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# Using a Social Semiotic Perspective to Inform the Teaching and Learning of Physics

TOBIAS FREDLUND



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### **Abstract**

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This thesis examines meaning-making in three different areas of undergraduate physics: the refraction of light; electric circuits; and, electric potential and electric potential energy. In order to do this, a social semiotic perspective was constituted for the thesis to facilitate the analysis of meaning-making in terms of the semiotic resources that are typically used in the teaching and learning of physics. These semiotic resources include, for example, spoken and written language, diagrams, graphs, mathematical equations, gestures, simulations, laboratory equipment and working practices.

The empirical context of the thesis is introductory undergraduate physics where interactive engagement was part of the educational setting. This setting presents a rich data source, which is made up of video- and audio recordings and field notes for examining how semiotic resources affect physics teaching and learning.

Theory building is an integral part of the analysis in the thesis, which led to the constitution of a new analytical tool – patterns of disciplinary-relevant aspects. Part of this process then resulted in the development of a new construct, disciplinary affordance, which for a discipline such as physics, refers to the inherent potential of a semiotic resource to provide access to disciplinary knowledge. These two aspects, in turn, led to an exploration of new empirical and theoretical links to the Variation Theory of Learning.

The implications of this work for the teaching and learning of physics means that new focus is brought to the physics content (object of learning), the semiotic resources that are used to deal with that content, and how the semiotic resources are used to create patterns of variation within and across the disciplinary-relevant aspects. As such, the thesis provides physics teachers with new and powerful ways to analyze the semiotic resources that get used in efforts to optimize the teaching and learning of physics.

*Keywords:* Social semiotics, semiotic resources, physics education research, interactive engagement, disciplinary affordance, disciplinary-relevant aspects, patterns of disciplinary-relevant aspects, the Variation Theory of Learning

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*To Maria, Emma, Vilma and Linnea*



# List of Papers and supporting work

## Papers

This thesis is based on the following papers, which are referred to in the text by their Roman numerals.

- I Fredlund, T., Airey, J., Linder, C. (2012) Exploring the role of physics representations. An illustrative example from students sharing knowledge about refraction. *European Journal of Physics*, 33:657-666.
- II Fredlund, T., Airey, J., Linder, C. (2013) Att välja lämpliga semiotiska resurser. In Lundqvist, E., Säljö, R., & Östman, L. (Eds.) *Scientific literacy : teori och praktik*. (pp. 59-70) Malmö, Sweden: Gleerups.
- III Fredlund, T., Linder, C., Airey, J., Linder, A. (2014) Unpacking physics representations: Towards an appreciation of disciplinary affordance. *Physics Review Special Topics – Physics Education Research*, 10, 020129.
- IV Fredlund, T., Linder, C., Airey, J. (Accepted for publication in the July issue) A social semiotic approach to identifying critical aspects. *International Journal for Lesson and Learning Studies*, 4 (3)
- V Fredlund, T., Airey, J., Linder, C. (In review) Enhancing the possibilities for learning: variation of disciplinary-relevant aspects in physics representations. (Submitted to *European Journal of Physics*)
- VI Fredlund, T., Linder, C., Airey, J. (Accepted) Towards addressing transient learning challenges in undergraduate physics: an example from electrostatics. (Submitted to *European Journal of Physics*)

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## Supporting work

Fredlund, T. (2010) *Multimodality in Students Physics Discussions*. Paper presented at the Multimodality and Learning International Conference, London, United Kingdom, July.

Fredlund, T. (2010) *Exploring Representations in Physics Teaching and Learning*. Poster presented at the JURE 2010, Connecting Diverse Perspectives on Learning and Instruction Conference, Frankfurt, Germany, July 19-22.

Fredlund, T., Linder, C. (2010) *Choosing the proper representation(s) in physics*. Presented at the EARLI SIG 2 conference, Tübingen, August 26-28, 2010.

Fredlund, T. & Linder, C. (2010) *Naturvetarnas 'språk': Användandet av figurer, artefakter, ekvationer och ord i studentdiskussioner om fysikaliska fenomen*. Poster presented at the 'NU2010 Dialog för lärande' Conference, Stockholm, 13-15 October.

Fredlund, T. & Linder, C. (2011) *Towards understanding affordances of representations: a case study using refraction of light*. Poster presented at the Foundations and Frontiers of Physics Education Research Conference, Bar Harbor, Maine, 13-17 June.

Fredlund, T., and Linder, C. (2011) *Appresentation in physics problem solving*. Paper presented at GIREP-EPEC 2011((International Research Group on Physics Teaching - European Physics Education Conference) joint conference, Jyväskylä, Finland, 1-5 August.

Fredlund, T., Airey, J. and Linder, C. (2011) *Representations in students' explanation of refraction: A case study*. A paper presented at GIREP-EPEC 2011 ((International Research Group on Physics Teaching - European Physics Education Conference) joint conference, Jyväskylä, Finland, 1-5 August.

Fredlund, T., Linder, C., and Airey, J. (2012) *A case study of the role of representations in enabling and constraining the sharing of physics knowledge in peer discussions*. Paper presented at the 1st World Conference on Physics Education, Istanbul, Turkey, 1-6 July.

Fredlund, T., Airey, J., Linder, C. (2012) *Critical aspects of scientific phenomena – to the fore, in the background, or not present in scientific representations*. Presented at the EARLI SIG 2 conference, Grenoble, August 28-31, 2012.

Fredlund, T., Airey, J. and Linder, C., (2012) *Choosing appropriate resources: investigating students' scientific literacy*. Paper presented in the Literacy and didactics: perspectives, practices and consequences II Symposium at the European Conference on Educational Research, University of Cádiz, Spain, 17-21 September.

Fredlund, T., Linder, C., (2013) Learning science and the selection of apt representations: an example from physics. Paper presented at the SAARMSTE Conference, University of Western Cape, South Africa, 14-17 January.

Fredlund, T., & Linder, C. (2013) *Making physics learning possible: exploring a variation perspective on representations*. Paper presented at the Third Joint Meeting of the Nordic Physical Societies, Nordic Physics Days, Lund, Sweden, 12-14 June.

Fredlund, T., Linder, C., Priemer, B., Boczianowski, F., and Pohl, A. (2013) *Perceptions and forms of reasoning. Refraction of light: a study of virtual image predictions*. Poster presented at the Foundations and Frontiers of Physics Education Research Conference, Bar Harbor, Maine, 17-21 June.

Fredlund, T., Linder, C., Airey, J. (2014) *Reverse rankshift : towards an appreciation of the disciplinary affordances of representations*. Paper presented at the 5th International 360 Conference. Encompassing the multimodality of knowledge, Aarhus, Denmark, 8-10 May.

Fredlund, T., Linder, C., Airey, J. (2014) *Exploring knowledge representation in terms of the enactment of idealized patterns of disciplinary-relevant aspects*. Paper presented at the 5th International 360 Conference. Encompassing the multimodality of knowledge, Aarhus, Denmark, 8-10 May.

Airey, J., Eriksson, U., Fredlund, T., & Linder, C. (2014) *The concept of disciplinary affordance*. Paper presented at the 5th International 360 Conference. Encompassing the multimodality of knowledge, Aarhus, Denmark, 8-10 May.

Fredlund, T., Linder, C., Airey, J. (2014) *Variation as a method for perceiving the disciplinary affordances of physics representations*. Paper presented at IACS-2104, the first Conference of the International Association for Cognitive Semiotics, Lund, Sweden, 25-27 September.

Fredlund, T., Linder, C., Airey, J. (2014) *Learning in terms of the semiotic enactment of patterns of disciplinary-relevant aspects*. Paper presented at IACS-2104, the first Conference of the International Association for Cognitive Semiotics, Lund, Sweden, 25-27 September.

Airey, J., Eriksson, U., Fredlund, T., & Linder, C. (2014) *On the disciplinary affordances of semiotic resources*. Paper presented at IACS-2104, the first Conference of the International Association for Cognitive Semiotics, Lund, Sweden, 25-27 September.



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# 1 Introduction

## 1.1 Introduction

A large body of research literature has illustrated how teachers' professional practices play crucial roles in creating productive classroom learning experiences (Hattie, 2012). Such practices include understandings, judgments and actions. At the same time extensive physics education research has repeatedly illustrated that physics knowledge cannot be shared in the classroom through recitation – “in order for meaningful learning to occur, students need more assistance than they can obtain through listening to lectures, reading the textbook, and solving standard quantitative problems” (McDermott & Shaffer, 2002, p.vii). As a step towards providing this “assistance” to students, Physics Education Research (PER) has explored the tools that are used to share the ways of knowing and doing in physics in terms of how they affect learning possibilities (see review in Section 2.2.2). Recently, a collective characterization of these tools has been made in terms the different semiotic resources that are used in physics, such as written and oral languages, diagrams, graphs, mathematics, simulations, apparatus and activities (for example, see Airey & Linder, 2009).

From my own experience as a physics teacher I feel a deep appreciation for how important it is for physics teachers to learn more about the role that semiotic resources play in the teaching and learning of physics. This therefore became the focus of my thesis research. My particular contribution to this field of study lies in my analysis of meaning-making in terms of the semiotic resources that are typically used in the teaching and learning of introductory undergraduate physics courses. To do this I chose the following areas of undergraduate physics: refraction of light; electric circuits; and, electric potential and electric potential energy. I chose these areas because I saw them all as being challenging to students and as having a rich array of semiotic resources associated with them.

Some of the most influential work that has been produced by the PER community is based on different forms of interactive engagement (see review in Section 2.2.1). Yet, relatively little research work has been carried out that specifically focuses on the roles that semiotic resources play in these interactive engagement based teaching methods, and the effects they thereby have on the learning of university level physics. Thus, all the empirical parts

of my thesis have been situated in interactive engagement learning environments.

