clip 5

Here you have high energy and here you have low energy. The electron can only be here because here you have this latent charge or in other words you have a barrier for the electron. The potential energy here which is caused by this charge on the plate causes a barrier for the electron—it cannot go over here— it's confined to this place. If you make the charge on the plates larger—you make the potential energy larger you can make these walls here sharper. You could make these walls infinitely high so that the electron absolutely cannot go out of this kind of well. Yeah, it's like a kind of well were the electron is fixed. You know well—in Swedish it's källa or brunn yeah? It's like the electron is, is fixed and it cannot go out—the walls are too high. So this is one problem where we use the Schrödinger equation and this is the problem that I earlier called the infinite square well. But let's write down the name the potential energy of that problem the potential energy function $v(x)$ would look like this. The electron is confined between a point $x=0$ and a point $x=l$ where l would be the width of this well. The electron is confined to this place and in this area the potential energy is zero, but outside of this area the potential energy is infini—infinite and the walls are infinitely high, so the function that's—you know—well it's the same as these functions in this case the function would look like this. With infinitely high—this would be infinite. Infinitely high walls—that's why it's called the infinite square well. This problem is also called the problem of a particle in a box, now if you imagine this to be not only in one dimension, like here where it's just a certain range of x but in three dimensions so you have a limita-

tion of x , but also a limitation in y and a limitation in z —then you have like a box and the particle is forced to be inside that box—that's why it's called a particle in a box.

- Interviewer: Okej, erm vad, vad tänkte du här, med den här situationen? Förstår du vad [the teacher] försökte visa här—vart [the teacher] vill komma?
- Student: Ja, nej. Vad jag tänker är att okej ett försök att beskriva ett svårt problem på ett enklare sätt, men den blir och blir ännu sjukare när man tittar på det här—tänk om någon utifrån skulle ser den här bilden! Nej det är väldigt luddigt.
- Interviewer: Men erm, förstår du vad det här var.
- Student: Ja, jag förstår det är med potential energi och hur det ändras då ah, visst. Men det här med den oändligt höga boxen ah nej det verkar lite diffust och konstigt.
- Interviewer: Men [the teacher] tar upp det här igen faktiskt på eftermiddag så det här var precis den allra sista sak [the teacher] sa...
- Student: Okej.
- Interviewer: ...så [the teacher] hade inte tid att utveckla mer, va? Så [the teacher] återkommer till det—jag ville bara se vad du erm, erfor om du vill från just det där va? Okej, men jag tänkte nu har vi pratat lite svenska här—känns det lättare för dig att pratar om dom här sakerna på svenska, eller?
- Student: Ah, det gör det faktiskt, ah.
- Interviewer: Men erm, när [the teacher] har beskrivit någonting på engelska och sen så ska du beskriva för mig på svenska...
- Student: Just det...
- Interviewer: ...det kan ju vara lite intressant va?
- Student: ...det hade jag faktiskt inte tänkt på att [the teacher] prata engelska [laughs] Ah, just det, ah. Vad sjukt!
- Interviewer: Det tänkte du inte på?
- Student: Nej, faktiskt inte! Ah där ser man!
- Interviewer: Då är det nog inte nåt större problem!
- Student: Nej, precis! [laughs]
- Interviewer: Er, okay now we go back to English and look at what [the teacher] did in the afternoon. Erm, [the teacher] actually went through quite a few problems, but then [the teacher] talked about a problem-solving strategy for quantum problems and this is what [the teacher] talked about here.

Video Transcript: Clip 6

Så i kapitel 40 så står det några väldigt bra 'hints' tips för att lösa kvantmekaniska problem på sidan 1203 i den här röda ramen så står det "problem-solving strategy". Och här, här

står det vad man ska göra med kvantmekaniska problem. Och erm, ni får läsa igenom det och jag kommer att följa ungefär samma, samma sätt som dom sa. Den här modellen den bygger på att man först att man har ett problem, en uppgift som är beskriven. Så först ska man titta på vilka krafter verkar på partikeln. Så vi behöva veta vilka krafter är det som, som, som gör att den rör sig och så vidare. Därifrån, bör man då försöka formulera en—göra en modell för potentiella energin. Så krafter—jag ska börja skiva ner det kort—krafter. Vad är då potentiella energin? Och när man vet det då bör man fundera på hur ändrar sig potentiella energin med x —med avstånd? Hur ser den här potentiella energikurvan ut? Så hur ser v of x ut? Om man har en modell som man då gör en graf av sen stoppar man in v i Schrödingers ekvation. Och lösa den, [writing on the board] så stoppa in $V(x)$ lösa... lösa den—lösa ekvationen. Det man vill då använda sig av när man gör det också är gränsvillkoren. Jag ska prata om det mer om en liten stund. Det betyder hur beter sig det här systemet på gränserna? Till exempel det är det jag visat er imorse den här med två elektroder en elektron som rör sig mellan två elektroder. Då är det—hur beter elektronen sig precis på elektroderna? På gränsen av det här rummet? När man löser den då får man ut, då får man ut värden för...för vågfunktionen men det blir olika värden så först skriver jag ett litet n här för det är många lösningar. Och sen måste man kolla vilka är—vilka av dom här lösningarna är riktiga vågfunktioner. Det man behöver använda här då är det här som jag sa att vågfunktioner ska alltid vara kontinuerlig—det här strategin för att lösa kvantmekaniska problem funkar nästan alltid.

Interviewer: Okay, This is what [the teacher] wrote up on the board [shows sheet] erm, I just thought this is what [the teacher] has just talked through, yeah? Er, could you describe to me what these, these steps are—what you think it is that [the teacher] wants us to do—or what it says in the book—cos this is directly from the book, yeah. What it says that you should do?

Student: Mmmh, well forces no, not quite familiar with exactly which forces, erm acts on the wave perhaps? Potential energy erm, I think [the teacher] was referring to the electron in the box.

Interviewer: Mmh, yeah. Okay so yeah then you could talk about what forces were acting on the electron?

Student: Yeah.

Interviewer: And then what's the potential energy?

Student: Yeah, then erm, okay this is a problem-solving strategy.

- Interviewer: Yeah.
- Student: Yeah, $V(x)$ what's the speed of the wave, erm you put it into this strange equation [laughs] solve it and then looking for this er, what do you say in English? Ah, gränsvillkoren. Erm, wave function?—no, I don't know what she meant by that. Normalize?—Ah the last two is a bit difficult.
- Interviewer: Yeah, cos this was what we had before—[the teacher] has got this psi squared as equal to one.
- Student: Yeah.
- Interviewer: Erm, but you're not so sure about what that is? And then here there's this psi n so [the teacher] said that there were lots of different values and then the question is which are real ones.
- Student: Yeah. No, er, no...[laughs]
- Interviewer: Okay, then erm, you remember when [the teacher] did the, the diagram with the, potential well?
- Student: Yeah.
- Interviewer: Now [the teacher] is gonna do it again, but more clearly—so we can take a look at that.

Video Transcript: Clip 7

En elektron som rör sig i ett fält den kan inte, kan inte röra sig utanför så den är begränsad alltså då kan vi i verkligheten ha en potential, en potential energi som kanske ser ut så här—om vi skulle mäta den [shows diagrams a) and b)]. Den här den kommer ifrån alltså de här elektroderna är negativt laddade och elektronen repelleras här då. Då blir potentiella energin högre—det blir som två barriärer, som två höga väggar som elektronen inte kan nå över. Nu kommer—det här alltså, steg ett här—potentiella energin. Sen så ska vi göra en modell här av det verkliga situationen för att göra det enklare. Modellen ser ut så här [shows diagram c)] så den är förenklad på det sättet att det är, erm, vertikala linjer här, vertikala väggar som är oändligt raka så att säga det blir ingen lutning kvar. Så med hjälp av det här så tror jag att vi kan göra en enkel beskrivning av den här, den här situationen. Okej, så nästa steg skulle då vara att vi behöver vi vet vad av v av x är, det här är v av x , en sån funktion. Här, härute är vx oändlig och här, härute är vx också oändlig, så jag kan inte hitta den där. Men mellan noll och l så är elektronen i potential brunnen. Nästa steg är att lösa Schrödinger's ekvationen—stoppa in v noll, lösa den gränsvillkoren. Okej det gör dock i det här fallet att vi delar upp problemet. Härinne har vi som vi sa då $V(x)$, härute är $V(x)$ lika med noll och härute är $v(x)$ lika med noll men härinne

är $v(x)$ inte lika med noll. så vi kommer att dela upp problemet i olika sektioner. Det första är i brunnen eller i hålen och det andra är utanför.