My work involved an extensive theoretical exploration that began with Lemke's (1990) book *Reading Science*. In this book, "thematic patterns" were introduced as a tool to analyse and present the meaning relationships between different units of spoken language. This led me to try to find out more about Lemke's work (e.g. 1983, 1990, 1995c; 1998, 2003) with a continual cross-referencing to Airey and Linder's (2009) work with different semiotic resources (see Section 2.2.4). My journey also went into the fields of Systemic Functional Linguistics, SFL (for example, see Halliday, 1978), multimodality (for example, see Jewitt, 2009; Kress, 2010; Kress & Van Leeuwen, 2001) and Systemic Functional Multimodal Discourse Analysis, SF-MDA (for example, see Lim, 2011; O'Halloran, 2008b). All of these fields are related to each other and are collectively referred to as social semiotics.

The journey of theory linking, which became a large part of my thesis work, led to the development of a new research tool that I characterize as "patterns of disciplinary-relevant aspects." The patterns of disciplinary-relevant aspects then became an integral part of the framing for the empirical studies that I carried out. All of my work has been underpinned by a social semiotic perspective; the way that I have constituted the social semiotic perspective for this thesis is given in Sections 2.4-2.8. Over time, this social semiotic perspective then provided me with the research tools that I needed for this thesis. And, although at times this has led to my thesis being highly theoretical, my underlying motivation has always remained wanting to open up the exploration of new possibilities that could be used to improve the teaching and learning of physics. Set in this background, I frame physics teaching as being about *optimizing the possibilities for learning* (see Linder, 2013; see Marton & Booth, 1997; Marton & Tsui, 2004).

## 1.2 Research questions

To explore how semiotic resources affect physics learning, in particular in the content areas of refraction of light, electric circuits, and electric potential and electric potential energy, I developed the Research Questions given below. In many ways, Research Questions 2-6 were generated from compelling aspects emerging from my analysis related to the first research question.

1. *In what ways can thematic patterns be developed as an analytical tool in order to analyse meaning-making in introductory undergraduate physics?*

2. A distinction is made in the literature between semiotic resources that “disappear” almost immediately after they have been produced, such as spoken language and gestures, and those which do not, such as written language and images. With respect to these non-persistent and persistent semiotic resources:

*During interactive engagement dealing with the refraction of light, what roles do non-persistent and persistent semiotic resources play in terms of the following facets:*

- *what are these roles and how can they be characterized;*
  - *which persistent semiotic resources are used by a group of students when engaging interactively in explaining the refraction of light;*
  - *what differences in disciplinary affordances of the persistent semiotic resources used by the students can be observed in such an explanation;*
  - *what aspects of persistent semiotic resources can account for disciplinary affordance differences in an explanation of the refraction of light;*
  - *to what extent can the different persistent semiotic resources that the students used be seen to present the disciplinary-relevant aspects that learners would need to be aware of in order to explain why the refraction of light takes place in a disciplinary manner;*
  - *how do students select a persistent semiotic resource around which to interactively engage; and,*
  - *how can the answers to the above facets be related to “Vision I scientific literacy” (Roberts, 2007a, 2007b)?*
3. Given that the social semiotic perspective constituted for this thesis has been used to problematize the access to disciplinary knowledge that different physics semiotic resources present:
    - 3.1. *What is the nature of the learning challenges associated with physics aspects that have been rationalized out of a typical semiotic resource used in physics education (an RC-circuit used in a student laboratory learning situation)?*
    - 3.2. *How can the results of 3.1 be theorized in terms of enhancing students’ appreciation of the disciplinary affordances of physics semiotic resources?*
  4. *What interconnections can be made between the analytic construct disciplinary-relevant aspects that was developed for this thesis and the Variation Theory of Learning’s notion of critical aspects?*
  5. *As a thought experiment, what are the implications of the answer to Research Question 4 for the teaching and learning of physics?*
  6. *As an exploratory case study using a physics tutorial where the assigned problem has the distinctions between the concepts electric potential and*

*electric potential energy in focus, what kind of intervention can be created to illustrate how the answer to Research Question 5 could be successfully implemented?*

Note: the relationship between Research Questions 4, 5 and 6 is as follows: RQ 4 offers a theoretical contribution to the student learning literature, RQ 5 builds on the results of RQ 4 to formulate implications for teaching and learning of physics, and RQ 6 empirically explores the implications made in RQ 5 using a small case study.

The terminology that I use in these questions will be explained in my conceptual framework in Chapter 2.

### 1.3 The scope of the knowledge claims making up the thesis

The work for this thesis has generated knowledge claims across four broad educational fronts:

- 1) Physics Education Research (PER): My thesis presents and uses a conceptual framing that has not been reported on in previous PER literature.
- 2) Social semiotics: For the thesis I constituted a social semiotic perspective that facilitated the creation of a new research tool that I call patterns of disciplinary-relevant aspects.
- 3) The Variation Theory of Learning: Through the items above I have illustrated how the application of the Variation Theory of Learning can be extended.
- 4) The teaching and learning of undergraduate physics: I provide examples of how my conceptual framework and the associated analyses lead to educational recommendations that can inform the design of successful learning opportunities in introductory undergraduate physics.

### 1.4 Organization of the thesis

Parts of the detail given in this thesis have been reported on in the attached Papers, which are labelled and referred to as Papers I-VI. This means that at times parts of these papers have been extracted and/or modified without further reference. The papers are attached at the very end of this thesis.

Table 1.1 gives the relationships between the different physics education areas that are examined, the research questions, the different datasets, and the papers that make up this thesis.



*Table 1.1.* The relationships between the different physics education areas examined, research questions, datasets and papers that make up this thesis.

Physics education area	Research Question	Dataset	Paper
Refraction	1-2	1	I, II
Electric circuits	3	2	III
Refraction	4	3	IV
	5	—	V
Electric potential and electric potential energy	6	4	VI

The thesis is organised as follows. In Chapter 2 the detail of my conceptual framework is given. This includes the literature review for the thesis. Then, in Chapter 3, the methods are introduced. The application of these methods and the results obtained, including the answers to my research questions, are given in Chapter 4. Chapter 5 gives a summary of the contributions I see my thesis making to the field of PER. In my concluding remarks in Chapter 6, I reflect on my PhD journey. A Swedish summary of my thesis is given in Chapter 7.

Then three supporting appendices are given. Appendix A contains illustrative data transcripts, Appendix B contains details of the ethical arrangements I made with the participants of the studies, and Appendix C contains two short papers that are ancillary to my work.

## 2 Conceptual framework

### 2.1 Introduction

In this chapter I discuss what Maxwell (2005) calls a conceptual framework, that is “the system of concepts, assumptions, expectations, beliefs, and theories” that supports and informs my research (see also Miles & Huberman, 1994; and Robson, 2002).

In order to do this, I first present an overview of the work done in Physics Education Research (PER) to show how this thesis is situated in PER. Here, I introduce those parts of PER that are most relevant for my work. These include interactive engagement, PER work with representations, the theoretical perspectives used thus far in PER, how the theoretical perspective that I introduce broadens the scope of PER, and how it links to scientific literacy. I then summarize specific PER work that has been done in the areas of refraction, electric circuits and electrostatics; which are related to the topics in introductory physics that I investigate in this thesis.

There then follows a presentation of a number of potential theoretical perspectives that I investigated in my research journey, leading up to a motivation for my choice of social semiotics as a framing for this thesis. The chapter continues with a general description of social semiotics before describing those aspects of this theory that are relevant for the thesis namely: Language as a semiotic resource system: an introduction to Systemic Functional Linguistics, Thematic patterns, Increasing the meaning potential of language, and The multiplicity of semiotic resources – Multimodality. Note that although this thesis deals with the use of semiotic resources, when I review the literature I sometimes use the terms representations and/or signs. This is because these are the terms used in the original literature that is being reviewed. The reader should see these terms as being synonymous with semiotic resources. In some of the sections the depth of detail given is perhaps more extensive than needed for an appreciation of my engagement with the research data. However, this is a reflection of the journey I undertook in order to answer the research questions.

The chapter closes with an introduction of the Variation Theory of Learning; a theoretical perspective that I used in this thesis because of the links that I came to see between it and the social semiotic perspective I constituted for this thesis.

## 2.2 Physics Education Research

Physics Education Research primarily deals with the teaching and learning of university physics. Its aim is to better understand relationships between teaching practices and praxes, and the learning of physics in order to contribute to enhancing students' learning outcomes. As such, PER has its own Special Topics journal in the American Physical Society (APS) Physical Review series<sup>1</sup>. Internationally, most PER has been carried out in physics departments. In the USA there are approximately 100 active PER "programs" at the time of writing this thesis (Physics Education Research Central, n.d.). In 2000, Uppsala University became the first university in Scandinavia to have a formalised PER group situated in a department of physics.

A number of overviews of work done in PER have been published, including McDermott and Redish (1999), Knight (2002), Redish (2003), Thacker (2003), Hsu, Brewe, Foster, and Harper (2004), Thompson and Ambrose (2005), Beichner (2009), Meltzer and Thornton (2012), and Docktor and Mestre (2014). What follows is a review of the PER work that is related to my own research.

### 2.2.1 Interactive engagement and successful PER-based teaching strategies

One of the most important aspects of successful university physics education that has been identified by Physics Education Research is interactive engagement (see, for example, Hake, 1998), which refers to active engagement in the interaction between students, or between students and teachers. Hake (1998) defines interactive engagement methods as those:

*designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors...* (p. 65, emphasis in original)

Fraser et al. (2014) strengthen this definition to emphasize the insufficiency of interactively engaging only a subset of students:

*interactive engagement methods promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate individual feedback to all students through discussion with peers and/or instructors.* (pp. 2-3, emphasis added)

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<sup>1</sup> See <http://prst-per.aps.org>.

The educational importance of interactive engagement is not a new idea, and was in fact pointed out, for example, by Dewey (1997; first published in 1916):

Schools require for their full efficiency more opportunity for conjoint activities in which those instructed take part, so that they may acquire a social sense of their own powers and of the materials and appliances used. (p. 31)

For an example of the application of interactive engagement in physics education, consider the use of “clicker questions” in lectures (see, for example, Mazur, 2009, p. 51), where students are asked to answer multiple-choice questions using an electronic device. After answering the questions and before the correct answer is revealed, students are encouraged to discuss their reasoning with each other. After this, students are allowed to give a new answer. The statistics provided by this approach can be displayed to the students, and clearly show that their discussions increase the number of correct answers given. Research has shown that this improvement is not simply due to students who know the answer telling those who do not (Smith et al., 2009). However, the inclusion of interactive engagement methods alone does not seem to be sufficient for successful education. For example, Prather, Rudolph, Brissenden, and Schlingman (2009) suggest that “it is the proper implementation of interactive learning strategies that is key to achieving higher gains in student learning” (p. 329).

Successful PER-based interactive engagement methods include Ranking Tasks (Andersson, 2011; Maloney, 1987), Tutorials (McDermott & Shaffer, 2002), Active Learning (Van Heuvelen & Etkina, 2006) and Peer Instruction (Crouch & Mazur, 2001). Although representations (semiotic resources in this thesis) can be seen to play an important part for these methods (also called PER-based instructional strategies, see Henderson & Dancy, 2007; Singh, 2014), theoretical perspectives on the role that representations play in interactive engagement have received relatively little attention in PER (two of the few studies that have been carried out are Bing & Redish, 2009, 2012). Thus, I propose that my research work makes a highly relevant contribution to PER.

## 2.2.2 Representations in PER<sup>2</sup>

In PER, work with student understanding of representations has been an integral part of the general aim of enhancing learning outcomes (for

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<sup>2</sup> Other scientific disciplines where representations have been investigated include computer science (Ainsworth, 1999), chemistry (Gilbert & Treagust, 2009; Tasker & Dalton, 2006), biology (Jaipal, 2010; Roth & Bowen, 1999; Schönborn & Bögeholz, 2009, 2013), and mathematics (Duval, 2008).

example, see McDermott & Shaffer, 1992). Here, a representation is generally taken to be an expression of some physical concept, quantity, process or problem (De Cock, 2012; Van Heuvelen, 1991a; Van Heuvelen & Zou, 2001). Examples include spoken and written language, mathematical equations, graphs, diagrams, and images<sup>3</sup>. The more focused PER investigations dealing with university physics students' use of representations began to emerge following the early work of Van Heuvelen (1991a, 1991b). This work has led to the development of new physics curricula, which emphasise students' active participation and the role of representations for qualitative reasoning (for example, see Van Heuvelen & Etkina, 2006). Van Heuvelen's research colleagues have continued the work in this area (for example, see Etkina, Gentile, & Van Heuvelen, 2013; Rosengrant, Etkina, & Van Heuvelen, 2007; Rosengrant, Van Heuvelen, & Etkina, 2009). An interesting development from their work focuses on the role of language<sup>4</sup> in physics education (Brookes, 2006; Brookes & Etkina, 2007, 2009), which includes students' difficulties in appropriately interpreting the analogies and metaphors that are used in physics.

The relationship between representations and analogies in physics education has been investigated in many areas of physics (for an early example in the area of refraction, see Harrison & Treagust, 1993; and regarding the nature of electromagnetic waves, see Podolefsky & Finkelstein, 2006; 2007a, 2007b, 2007c). Kohl and Finkelstein have done work at both micro and macro levels of physics students' use of multiple representations, especially in problem solving (Kohl & Finkelstein, 2005, 2006a, 2006b, 2008; Kohl, Rosengrant, & Finkelstein, 2007). For example, in their 2008 paper Kohl and Finkelstein reported that novice problem solvers spend more time than expert problem solvers exploring representations, and they used this outcome to suggest how the use of multiple representations could be effectively taught.

Students' use of gestures in physics has also received attention. For example, Scherr (2008) concluded that gestures could help researchers to investigate the content, source and "novelty to the speaker" of "student ideas." Also, she found physics education to be "a rich field for exploring these issues further" (p. 8).

The use of mathematical representations in physics has also received attention. Some of this research has investigated students' work with particular mathematical representations such as graphs (see, for example, Christensen & Thompson, 2012), equations (see, for example, Domert, Airey, Linder, & Lippman Kung, 2007; Kuo, 2013), and algebraic and arrow

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<sup>3</sup> Note that the term semiotic resource used in this thesis has a wider definition than the PER view of representation, including as it does other meaning-making resources such as experimental apparatus and action (see Section 2.2.4).

<sup>4</sup> This includes a Systemic Functional Linguistic (SFL) perspective, which will be explained further in Section 2.5.

representations of vectors (see, for example, Hawkins, Thompson, Wittmann, Sayre, & Frank, 2010; Heckler & Scaife, 2015). Other research has investigated how students bring different mathematical representations together (see, for example, Von Korff & Rebello, 2012).

Despite extensive research showing that physics students experience many difficulties with representations, teachers often do not easily appreciate the full extent of these difficulties. For example, Meltzer (2005) notes that “the instructor’s view of the ease or difficulty of a particular representation in a particular context might not match the views of a large proportion of students” (p. 473). This inability of physics lecturers to judge the difficulties a given representation will pose for students has also been reported on by other researchers (Linder, Airey, Mayaba, & Webb, 2014; McDermott, 1990; Tobias, 1986). In this respect, Northedge (2002) claims that university teachers’ thoughts are “so deeply rooted in specialist discourse that they are unaware that meanings that they take for granted are simply not construable from outside the discourse” (p. 256). In other words, in many cases teachers have become so familiar with the disciplinary representations that they use that they no longer “notice” the learning hurdles involved in interpreting the intended meaning of those representations.

### 2.2.3 Theoretical perspectives in PER

A contemporary trend in PER has been one of using a number of different theoretical perspectives to explore issues in the teaching and learning of university physics (for example, see Close, Conn, & Close, 2013; Forsman, Moll, & Linder, 2014; Jones, Malysheva, Richards, Planinšić, & Etkina, 2013). Most of the seminal perspectives used have derived from different forms of constructivism (Redish, 2003) and from the notions of P-prims – phenomenological primitives (diSessa, 1983) – and more recently, from the idea of framing (see, for example, Hammer, Elby, Scherr, & Redish, 2005). These perspectives can be seen to provide a bridge between PER and other educational research through the introduction of new ideas and concepts. For example, “scaffolding” as a way to enhance learning, has long been used in educational research (for an early seminal example, see Wood, Bruner, & Ross, 1976), and has recently played an important part in PER (see, for example, Lindström, 2010; Lindström & Sharma, 2009, 2011; Podolefsky, 2008). Constructs such as “artefacts” and “zone of proximal development” from different sociocultural and cultural-historical perspectives on education (see, for example, Engeström, 1987; Wertsch, 1985) are increasingly being taken up in the work of the PER community (for example, see Frank & Scherr, 2012; Manogue, Browne, Dray, & Edwards, 2006; Nwosu, 2012). Recent PER work has also included using Legitimation Code Theory (LCT,

see Section 2.3.5) in its theoretical framing. For example, Georgiou, Maton and Sharma (2014, p. 264) have used LCT to discuss the “context dependence of meaning” in a thermodynamics setting.

## 2.2.4 Broadening the scope of PER

In this thesis I draw on a well-established theoretical perspective that is relatively new to the PER community: social semiotics (see, for example, Halliday, 1978; Hodge & Kress, 1988; Kress, 2010; Lemke, 1990; Thibault, 1991; Van Leeuwen, 2005). Social semiotics will be used in this thesis to inform the analysis of semiotic resources. In social semiotics:

Semiotic resources are not restricted to speech and writing and picture making. Almost everything we do or make can be done or made in different ways and therefore allows, at least in principle, the articulation of different social and cultural meanings. Walking could be an example. (Van Leeuwen, 2005, p. 4)

Introducing social semiotics into PER, Airey (2009) and Airey and Linder (2009) broadened their interest in the representations used in physics education by explicitly including the tools that get used (for example, laboratory equipment) and the activities that take place (what physicists *do*) as being semiotic resources. Physics learning could thus be described as becoming “fluent in a critical constellation of the different semiotic resources” (Airey & Linder, 2009, p. 28). Social semiotics is further introduced in Section 2.4.

In this thesis I also use the Variation Theory of Learning (Marton, 2015; Marton & Booth, 1997; Marton & Tsui, 2004) as a perspective that I drew on after seeing the links to the social semiotic perspective I constituted for this thesis. The Variation Theory of Learning was introduced to PER by Linder, Fraser and Pang (2006) and Linder (2007) and describes learning as coming to experience the world in new ways. A necessary condition for this to take place is the experience of variation (Marton, 2015). Further examples of the small amount of work that has been done in PER using the Variation Theory of Learning are: Fraser and Linder (2009), Ingerman, Linder and Marshall (2009), Bernhard (2010) and Ingerman, Berge and Booth (2009). The Variation Theory of Learning is further discussed in Section 2.9.

In the following section I introduce scientific literacy as a term for an important goal in science education. This term has been used in conjunction with the social semiotic perspective in PER.

## 2.2.5 Scientific Literacy

For this thesis I want to make a case for relating disciplinary meaning-making with a notion of scientific literacy. Here I will draw on Roberts's (2007a, 2007b) Vision I and Vision II depictions of scientific literacy and on the work of Norris and Phillips (2003, p. 224) to treat scientific literacy as a special case of "literacy in its fundamental sense," which can be characterised as having similarities to what Halliday (1996, p. 367) in his work in social semiotics describes as "the making of meaning in language."

While focusing on reading, Norris and Phillips (2003, p. 228) include in their view of scientific literacy<sup>5</sup> "the panoply of literate objects including not only printed words, but also graphs, charts, tables, mathematical equations, diagrams, figures, maps, and so on". As mentioned in the previous section, Airey and Linder (2009, p. 28) claim that physics students need to become "fluent in a critical constellation of the different semiotic resources." In this respect, Airey (2009) suggests that students become scientifically literate with respect to a given physical phenomenon through repetition. Airey (2009) also essentially proposes that the terms fluency and literacy can be taken to be synonymous, which can be linked to Norris and Phillips' (2003) view on scientific literacy. This is the framing of literacy taken by Linder et al. (2014) to present a wider sense of literacy under the label disciplinary literacy (see also Airey, 2013).