- Interviewer: Okay, mmh what did you think about this was it—did you understand a bit more now or...
- Student: Yeah, it was small pieces that er...kompletterade.
- Interviewer: To what extent do you think that you, you could follow what was going on or was it still something that you're gonna have to do afterwards?
- Student: Yeah, I think it's something I have to do afterwards to understand it completely—if I ever will [laughs]
- Interviewer: So what do you think the lecturer—as you understand it now—what do you think the lecturer was trying to say there?
- Student: Er, yeah, to solve the problem you try to divide it into small pieces in the area and er, now so [the teacher] was talking about the potential difference between these two and then I can see—yeah okay maybe it's gonna bounce back and forth, yeah but still quite a bit of a mystery okay what [the teacher] wants to get at.
- Interviewer: Okay, then [the teacher] carries on with this er and goes through a whole solution, so we'll be able to follow that now so may be it becomes even more clear...
- Student: [laughs]
- Interviewer: ...men den här kommer vi att ta på svenska. Här har [the teacher] följt den här plan för hur man skulle lösa dessa problem
- Student: Ah
- Interviewer: [the teacher] hade ritat upp den där potential och sen så löste [the teacher] det på det här sättet och så kommer man ner till de här tre diagram till slut. Erm jag tänkte skulle du kunna liksom försöka gå igenom det här och ser vilka steg du fattar liksom? Så berätta för mig vad det är du förstår här.
- Student: Oj, oj, oj ja...
- Interviewer: För du kommer ihåg att hon hade någonting som är lite så här—inte riktigt men med väldigt höga väggar...
- Student: Ah, just det
- Interviewer: ...och då pratar [the teacher] om i brunnen och utanför brunnen...
- Student: Ah, o ah precis då jag kan tänka mig att [the teacher] har delat upp den redan då, i brunnen, utanför erm, och om den går mot oändligheten så är vågfunktionen noll—aha
- Interviewer: Är det klart för dig varför det är så?
- Student: Nej det är det inte...Nej.
- Interviewer: Vad skulle den här vågfunktionen beskriva?

Student: Erm... Nej jag vet faktiskt inte det är...

Interviewer: Men låt oss ta det här och säga "okej så $V(x)$ är noll erm då kan du stoppa in det där i den här och då försvinner den där termen

Student: Ah, just det.

Interviewer: Så då får [the teacher] det där som ser mycket lättare ut för mig i alla fall[laughs] Men vad är det som vi har nu då?

Student: Erm, ah jag har ingen aning—det säger mig inte så mycket alls...

Interviewer: Men vad kan E vara då?

Student: Ah någon vågen energi eller nånting.

Interviewer: Men här flyttar [the teacher] bara om saker. Så det ser ut på det här sättet.

Student: Ah just det.

Interviewer: Och sen så har vi cos och sin—det skulle inte kunna vara cos...

Student: Ah nej. Det där har jag också funderat på och jag förstår inte varför det inte kan vara det.

Interviewer: Men då tar vi och köper det igen precis som du gör i lektionen och sen så börjar jobba med det. Om vi tar den, den måste vara sin funktion—om vi tar det och säger att det måste vara så—erm, sen så pratar [the teacher] om dom här [points to the three diagrams] kan du klarar av att..om vi säger nu kommer det att vara den här funktion...

Student: Ah, ah, just det. Och om x funktionen, alltså er det måste vara en sträcka av nåt slag—om den är noll då.

Interviewer: Du kommer ihåg att du hade den här lådan som började från fram till x är lika med l ...?

Student: Ah, just det. Ah.

Interviewer: Så vid noll så gick brunnen upp så här och vid l gick brunnen upp så här—oändlighet...

Student: Ah, just det.

Interviewer: ... så det är mellan det där som vi är intresserade av.

Student: Ah, just det.

Interviewer: Men vad är det som dom här säger nu

Student: Erm, om x är noll då kommer vågfunktionen vara noll. alltså aha det skulle jag nog bara acceptera än så länge okej om man koppla ihop det med att det går mot oändligheten då.

Interviewer: Och när x är L är det också lika med noll—eller lika med $A \sin(kL)$ om du tänker på vågen—här är den noll och här är den noll

Student: Ah, okej det är dom yttersta gränserna.

Interviewer: Ah just det så kommer [the teacher] fram till den här—vad förstår du av det?

Student: [silence]

Interviewer: När är sin noll?