Roberts (2007a, 2007b) makes a distinction in the different existing descriptions of scientific literacy between, on the one hand, scientific literacy within the academy and, on the other, the application of science within society. He refers to these as Vision I and Vision II, respectively. Vision I scientific literacy (i.e., in the academy) is seen as being a subset, and a special case, of Vision II scientific literacy (i.e., in society). This is because many aspects of Vision II scientific literacy, including societal consequences of science and ethical issues relating to science, do not apply to, or are not seen to be focused upon in Vision I scientific literacy. When I talk about scientific literacy in this thesis I mean Vision I scientific literacy.

The implications that my work has for scientific literacy in its wider sense are problematized in Paper II, which provides part of the answer to Research Question 2 (see Section 4.2.5). In the following section I review the PER work that has been carried out in the particular areas of physics that I deal with in this thesis.

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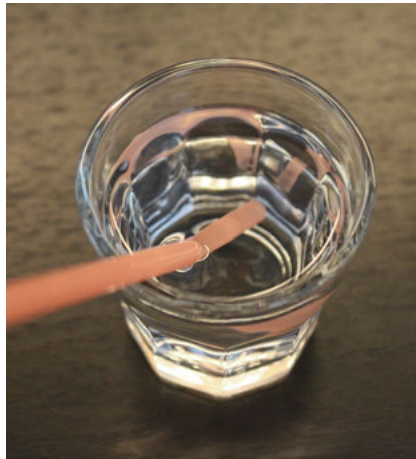
<sup>5</sup> The inclusion of semiotic resources other than language in literacy has led to descriptions such as "multimodal literacy" (Jewitt & Kress, 2003), "new literacies" (Unsworth, 2008), and "multiliteracies" (Cole & Pullen, 2010; Hanauer, 2006; New London Group, 1996).



## 2.2.6 PER work on refraction, electric circuits and electrostatics

### *Refraction*

A large part of this thesis deals with meaning-making in the context of the refraction of light. Refraction is a change of the direction of propagation of light at the surface between two media with different refractive indices, that is, two media in which the speed of light is different (see the explanation in Section 4.4). A visual effect of refraction is that a straight object partially immersed in water will appear to bend at the water–air boundary (see Figure 2.1).



*Figure 2.1.* An everyday manifestation of the refraction of light (from Paper IV).

When set against other areas of introductory university physics, comparatively little work has been done in the area of refraction, particularly in relation to the different semiotic resources that are used. Investigations into which representations and analogies are used in university level textbooks in the field of refraction have been made (see, for example, Harrison, 1994; Hüttebräuker, 2010). Hüttebräuker (2010) showed that the most common representations used are ray diagrams, present in almost all of the 93 German and English undergraduate physics textbooks dealing with refraction that he reviewed. Wavefront diagrams are used in less than half of the reviewed textbooks. Common analogies that are used include wheels rolling from one surface characteristic onto another, and (according to Newton's, 1730, mistaken corpuscular theory of light) a small sphere rolling on a surface first at one angle of inclination and then at an increased angle of inclination.

Explanatory models of refraction used in introductory physics include Huygens' principle (based on a wave theory of light, where each point on a wavefront is the source of a new wave, and the "envelope" of all these new waves creates a new wavefront; Huygens, 1678, 1912), and Fermat's

principle (or the "principle of least time", where light always takes that path between two points in space which minimises the time of travel between those points; see, for example, Mahoney, 1994). Knowledge about refraction of light has also been analysed in terms of a knowledge structure (Singh & Butler, 1990).

It has also been shown that many introductory university physics students have difficulties with representing light appropriately and usefully as waves (Ambrose, Heron, Vokos, & McDermott, 1999; Kryjevskaja, Stetzer, & Heron, 2012; Sengören, 2010). For a more comprehensive explanation of refraction, see the text extract from Feynman, Leighton and Sands (1963) in Section 4.4.

### *Electric circuits and electrostatics*

In this thesis I also analyse how students work with electric circuits. The research that has been carried out on electric circuits in PER has mainly dealt with basic concepts such as current and voltage, and the meaning of a closed circuit (see, for example, Entwistle, Nisbet, & Bromage, 2004; McDermott & Shaffer, 1992; Shaffer & McDermott, 1992; Stetzer, van Kampen, Shaffer, & McDermott, 2013).

In addition, I analyse data where students work with electrostatics, in particular the two concepts of electric potential and electric potential energy. While electric potential and electric potential energy have been addressed in PER in terms of how students struggle with making meaning of the concept of electric potential (Chen & Gladding, 2014; Meltzer, 2007; Pepper, Chasteen, Pollock, & Perkins, 2012; Planinic, 2006; Sayre & Heckler, 2009), these two concepts have mainly been addressed in the context of electric circuits (see, for example, Stetzer et al., 2013).

In the next section, I move from reviewing the PER literature that is relevant for my thesis to discussing a number of potential theoretical perspectives that I considered using in this thesis.

## 2.3 Choosing the theoretical perspective

### 2.3.1 Introduction

In this thesis I use a social semiotic perspective. However, my research journey also included looking at possible alternative theoretical perspectives. In the following sections I outline the most relevant of these and my reasons for deciding not to use them.

### 2.3.2 Ethnomethodology and Conversation Analysis

Ethnomethodology was introduced by Garfinkel (see, for example, 1967) as a method for observing how scientists and science work. Garfinkel was inspired by the social phenomenologist Schutz's description of the difference between our everyday "lifeworld", and science as a "finite province of meaning" (Schutz, 1962, p. 231). An example of a detailed study of scientists from an ethnomethodological perspective was completed by Lynch and Woolgar (1990), who talk about how scientists use representations in their daily work. This work can then be compared with theories about how scientists and science work as proposed by researchers in the philosophy of science (see, for example, Sharrock, 2004). Ethnomethodology accomplished this by taking a "microanalytic focus" (Streeck, Goodwin, & LeBaron, 2011, p. 10) in their empirical investigations of scientists' use of representations and equipment, etc.

Closely related to ethnomethodology is Conversation Analysis (CA). CA has developed into a detailed method for investigating spoken language (Sacks, 1992). In my thesis work, after completing an initial transcription using the analytical tools described in Section 3.3.2, I decided to do a second transcription of the same dataset according to one of the commonly used CA conventions (Schegloff, n.d.) to see if it would be fruitful to use as an analytical tool. However, the extra fine detail that such transcription of spoken language yielded did not prove to be necessary for my purposes, and therefore I decided not to continue using it further for my research work. For an example of a CA transcript, see Appendix A where I present the CA transcript that I produced.

Well known social semioticians have drawn on an ethnomethodological framework in their studies (see, for example, Bezemer, Murtagh, Cope, Kress, & Kneebone, 2011). However, an important difference between ethnomethodology (and therefore CA) and social semiotics lies in the analytical focus. Social semiotics, for example, deals with any kind of text, whereas ethnomethodology deals only with interaction between people and their social environment. Consequently, I chose to use a social semiotic rather than an ethnomethodological or CA perspective in this thesis.

### 2.3.3 Cognitive science

Social semiotics shares its interest in semiotic resources with cognitive science (see, for example, Ainsworth, 1999, 2006; Duval, 1999). Indeed, much of the work on the use and/or production of multiple semiotic resources that has been conducted in education research (particularly in science and mathematics education) has its theoretical groundings in the cognitive paradigm. An example of the similarities between the perspectives can be seen in the way that the term "graphicacy" has recently been adopted

in cognitive science in order to talk about students' "abilities to *interpret* and *generate* graphical semiotic resources, such as charts, diagrams, maps and graphs" (Bétrancourt, Ainsworth, de Vries, Boucheix, & Lowe, 2012, emphasis theirs). However, the two paradigms are in many ways very different. Epistemically, social semiotics takes on an interindividual perspective (Halliday, 1978), focusing on the role of semiotic resources in communication and meaning-making. Cognitive science on the other hand, although deeply interested in learning, mostly takes an intraindividual perspective. This means that its focus is on the different parts that together make up an individual. Many of the research interests in cognitive science can be seen to be closely related to the biological roots of cognition, working in the field between the biological and the social, in other words, the psychological. Common metaphors in cognitive science include intangible constructs such as mental models, internal representations (and hence the need for a term such as Multiple External Representations, MER), cognitive load, multimedia effect, long and short term memory, etc. (see, for example, Gentner & Stevens, 1983; Leutner, Leopold, & Sumfleth, 2009; Reif & Allen, 1992). However, I see these constructs as having little applicability for my work. This is because I view semiotic resources to be resources for communication and meaning-making, and adopt the wider definition of semiotic resources (described in Section 2.2.4) that includes both laboratory equipment and activities (see also Section 2.4.2).

Cognitive science relies mostly on quantitative research methods, such as pre- and post-tests, etc. However, a qualitative research grounding, such as the one that social semiotics uses, is best suited for my research design. This was a further reason for me not to draw extensively on cognitive science.

### 2.3.4 Sociocultural and cultural-historical perspectives

As mentioned in Section 2.2.3 an array of sociocultural and cultural-historical perspectives have been incorporated into PER. These perspectives can be traced back to Vygotsky (see, for example, 1978, 1986) whose body of work was not widely known outside the Soviet Union until it was popularised in North America by Wertsch (see, for example, 1985) over 40 years after Vygotsky's death. Vygotsky's theorising includes the internalisation of socially and culturally shared skills and tools (including language and other artefacts). These tools are said to mediate action. In a Swedish context, research grounded in a sociocultural perspective has looked at how students learn by using various artefacts (see, for example, Bliss, Säljö, & Light, 1999; Säljö & Bergqvist, 1997). A colleague of Vygotsky's, Aleksei Leont'ev (see, for example, 1978), pioneered a field known as cultural-historical activity theory. This field builds on sociocultural theory, and uses such terms as subject, object, internalisation,

externalisation and tools. More recently, the activity theory field has incorporated influences from other theoretical perspectives, such as pragmatism and ethnomethodology (see, for example, Engeström, 1999).

The perspectives described above have much in common with a social semiotic perspective. For example, Jewitt (2006), although explicitly working in social semiotics, has drawn extensively on activity theory in order to describe teaching as “[a] process that is both shaped by teacher’s interactions as agents and by a variety of social factors and forces that the teacher operates within” (p. 138). However, although this overview of alternative theoretical perspectives has shown social semiotics to have an inclusive character, it still has its own distinct theoretical framing with its own constructs. Since I have chosen to focus on the role of the semiotic resources themselves, rather than on the psychological mechanisms such as internalisation, I have found the theoretical framework of social semiotics to be the most appropriate for my analysis.

### 2.3.5 Legitimation code theory

A theoretical framework that is receiving an increasing interest in education research is legitimation code theory (LCT; see, for example, Maton, 2013). LCT is described as a “toolkit” (Van Krieken et al., 2014, p. 173) that draws on different sociological and sociolinguistic perspectives. For example, LCT compares the characteristics of the knowledge structures in different disciplines. LCT has also developed the term “semantic density,” which refers to “the degree to which meaning is condensed within symbols (a term, concept, phrase, expression, gesture, etc.)” (Maton, 2008, p. 10). This can be seen to have similarities to the social semiotic term “condensation” (1990, p. 101, see Section 2.7). LCT argues that in order for learning to take place it is important that the teacher creates a “semantic wave” (Maton, 2013) where sequences of lower and higher semantic density are created in the classroom. However, as mentioned in the previous section, social semiotics is an inclusive framework, and has already started to incorporate aspects of LCT and describe them in social semiotic terms. This includes relationships between semantic density and the discipline-specific taxonomies of meanings (see, for example, Martin, 2013). For this reason I had no need to explicitly use LCT.

### 2.3.6 Social semiotics

In order to analyse the different semiotic resources that are typically used in introductory undergraduate physics courses, I needed a theoretical perspective to guide my work. I found social semiotics to best meet this requirement and to facilitate my exploration of the relationship between the

subject matter of physics (the content) and its realisation through the production of semiotic resources. The terminology of social semiotics is specialized for dealing with this type of enterprise and allows descriptions of how the experience of physics “is transformed into meaning” (Halliday & Matthiessen, 2004, p. 29) through the use of semiotic resources.

Important for my choice of social semiotics was Airey and Linder’s (2009) work on semiotic resources (see Section 2.2.4) and the reading of Lemke’s (1990) book *Reading Science*. This book presents “thematic patterns” (see Section 2.6) as a way to analytically capture and present the meaning relationships that are realised in text. Initially developed for analysis of language (for an early example, see Lemke, 1983), the use of thematic patterns has recently been extended to analyse other kinds of semiotic resources (see, for example, Tang, Tan, & Yeo, 2011). I found the idea of thematic patterns fascinating and saw them as a promising tool that I could build on to support my analysis of the semiotic resources that are used in physics education contexts. My creation of a new research tool, what I have called “patterns of disciplinary-relevant aspects”, enabled me to analytically capture and map the meaning relationships that are realised in different semiotic resources.

As I learnt more about social semiotics I found it to provide several powerful new ways to explore how the semiotic resources that are used by teachers and students in undergraduate physics affect student learning. This was the reason for formulating my research aim as:

In what ways can a social semiotic perspective inform the teaching and learning of undergraduate physics?

In Sections 2.4-2.8 I introduce the way that I have come to constitute the social semiotic perspective for this thesis. For historical reasons all of these sections, which present the theory behind thematic patterns as a research tool, deal to a large extent with language as it is described in Systemic Functional Linguistics, SFL. This is to be expected since language is the most well researched semiotic resource system. Thus, as mentioned in the introduction to this chapter, social semiotics is introduced under the following main headings, which capture those parts that are most pertinent for my work: Social semiotics, Language as a semiotic resource system: an introduction to Systemic Functional Linguistics, Thematic patterns, Increasing the meaning potential of language, and The multiplicity of semiotic resources - Multimodality. In Section 2.9 I introduce the Variation Theory of Learning. Initially, the Variation Theory of Learning was not part of my conceptual framework but, as my study progressed, strong links to this theory became apparent (see Section 4.2.4). These links are reflected in my answers to Research Questions 4-6.

## 2.4 Social semiotics

### 2.4.1 Introduction to semiotics

Semiotics is traditionally closely linked to the work done by Saussure (1857-1913) and Peirce (1839-1914) – “the systematic study of the systems of signs themselves” (Lemke, 1990, p. 183).

Saussure’s work principally focused on “signs” in spoken language (Chandler, 2007). Here, signs were taken to be the unity of a signifier (a word) and a signified (an idea or a concept). The meaning of a signifier (such as the word “tree”) thus came from its being paired with something “dissimilar” (Saussure, 1959, p. 115) – the signified (such as the idea of a tree; the “value” of the sign). However, equally important for Saussure was that the word be compared with other words, from which it differs, such as “tree” with “bush.” Saussure described language as a “system” of such oppositions between words. For example,

synonyms like French *redouter* ‘dread,’ *craindre* ‘fear,’ and *avoir peur* ‘be afraid’ have value only through their opposition: if *redouter* did not exist, all its content would go to its competitors (Saussure, 1959, p. 116).

Peirce, on the other hand, was occupied with categorization of signs into various triadic categories. The triad perhaps most often referred to is the distinction between symbols, icons and indices. Here, a symbol is described as a “conventional sign, or one depending upon habit” (Peirce, 1998, p. 9) in that it does not have any apparent similarity with or direct link to what it means. For example, in Peirce’s view, words are symbols:

Any ordinary word ... is an example of a symbol. It is *applicable to whatever may be found to realize the idea connected with the word*; it does not in itself, identify those things. (Peirce Edition Project, 1998, p. 9; emphasis theirs)

An icon resembles what it means (for example, a drawing of a spring that is meant to look like a spring). An index, in turn, points at what it means (such as an arrow pointing out a direction).

### 2.4.2 Introduction to social semiotics and semiotic resources

In this thesis I have chosen to draw on social semiotics as my theoretical perspective. Social semiotics takes as its object of study not only the

“formal” semiotics of Saussure and Peirce<sup>6</sup> (Lemke, 1990, p. 183), but also meaning-making in its widest sense, particularly in relation to the social contexts at hand (Thibault, 1991; Van Leeuwen, 2005). Social semiotics is thus concerned with the “act of meaning making” (Thibault, 2004, p. 68). This is what makes it an appropriate perspective for my aim to explore how the semiotic resources in undergraduate physics affect student learning and to inform my analyses of meaning-making in physics.

From a social semiotic perspective, all meaning is realised in material form through the production of semiotic resources. It follows that all our communication – all of how we share ways of figuring, knowing and doing – is constituted through the two complementary aspects of communication, namely the production and the interpretation of semiotic resources (see, for example, Kress, 2010). In social semiotics, semiotic resources have been defined as “the actions and artefacts we use to communicate, whether they are produced physiologically – with our vocal apparatus; with the muscles we use to create facial expressions and gestures, etc. – or by means of technologies – with pen, ink and paper; with computer hardware and software; with fabrics, scissors and sewing machines, etc.” (Van Leeuwen, 2005, p. 3). Semiotic resources are thus seen as the material result of the meaning-making process, in other words, the materialisation or realisation of meanings (Kress, 2010).

The meaning of any semiotic resource is always inherently partial (Airey & Linder, 2009; Kress, 2003). In physics education contexts no individual semiotic resource is therefore sufficient to realise all the meanings one wishes to make. For example, as McDermott (1990) points out, “different representations emphasize different aspects of a concept”. However, the meaning of an isolated semiotic resource is not definite either. Rather, there is a set of different meanings that any given semiotic resource can realise. This set is called the “meaning potential” (Kress, 2010, p. 90) of that semiotic resource. Different parts of this meaning potential are activated in different contexts. For example, in an everyday context a gesture such as a raised right thumb can be the realisation of the fact that ‘all is going well’ or a wish to ‘hitch a ride’ if made by a person standing on the side of a highway. In a physics context the gesture is instead more likely to mean, for example, the orientation of a magnetic field around a conductor, or the direction of an angular velocity vector. In the production of an *instance* of a semiotic resource (such as raising the thumb and curling the fingers) the intent is to realise some contextually<sup>7</sup> relevant part of the meaning potential of the kind of semiotic resource at hand.

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<sup>6</sup> Social semiotics work most often epistemically references the work of Saussure rather than Peirce, whose work is much less referred to (see, for example, Lemke, 2003; Martin & Rose, 2007).

<sup>7</sup> In social semiotics, context is “a semiotic not a material phenomenon...” (Hasan, Cloran, Williams, & Lukin, 2007, p. 725)



It is important to note that the meaning potential of a particular kind of semiotic resource can change with time. Kress (2010) points out that it is in the production of instances of semiotic resources that there is a possibility of a change in the meaning potential of the semiotic resource at hand (see also Halliday, 1978). Thus, the meaning potential of a particular kind of semiotic resource is not static in a long-term perspective<sup>8</sup>, but reflexively evolving. This is the view of language that is taken by Halliday (1978), who is the founder of Systemic Functional Linguistics, commonly known as SFL<sup>9</sup>. Halliday (1991) characterises language as a “dynamic open system” (p. 41), in other words, a “semiotic system” (see, for example, Halliday, 1978; Hasan, 1995; Kress & Van Leeuwen, 2006) or a “semiotic resource system” (Lemke, 1995b, p. 86). It is the dynamic production of instances of language – text – that can alter the system and its meaning potential. Language should therefore not be interpreted “as a set of rules but as a *resource*” (Halliday, 1978, p. 192, emphasis his).