Student: Ah det är noll
Interviewer: Och
Student: Ah [laughs]
Interviewer: Det finns ju flera...
Student: Ah ah just det erm... pi?
Interviewer: Just det det är det som vi har här va? Att det kan vara n pi så då får [the teacher] att våglängd är $2L$ över n så för varje n så får man en ny lösning som passar in i det blir som varje topp eller sväng motsvarar n för det blir en halv våglängd—här är den halv (n är ett) här blir den hel (n är 2) och här blir den en och en halv (n är 3)
Student: Ah just det.
Interviewer: För det är de lösningar som finns där sin är noll och noll [points to the two boundaries 0 and L]. Så det är det [the teacher] menar med den här liksom. Om man köper att det är en sin funktion då är det dom här lösningar som kommer ut och [the teacher] menar att de är "quantized" automatiskt på det sättet på grund av n
Student: Ah...Just det!
Interviewer: ...Så det här kvant—det kommer ut av sig själv
Student: Ja—precis!
Interviewer: [laughing] ah i alla fall det var det [the teacher] försökte visa!
Student: Ah [laughs] Jag hade inte greppat det på lektionen!
Interviewer: Erm—Finally erm I'd like to just take a look at this Schrödinger equation again er that we had earlier on. Now that we've talked about that and you've seen some more—you've had more to think about this erm what, what things do you see here now? Maybe it's getting slightly clearer? Or is it still just a mess?
Student: Yeah pretty much! [laughs]
Interviewer: Erm, you said that—okay you recognize this bit h bar squared over two m ...
Student: Yeah.
Interviewer: You've seen that bit before? What about here? [points to psi]
Student: Er, a wave function
Interviewer: So that is what we're trying to get out what about this then? [points to potential V]
Student: Erm. the speed of the wave
Interviewer: And then we had this i here
Student: [long pause] No, I haven't seen that before [laughs]
Interviewer: Well, okay—where do you think the actual equation comes from?
Student: Er, I don't know.

- Interviewer: But er, do you have any idea about when you can use it—what we can use it for?
- Student: No, no.[laughs]
- Interviewer: Right. Then we can go on and look at erm, just a comparison—you remember I was talking about these three languages: mathematics and English and Swedish? Erm, what do you think about mathematics when you're learning physics—what, what is it that the mathematics does?
- Student: Erm, for me it describes the physical parts—cos 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.
- Interviewer: Erm, and then we've got er, English and Swedish, these languages erm do they do pretty much the same thing. That you've got some English or Swedish that helps describe this thing? Like you just described mathematics working. Or is it like that for Swedish and then for English there's an extra step or?
- Student: Yeah it's an extra step for when someone tries to explain something in English. It's like you have to think twice.
- Interviewer: So which do you prefer?
- Student: Language?
- Interviewer: Yeah
- Student: Er, Swedish.
- Interviewer: Erm, would it have been different if you'd just had lessons in English? I mean everything in English, the book, and everything—the whole...?
- Student: Um, yeah... it would have been more difficult, but I think it would have worked out fine in the end. [laughs]
- Interviewer: What about if everything was in Swedish—absolutely everything—the book and everything?
- Student: Ah it would be heaven! [laughs] But I think it would be a little bit more easy to learn stuff.
- Interviewer: Er, how do you feel about English and Swedish in the degree as a whole?—do you think the, there should be some sort of balance between these things or...?
- Student: Yeah, erm well I see English more like a, a language that is spoken all aver the world so of course, if you don't know any English at all then you, you'll have some trouble in the future if you go to work with stuff like this. But I believe when you're learning things you could do it in Swedish and then apply perhaps in the end of the course you could more, do more English exams and so on.
- Interviewer: So some sort of, towards the end, moving more over towards English?

Student: Yeah.
Interviewer: But here you're right at the beginning?
Student: Yeah, and that's not good. [laughs]
Interviewer: Do you think that once you've got through it maybe you'll think it was quite good?
Student: Yeah, perhaps
Interviewer: But you've had to do more work somehow?
Student: Yeah. Yeah I have to use it someday so well we might as well start now.
Interviewer: But now when you're having to do this you're feeling that you're having to work much harder?
Student: Yeah, absolutely.
Interviewer: Does that mean you have to put in more hours or, or is it just more difficult to understand?
Student: Yeah, I find some lack of understanding er perhaps on the lectures if [the teacher] would do it in Swedish perhaps there might be more pieces that would have got into my thick head!
Interviewer: Erm, then I think I've got enough—more than enough information actually [laughs]
Student: [laughs]
Interviewer: Okay, I've got a cinema ticket for you...

Appendix H: Example of data analysis for research question 3

This appendix gives an example of the way in which texts were prepared and analyzed in order to estimate bilingual scientific literacy. The example given is for one of the four texts used for a second-year student (from case study 1).

Original transcript excerpt:

- Interviewer: [...] well this is the one that he's going to change erm, can you tell me what this, what this particular equation tells us...?
- Student: Er, that the curl of E is zero, that means er er that the E is a conservative field—vector field—it means that if you have a charged particle in an electric field and you move it in a circle or in any path and, and up it at the same point, the energy gained or lost is nothing—its, you haven't er er consumed or...nothing it's...so to speak.
- Interviewer: So this, this curl then. Erm what do you understand by that?
- Student: The curl is an operation—it's a, the, the operator nabla is a partial derivatives d/dx d/dy d/dz and er it's a, it's a vector product between the electric field which is a vector and er the nabla which is a vector too.

First, all speech by the interviewer is deleted and marked by a double return in the transcript. The length of time the student speaks for is then calculated. Next, all noticeable pauses—both filled and unfilled—are marked by entering a single return. This creates a transcript of phrases of various lengths, each on a separate line. Then, all utterances in filled pauses—where the student uses sounds such as aah, um, er, etc.—are deleted. At this point a word count for the whole transcript is made. Finally, each word in the transcript is divided up manually into syllables and a second word count (syllable count) is made. The SPS value is calculated by dividing the total number of syllables in the transcript by the total student speaking time. MLR is calculated by dividing the total number of syllables in the transcript by the number of text lines (excluding empty lines). Instances of code-switching are highlighted in bold and a subjective judgement about the disciplinary of the description is made. The results of this process on the above transcript can be seen on the following page.

Prepared transcript and resulting values

Stop 29:22 29:49
Start 28:53 29:28
Time 29 + 21 = 50
Total words 114
WPM 136
Total syllables 150
SPS 3.0
MLR 5.8
Codeswitch 0
Disciplinarity 3-4

That the curl of E is zero
That means that the
E is a conservative
field
vector field
it means that if you have a charged particle in an electric field
and you move it in a circle or in any path and end up at the same point
the energy gained or lost is nothing
it's
you haven't
consumed or
nothing
it's
so to speak

the curl is an operation
it's a
the
the operator nabla is a
partial derivatives dee dee ex dee dee wai dee dee
zee
and
it's a
it's a vector product between the electric field
which is a vector
and the
nabla which is a vector too

Appendix I: Conference presentations

The following 29 presentations have been made during the course of the PhD (for peer reviewed publications see page x):

- Airey, J. (2003) Supporting act? The role of English language in Swedish university degree programmes. (pp 46-51). *Developing Language and Communication in Higher Education: Trends in Teaching and Research*. Chalmers Lindholmen University, Gothenburg, Sweden.: Online, available from http://www.chl.chalmers.se/main/inst_fack/dlc/DLC_extended_abstracts.pdf.
- Airey, J. (2003) Can you teach it in English? The language choice debate in Swedish higher education. Conference paper at *Integrating Language and Content. Meeting the Challenge of a Multilingual Higher Education*, Universiteit Maastricht, 23rd-25th, October 2003 Maastricht, Netherlands.
- Airey, J. (2004) Language aspects in physics education. Invited Speaker. *Meeting the Challenges of University Physics Education*, Symposium on Physics Education, University of Lund, June 3-4 2004, Lund, Sweden.
- Airey, J. (2004) The language of instruction and the experience of learning university physics. Invited Speaker. *Annual Meeting of Physics 'studierektorer'* University of Lund, 10 June 2004 Lund, Sweden.
- Airey, J. & Linder, C. (2004) Language, bandwidth and the shared space of learning *Phenomenography and Variation Theory Go to School*, Research Conference on Learning and Education 18-21 August 2004 University of Gothenburg, Gothenburg, Sweden.
- Airey, J. (2004) The shared space of learning, or why some students just don't get it. Invited Speaker, *Teacher Education Day*, University College Kalmar. October 2004 Kalmar.
- Airey, J. (2004) Language choice: a question of bandwidth? Invited Speaker, *Sociolinguistics Seminar Series Institutionen för Nordiska Språk*. Uppsala University 29 September 2004, Uppsala.
- Airey, J., & Linder, C. (2005). Looking for links between learning and the discursive practices of university science. Paper presented at 11th EARLI biennial conference: University of Cyprus, 23-27 August 2005, Nicosia, Cyprus.
- Airey, J. (2005) Discourse and modes of meaning. University of Kalmar PhD Seminar Series 27 September 2005 Kalmar
- Airey, J. & Linder, C. (2006) Learning in a second language. Two case studies from university physics. Paper presented at *ICLHE 2006: Integrating Content and Language in Higher Education*. University of Maastricht. 28 June–1 July 2006, Maastricht, Netherlands.
- Airey, J. & Linder, C. (2006) Languages, modality and disciplinary knowledge. Paper presented at *ICLHE 2006: Integrating Content and Language in Higher Education*. University of Maastricht. 28 June–1 July 2006, Maastricht, Netherlands.
- Airey, J., Domert, D. & Linder, C. (2006) Representing disciplinary knowledge? Undergraduate students' experience of the equations in physics lectures. Paper presented at *EARLI SIG-2 2006 biennial meeting*, University of Nottingham, 30 August - 1 September 2006, Nottingham, UK
- Airey, J. & Linder, C. (2006) Representations, tools and activities: A disciplinary discourse approach to multimodal science learning. Paper presented at *EARLI SIG-2 2006 biennial meeting*, University of Nottingham, 30 August - 1 September 2006, Nottingham, UK