## 2.5 Language as a semiotic resource system: an introduction to Systemic Functional Linguistics

By far the most well-researched semiotic resource system is that of language. A central aspect of Halliday’s work (for example, see 1978, 1979, 1991, 1996, 1998b, 1999, 2004e, 2007) has been concerned with characterising language in terms of Systemic Functional Linguistics, SFL. “Systemic” refers here to a description of language as a system of possible options of choice (see Section 2.5.2). This is also referred to as the paradigmatic organisation of language. “Functional” refers to how language always plays different social functions, and thus develops following changes that are of a social nature<sup>10</sup>.

Apart from viewing language as a system of choices, SFL is simultaneously looking at instances of language – in other words, text – where choices have actually been made in the system. From this perspective it is the structure of language that comes into focus. This is also called the syntagmatic organisation of language, which refers to the order or sequence of different units of language<sup>11</sup>. And it is this perspective on language that I

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<sup>8</sup> Such long-term development of language is said to take place in a “phylogenetic” timescale (Halliday & Martin, 1993, p. 20).

<sup>9</sup> As mentioned in Chapter 1, SFL can be considered a subset of social semiotics.

<sup>10</sup> It should be noted that the development of SFL terminology is still taking place and this means that different authors who have participated in developing SFL, including Halliday (see, for example, 1978), Martin (see, for example, 1992); Hasan (see, for example, 1984); and Matthiessen (see, for example, 2009a), at times use somewhat different terminology.

<sup>11</sup> For more about paradigmatic and syntagmatic organisation see, for example, Chandler (2007), Halliday and Matthiessen (2004), Hodge and Kress (1988), and Martin (1992.)

will begin to introduce before returning to describe the relationship between instances of language and the system of language in Section 2.5.2.

In order to describe SFL's view on text I need to introduce the division of the functions of language into three major parts – metafunctions – that are interwoven and simultaneously performed in text production (Halliday & Matthiessen, 1999). These are called the “ideational”, the “interpersonal” and the “textual” metafunctions. For this thesis it is the ideational<sup>12</sup> metafunction of language that is the most important since it is the one that I have used for the construction of my patterns of disciplinary-relevant aspects (see Section 3.3.3).

The ideational metafunction deals with the linguistic construal of human experience and, as such, relates to what is going on in a text, who or what is participating, where and when it takes place, etc. Human experience is, in turn, seen in SFL as:

a resource, as a potential for understanding, representing and acting on reality. It is in terms of this potential that the particulars of daily life are interpreted: they make sense because they are instantiations of this potential. (Halliday & Matthiessen, 1999, p. 1)

Language, then, is a tool for “construing” experience, and this is the role of the ideational metafunction of language. Here, construing means to “construct semiotically” (Halliday, 2004c, p. 9).

The interpersonal metafunction relates to the managing of relationships between interacting parties within a text, and between the writer and reader of written language, or the speaker and listener of spoken language. Analysis of this function of language could, for example, be useful for studying group dynamics in physics education. However, I have not carried out any such analyses of my data. This omission is a consequence of the ethical agreement that I formulated with the participants (see Appendix B; for a discussion about how group dynamics might affect students' problem solving in groups, see Heller & Hollabaugh, 1992).

The textual metafunction relates to the managing of the other two metafunctions and deals with issues such as coherence and cohesion in a given text (Halliday & Matthiessen, 2004; Hasan, 1984; Martin, 1992, 2001).

It is through this function [the textual metafunction] that language makes links with itself and with the situation; and discourse becomes possible, because the speaker or writer can produce a text and the listener or reader can

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<sup>12</sup> In SFL, the ideational metafunction is sometimes divided into an experiential component and a logical component (Halliday, 2002), but following Kress (2010) I do not make or use this distinction in my analysis.

recognize one. (Halliday, 2002, p. 92. Note that "discourse" in Halliday's use of the term means the process of meaning exchange)

One of the important responsibilities of the textual metafunction is that of referencing, "phoricity" (Halliday & Matthiessen, 2004, p. 89). Referencing is important also for meaning-making in university physics since it is one of the means by which we build knowledge by referring back to already established meaning. As such, referencing helps creating cohesion<sup>13</sup> within a text because it allows, for example, people and objects to be "tracked" (for a recent example, see Rose & Basturkmen, 2013). From a linguistic point of view, reference in an oral discussion may begin with what is are called "exophoric references" (Halliday & Matthiessen, 2004, p. 535), which means reference to what is outside of the text (text is here meant as an instance of *language*) yet physically present in the "material situational setting" (Cloran, 1999, p. 177). Exophoric reference is often accompanied by a simultaneous physical pointing at the person or object referred to. By contrast, "endophoric reference" (Halliday & Matthiessen, 2004, p. 552) means reference to something which is *in the text itself*, and may be of one of two different kinds: either it refers to something that has already been established in the text ("anaphoric reference," Halliday & Matthiessen, 2004, p. 552), or to something that is yet to come ("cataphoric reference", Halliday & Matthiessen, 2004, p. 552). Referencing the same thing throughout a text (although in different ways) creates a "reference chain" (Veel, 1998, p. 133), which has been found to play an important role for the cohesion of a given text (Halliday & Matthiessen, 2004; Hasan, 1984; Martin, 2001; Martinec, 1998).

For an interesting discussion of the simultaneous use of different kinds of references, see Martin (1992). And for an example of how students participating in physics discussions use reference, see the discussion of my dynamic analysis of the first dataset in Section 4.2.2. In my analysis, however, semiotic resources other than language are also analysed and thus the line between what is within or outside the text cannot be drawn at the boundaries of language (see Section 2.8).

Next, I introduce the parts of SFL's analysis of language that I needed for the kind of analysis of language that I have carried out. The reason for presenting this here is twofold: first, to provide a background to how I built on thematic patterns to create a new research tool that I call patterns of disciplinary-relevant aspects; and second, to enable a discussion about how language makes a powerful resource for meaning-making in physics. From here, this argument has the potential to be extended to semiotic resources other than language, which is the focus of this thesis. This theoretical

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<sup>13</sup> Other aspects of language that contribute to the cohesion of text include conjunctions such as *and*, *or*, *then*, *so*, and *thus* (Martin, 2001; Martin & Rose, 2007).

presentation of SFL also provides the background to terms that I develop later in this thesis, such as “reverse rankshift” (see Section 2.7).

## 2.5.1 Introduction to the analysis of spoken and written language in SFL

In SFL instances of spoken and written language – texts – are analysed<sup>14</sup> (Matthiessen, 2009a). The analysis of spoken and written language in SFL is primarily based on the division of language into the different metafunctions (ideational, interpersonal and textual; see the previous section). As I have pointed out, for my thesis work I am mostly interested in the ideational metafunction and in what follows I will therefore mainly focus on this metafunction.

The analysis of language in SFL is also based on the division of language into different levels or “strata” (Halliday, 1978; Matthiessen, Teruya, & Lam, 2010). As shown in Figure 2.2, spoken language has a content plane that consists of semantics<sup>15</sup> and lexicogrammar, and an expression plane that consists of phonology and phonetics<sup>16</sup>. The stratum of semantics is described as one of “meaning” (Halliday & Matthiessen, 2004, p. 25) and is the uppermost stratum of language that functions as an “interface” to context<sup>17</sup>. The relationship between the different strata in the model in Figure 2.2 is such that a higher stratum is *realised* by a lower one. This relationship can be seen to be repeated so that context is realised by semantics; semantics is realised by lexicogrammar; etc.<sup>18</sup>

Lexicogrammar is a construct that is unique to SFL and therefore calls for a special description. SFL describes lexicogrammar as a “continuum” (Halliday & Matthiessen, 1999, p. 299) between the words and the grammar, where the wording represents the more fine-grained – delicate – end of the continuum. Thus, in SFL’s view, grammar and wording play similar roles for meaning-making in language. For my analysis lexicogrammar and semantics are the most relevant strata, and particularly the relationship between the two. In order to discuss this relationship I need to introduce the different units into which each of these two strata of language are divided.

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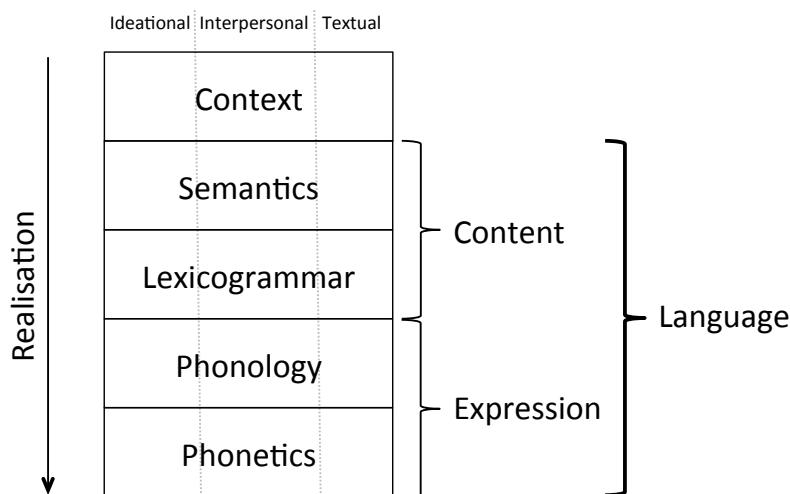
<sup>14</sup> Being a linguistic theory, SFL only analyses spoken and written language and essentially ignores other semiotic resources. Apart from this analysis, SFL also describes the meaning potential of language (Matthiessen, 2009a, for more about meaning potential, see Section 2.5.2).

<sup>15</sup> Martin (1992) calls this stratum “discourse semantics.”

<sup>16</sup> The equivalents for written language are graphology and graphetics (Matthiessen et al., 2010, p. 194)

<sup>17</sup> Martin (1992) divides context into register and genre. Halliday does not explicitly deny the possibility of more abstract strata above context.

<sup>18</sup> This relationship between the different strata has been characterized as “meta-redundancy” (Lemke, 1995c, p. 143)



*Figure 2.2.* Stratification of (spoken) language. The content and expression planes of language, and realisation (see, for example, Halliday & Matthiessen, 2004). At the top of the figure the three metafunctions that are described in the previous section can be seen<sup>19</sup>.