- Airey, J. (2007) Research into Teaching and Learning in a Second Language. Invited speaker, language training course for university lecturers University of Lund, 14 March 2007, Lund.
- Airey, J. (2007). Vi blir dummare på engelska, but is there anything we can do about it? Panel debate organised by Stockholms Akademiska Forum, Forskning och Framsteg, The British Council and Vetenskap och Allmänhet Kulturhuset, Sergels torg, 24 May 2007 Stockholm.
- Airey, J. (2007). Utbildning på engelska – hur förbereder vi studenterna genom marknadsföring och information? Panel debate, Högskoleinformatörskonferens Mittuniversitet, 31 May 2007, Östersund.
- Airey, J., & Linder, C. (2007). Learning from complementary representations: a disciplinary discourse approach. Paper presented at the 12th biennial EARLI 2007 conference University of Szeged, 27 August-1 September 2007, Budapest, Hungary.
- Airey, J. (2007). Learning physics in a second language. Paper presented at the Forum on English for Specific/Academic Purposes, Royal Institute of Technology 22-23 October 2007 Stockholm.
- Airey, J. (2007). The Relationship between the Language of Instruction and the Experience of Learning University Physics. Invited speaker, ASES workshop Engelska vs svenska som undervisningsspråk Malmö högskolan 19 November 2007 Malmö.
- Airey, J., & Linder, C. (2008). Learning through English: further insights from a case study in Swedish university physics. Paper presented at NU2008 University of Kalmar. 7-9 May 2008, Kalmar.
- Airey, J., & Linder, C. (2008). The disciplinary discourse of university physics: learning through fluency in a critical constellation of representations. Paper presented at NU2008 University of Kalmar. 7-9 May 2008, Kalmar.
- Airey, J. (2008). Research into the Relationship between Learning and the Language of Instruction Invited speaker, first meeting of the reference group on Engelsksproggede uddannelser og undervisning Danish Evaluation Institute (EVA) 5 May 2008 Copenhagen, Denmark.
- Airey, J., & Linder, C. (2008). Bilingual scientific literacy. Paper presented at Canadian Society for the Study of Education Conference 2008. University of British Columbia 31 May-5 June, Vancouver, Canada.
- Airey, J. (2008). Teaching in English: The effects of language choice on student learning in Swedish university science. Paper presented at the international conference on language planning and language policy. 9-10 June 2008, Saltsjöbaden, Stockholm.
- Airey, J. (2008). Content and language: Bilingual scientific literacy in Swedish universities. Paper presented at the International CLIL Fusion Conference 24-25 October 2008, Tallinn, Estonia.
- Airey, J. (2008) Language and engineering: Towards bilingual scientific literacy. Paper presented at Engineering Education Development 2008. Royal Institute of Technology 26-27 November 2008. Stockholm.
- Airey, J. (2008) Learning through English: Researching language environments in Scandinavian universities. Symposium organized for the conference Cultural and Linguistic Practices in the International University. Roskilde University 15-17 December 2008, Roskilde, Denmark.
- Airey, J. (2008) Learning and language: Mapping the bilingual scientific literacy of Swedish science students. Paper presented at the conference Cultural and Linguistic Practices in the International University. Roskilde University 15-17 December 2008, Roskilde, Denmark.

Airey, J. (2009) Assessing bilingual scientific literacy: A study of students speaking about physics in English and Swedish. Paper presented at the Symposium for English for Special Purposes. University of Gothenburg and Chalmers university of Technology. 12-13 January, Gothenburg.