In SFL, the different constituent units of lexicogrammar are hierarchically organised in a “rank scale” (Halliday & Matthiessen, 2004, p. 31). Rank describes a way to classify language according to “structural unit” (Halliday & Matthiessen, 2004, p. 61). In lexicogrammar the rank scale, from highest to lowest is: clause, phrase (in other words, a “contraction of a clause”, p. 311) or group (in other words, an “expansion of a word”, p. 311), and word. The relationships between the different units are such that the lower units constitute – build up – the higher ones. For example, several words can build up a group, such as “the red line.” Several groups can build up a clause, such as in “I will be taking the Red line to Norsborg.” Clauses can, in turn, be put together to create clause complexes. Thus, for example, a sentence may consist of one or more clauses.

The semantic stratum is also divided into different constituent units. There is no rank in the semantic stratum that corresponds to a word. The lowest rank in the semantic stratum is “element” (Halliday, 1998b, p. 189; see also, Halliday & Matthiessen, 1999, pp. 49, 177), which is typically realised by a group or a phrase in lexicogrammar. Configurations of elements in turn make up figures (Matthiessen et al., 2010, p. 97), which are typically realised by clauses in lexicogrammar, and sequences of figures in the semantic stratum correspond to clause complexes in the lexicogrammar.

<sup>19</sup> The different metafunctions of language can be seen to also pertain to context. However, in SFL they correspond largely to the contextual variables field, tenor, and mode (Halliday & Matthiessen, 1999).

The highest rank in the semantic stratum is text<sup>20</sup> (Halliday, 1978, 2002; Halliday & Matthiessen, 1999), to which there is no corresponding unit in the lexicogrammar stratum. As such, text is not limited in length as are the units of lexicogrammar. Texts can therefore range in length from “a line on a public sign to a folk tale...” (Matthiessen et al., 2010, p. 218).

For the ideational metafunction that I am interested in, the smallest building blocks of the semantic stratum are thus the elements, which are of different kinds. In order from the more “central” to the more “peripheral” elements (Halliday & Matthiessen, 2004, pp. 175-176), these are: processes (what goes on); participants (who or what is participating); and, circumstances (for example, when, where or how something takes place).

In order to construe experience in language the different elements of the semantic stratum are in turn realised by different groups or phrases in the stratum of lexicogrammar, viz.: processes are typically realised by verbal groups, participants by nominal groups, and circumstances by adverbial groups or prepositional phrases (Halliday & Matthiessen, 1999; Halliday & Matthiessen, 2004). For example, in the sentence “I will be taking the Red line to Norsborg” the verbal group *will be taking* realises a process, the nominal groups *I* and *the Red line* realise participants, and the prepositional phrase *to Norsborg* realises a circumstance. This kind of analysis of language is an important basis for creating thematic patterns (Lemke, 1990; see Section 2.6), which I built on to create my research tool, patterns of disciplinary-relevant aspects.

Thematic patterns (Lemke, 1990) can also include more detailed analysis of language. For example, in the analysis of the semantics of a clause the process, participant and circumstance elements can be further categorised (Halliday & Matthiessen, 1999). For example, processes can be divided into the following types: “material”, “behavioural”, “mental”, “verbal”, “relational” and “existential” (Halliday & Matthiessen, 2004, p. 260). Even further division of most of these types is also possible. For example, the type material (“doing”) can be divided into action (“doing”) and event (“happening”). The type relational (which deals with “being”) can be divided into attribution and identification, which are particularly important in science texts (Halliday, 1998b). For example, in the clause “the valence band is filled” (Serway, Moses, & Moyer, 1997, p. 456), *is*, is an attributive process connecting “the valence band” with the attribute “filled.” On the other hand, in the clause “[o]ne of the most important light sources for fiber-optics is the semiconductor laser” (Serway et al., 1997, p. 455), *is*, is an identifying process that identifies “one of the most important light sources

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<sup>20</sup> While there appears to be agreement in SFL that text is the highest rank in the semantic stratum, there appears to be less agreement regarding what the lower ranks are (see, for example, the units proposed in Hasan, 2010). In fact, there is not even agreement that there exists a rank scale in the semantic stratum (Kappagoda, 2009).

for fiber-optics” with “the semiconductor laser.” All of these process types serve the “role” or “structural function” (Matthiessen et al., 2010, p. 102) of Process<sup>21</sup> in the clause (Halliday & Matthiessen, 1999).

Participants can be further divided into, for example, the common “participant roles” (Halliday & Matthiessen, 2004, p. 190) “Actor” (“the one that brings about the change”) and “Goal”<sup>22</sup> (the one that “undergoes” the process”, “the goal of impact”, Halliday & Matthiessen, 2004, pp. 179-181)<sup>23</sup>. For example, in the clause “the atom absorbed a photon” (Schumacher & Westmoreland, 2010, p. 37), “the atom” is Actor, “absorbed” is Process, and “a photon” is Goal<sup>24</sup>.

Circumstances can be divided into, for example, the circumstance roles “Location” and “Extent,” which “construe the unfolding of the process in space and time” and into “Manner,” which “construes the way in which the process is actualized” (Halliday & Matthiessen, 2004, pp. 263-267).<sup>25</sup>

Another important aspect of analysing language in order to create thematic patterns is the analysis of groups. This analysis typically focuses on categorising the “group functions” (Matthiessen et al., 2010, p. 170) that are realised by the different words that make up the group<sup>26</sup>. Particularly important for this thesis are nominal groups, which typically realise participants. The main functions in the nominal group are labelled “Deictic,” “Numerative,” “Epithet,” “Classifier” and “Thing” (Halliday & Matthiessen, 2004, p. 312). The first four of these categories are different kinds of “qualities” (see Halliday & Matthiessen, 1999, p. 184) of the final “Thing.” A special case of a nominal group is one that contains only one word. For example, consider “microscope,” which in this analysis is a Thing. By adding qualities to this nominal group the Thing is further elaborated, such as in “A three-dimensional (3D) laser-scanning confocal reflecting microscope” (Maruo, Inagawa, Toratani, Kondo, & Matsushita, 2014, p. 233). Of all the different constituents of this nominal group only

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<sup>21</sup> Note that there is a convention in SFL to capitalize the different roles/structural functions.

<sup>22</sup> In this thesis I am exclusively going to use SFL’s transitive model – an “organisational” model where, for example, “a process is acted out by one participant” (Actor) and may “impact another participant” (Goal) (Matthiessen et al., 2010, p. 232).

<sup>23</sup> Other participant roles in the different process types are: in material processes “Recipient, Client; Scope; Initiator; [and] Attribute”; in relational processes “Carrier, Attribute; Attributor, Beneficiary; Identified, Identifier; Token, Value; [and] Assigner”; and, in other process types “Behavior; Behaviour; Sensor, Phenomenon; Sayer, Target; Receiver; Verbiage; [and] Existent” (see Halliday & Matthiessen, 2004, p. 260).

<sup>24</sup> There is also a more general alternative to the transitive model, called the ergative model. Here, “the atom” would be Agent, the “external cause” (Halliday & Matthiessen, 2004, p. 285), who is responsible for the process, and “the photon” would be Medium, as in “the medium through which the process is actualized” (p. 284). (In the ergative model, Medium may replace either Actor or Goal, and Agent may replace Actor (Halliday & Matthiessen, 2004, p. 291).)

<sup>25</sup> Other circumstance types are “Cause; Contingency; Accompaniment; Role; Matter; and, Angle” (Halliday & Matthiessen, 2004, pp. 262-263).

<sup>26</sup> Groups may be of the types verbal, nominal or adverbial groups.

“microscope” is a Thing, and the other constituents are a few of the Thing’s most salient qualities (or rather, those qualities that are most relevant for the context at hand). The wide range of possibilities to elaborate the meaning of Things that nominal groups provide contributes to the equally wide range of Things and their organisation in taxonomies:

The nominal group has the potential for intersecting any number of qualities in the representation of a participant; and this makes it possible for the taxonomic ordering of participants to be considerably more elaborated than that of processes. (Halliday & Matthiessen, 1999, pp. 180-181)

Taxonomies will be discussed further in Section 2.5.2 where I deal with the systemic perspective on language.

According to SFL Things are “experientially complex” (Halliday & Matthiessen, 1999, p. 185). As the microscope example above indicates, Things can be described as “an assemblage of different qualities” (Halliday & Matthiessen, 1999, p. 186). Qualities, on the other hand, “tend to be experientially simple, specifying values along a single dimension or scale, such as age, size, weight, loudness, colour...” (1999, p. 186). The dimension along which a quality varies can be divided in three different ways: as scalar (continuous), binary (twofold) or taxonomic distinctions (Halliday & Matthiessen, 1999, pp. 186, 211). Scalar dimensions include tall vs. short and heavy vs. light; binary dimensions include alive vs. dead and married vs. single; and taxonomical dimensions include red, blue, green, ..., and 1, 2, 3, .... Continuous distinctions can be compared with what Lemke (2003, pp. 220-221) calls “topological meaning” (“meaning-by-degree”), and the binary and taxonomic distinctions with his “typological meaning” (“meaning-by-kind”) These terms used by Lemke are discussed in Section 2.8.2.

The brief introduction to SFL’s analysis of text that has been presented here is the basis for the analytical tool “thematic pattern” (Lemke, 1990) that I have built on in my work. A thematic pattern is an analysis from what Lemke (1990) calls a “synoptic” perspective, which is one of two complementary perspectives that are useful for text analysis. The alternative perspective is called “dynamic” (1990). The synoptic<sup>27</sup> perspective is a time *independent* analysis of a given text. This perspective thus tells us “how things turned out in the end” (Lemke, p. 197). Thematic patterns thus represent the time independent (synoptic) analysis of the meanings that have been realised in spoken or written language. Thematic patterns will be further introduced in Section 2.6. The dynamic perspective examines meaning-making as it develops with time. This involves, for example, how

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<sup>27</sup> Note that, here, synoptic does not mean space independent, which is the common meaning of the term.



what is said or done relates to what has been said or done before, and how the meaning of what was said or done before can be re-interpreted by that which is new. In SFL, the dynamic production of text is described as taking place through a series of choices within the system of language. The system of language is introduced in the next section.

## 2.5.2 The relationship between system and instance of language – instantiation

At the same time as text in SFL is a unit of meaning in a particular context – in turn realised by the grammar and the wording used – it is also an instance of the “meaning potential” of language. In this section I introduce SFL’s description of the meaning potential of language and how it relates to instances of language – text. This description is somewhat technical, but is related to my use of thematic patterns as a research tool.

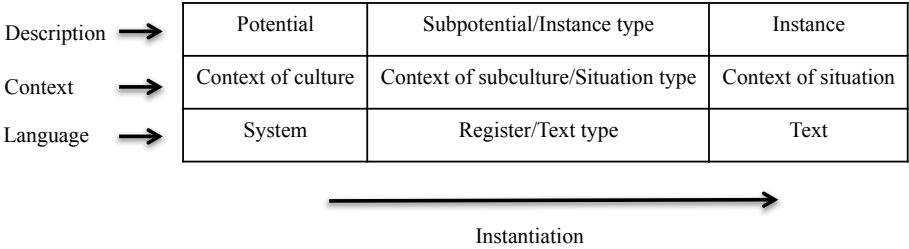
The meaning potential of language is described in SFL in terms of a network of sets of contrasting options of choice, where each set is called a system. (Another term for system that is used in SFL is “paradigm,” Matthiessen et al., 2010, p. 155.) A language as a whole is described by a “very large network of systems – a **system network**” (Halliday & Matthiessen, 2004, p. 23, emphasis in original), which is conventionally shortened to just system (see Halliday & Matthiessen, 2004, p. 26).

To give an example of the kinds of choices that are involved in language I will use the lexicogrammatical stratum. As mentioned in the previous section, in SFL this stratum is described as a continuum between a lexical end (wording) and a grammatical end. At the lexical end of the continuum, choices are made between different words to find the one that best captures the intended meaning, such as in Saussure’s example in Section 2.4.1 with the different variants of the word “fear”. The lexical end of the lexicogrammar is therefore considered the more delicate/fine-grained, and can be seen to be organised into taxonomies.

In the grammatical end of the continuum more general meanings are contrasted, which are less dependent on the actual words that are used to realise them. Here, choices are made in terms of, for example, time (in the sense of tense): past: something did take place/took place, present: something does take place/takes place, or future: something will take place.

Note that Halliday (see, for example, 1993a) emphasizes that the choices made in the system of a language are not necessarily conscious, rather to talk about choices in the system is an analytical description of the production of instances of language. Choices in the system “may also result from a convention followed unthinkingly, a habit acquired unreflectively, or an unconscious impulse” (van Leeuwen, 1999, p. 29).

In Section 2.5 I introduced the two simultaneous organisational principles of language as described in SFL: the systemic (paradigmatic) and the structural (syntagmatic) (Halliday & Matthiessen, 2004; Martin, 1992). The first principle describes the meaning potential of language (the possible options of choice), and the second describes instances of language. The relationship between the two is captured through the term “instantiation” (Halliday & Matthiessen, 1999, p. 14). Instantiation means that choices are made (although, as mentioned above, not necessarily consciously) from the systemic network to produce text. This takes place in a “logogenetic time frame” (Halliday & Matthiessen, 1999, p. 18), viz. “the time frame of the unfolding of a text” (Matthiessen et al., 2010, p. 197). Instantiation is represented in the “cline of instantiation” (see Figure 2.3; Halliday & Matthiessen, 2004; Matthiessen, 2009a).



*Figure 2.3.* The cline of instantiation (after Halliday & Matthiessen, 2004; Matthiessen, 2009a).

Instantiation concerns not only language, but also context. Halliday (1991) has theorised that in a given context there is a probability distribution for the choices that are typically made in the system networks. As the context is increasingly specified there is a gradual change in these probabilities. For example, there is a greater chance of finding, “an electric field” in a text in a physics context<sup>28</sup>, than there is in an everyday context. By restricting the context to a physics one (a context of subculture, see Figure 2.3), the probabilities in the meaning potential of the network system of language are simultaneously shifted towards those of the applicable subpotential. In Figure 2.3 the subpotential is located in the same box as instance type, between potential and instance. Subpotential and instance type are essentially two different names for the same thing, but viewed from different perspectives, from the potential and instance respectively. From the more descriptive potential-end of the cline it is the subpotential that is seen, viz. the context of subculture for context and the register for language.

<sup>28</sup> Note that context here is not defined as much by the physical environment, as by what has been presented in the preceding discussion (see also Footnote 7 in Section 2.4.2). The physical environment may nevertheless change the probability that a particular context becomes realised.

Viewed from the instance end of the cline it is the instance type that is seen, viz. situation type for context and text type for language (see, for example, Halliday & Matthiessen, 2004, p. 27). Restricting the context further to an actual instance we get the context of situation (an instance of context, see Figure 2.3). The corresponding instance of language is a text.

The description of language as a system has also been used to deal with the meanings that an individual has at his or her disposal. In this respect the meaning potential of a language as a whole is described in SFL as a “reservoir,” and the parts of the meaning potential of a language that an individual has at his or her disposal is described as a “repertoire.” For example, Matthiessen et al. (2010) describe this in relation to the cline of instantiation as follows.

“For a person—a meaner, learning ... involves moving up the cline of instantiation from the instance pole towards the overall meaning potential. However, while individual meaners increase their repertoire of registers as they go through life and will typically be able to take on an increasing range of roles in different situation types, they will never reach the potential pole of the cline of instantiation: the overall meaning potential is a collective system, not a personal one. This **meaning potential** is a reservoir of meanings of a given society; and the personal repertoires of meaning are drawn from this reservoir” (pp. 117-118, emphasis theirs).

Similarly, building on Lemke’s (1990) thematic patterns, which are introduced in the next section, Halliday and Matthiessen (1999, p. 330) argue that students need to “build up” their own *systems* of meanings. These could be analytically described as taxonomies, which the students can then draw on in their work. Such development can be seen to take place on an “ontogenetic time frame” (Halliday & Matthiessen, 1999, p. 17), viz. “the time frame of development in the individual” (Matthiessen et al., 2010, p. 197). The development of taxonomies, which has been pointed out as a critical part of an individual’s development of language (Matthiessen, 2009b; Painter, 1999), also continues to play a critical role for the learning of specialized fields (Halliday, 1998a) such as physics. Typical relationships *between* the units in a taxonomy include part-whole relationships, such as between leg and chair (also referred to as meronymy); subclass-class relationships, such as between dog and mammal (also referred to as hyponymy); and contrast pairs, such as wet and dry (also referred to as antonymy) (see, for example, Halliday & Matthiessen, 1999, pp. 82-95, 236; and Lemke, 1990, p. 222, who uses these constructs in his thematic pattern analyses).

Contrast pairs play an important role in the analysis of all datasets in this thesis (see Sections 4.2.3, 4.3.1, 4.4, and 4.6). These relationships can be seen in a “strict taxonomy” (Halliday & Matthiessen, 1999, p. 38), which can be described as a tree-structure where each unit is located in only one

position. In this respect, Halliday (2004a, p. 119) points out that “[t]he categories and relations of our commonsense world are not given to us readymade; we construe them grammatically, using grammatical energy to theorize – to select among the indefinitely many ways in which experience could be ‘parsed’ and made to make sense.”<sup>29</sup> From this view, when we learn a language, we simultaneously learn to organize our experience in accordance with the resources of the language:

...when children learn a mother tongue, they are shaping their own experience as individuals according to the accumulated experience of the human species, as already construed for them by the grammar. The grammar defines for them the basic experience of being human; with lots of local variations, but shaping, as a whole, the form of their commonsense knowledge: their knowledge of the ecosocial system that is their environment, and of their own place, and their own identity, within it. (Halliday, 2004d, p. 12).

In this thesis I frame learning physics in a similar manner. Students need to transform experience into meaning by appropriately engaging with disciplinary-specific semiotic resources in order to become disciplinary literate (Airey, 2013). In other words, students need to learn to appropriately construe meaning by leveraging the meaning potentials of disciplinary-specific semiotic resources – what I have termed “disciplinary affordance” (Paper I, p. 658, see Section 2.8.6).

In the next section I further introduce thematic patterns.

## 2.6 Thematic patterns

This section serves to introduce Lemke’s thematic patterns, which I have built on to create my patterns of disciplinary-relevant aspects (see Sections 3.3.3 and 4.2.3). According to Lemke<sup>30</sup> (1983, 1990, 1998), scientific texts about a given topic are characterized by certain regularities – certain recurring thematic patterns, also called thematic formations or thematic systems:

In scientific text ... there are highly conventionalized, and therefore quite easily recognizable, systems of meaning relationships among terms and concepts. The relations among light, heat, temperature, energy, absorption, reflection and radiation form such an open system of thematic meaning relations in physics, which could be reconstructed from any of thousands of

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<sup>29</sup> Compare also with the Saussure quote about “fear” in Section 2.4.1.

<sup>30</sup> Jay Lemke received his PhD in theoretical physics in 1973 from the University of Chicago. After having taught both “physics and science education” he “specializ[ed] in the role of language in the communication of science” (Lemke, 2012). His work has had profound impact on the field of social semiotics.

texts or text-fragments, all of which share what I will call a common thematic system. (Lemke, 1983, p. 160)

Thematic patterns/systems can be seen to capture important similarities between different texts<sup>31</sup> (see Lemke, 1990). Texts that are based on the same thematic pattern can be said to be “cothematic” (Lemke, 1990, p. 204). In other words, they share “intertextual thematic systems” (Lemke, 1983, p. 160)<sup>32</sup>. Here, the term intertextual (Kristeva, 1980) refers to how “[e]verything makes sense only against the background of other things like it” (Lemke, 1990, p. 204). This means that, in order to make sense, many texts presuppose meanings that have to be brought in from other texts, which are explicitly or implicitly referenced. Thus texts often make sense (only) by relating to other texts and, together with these texts, they make up a web or a pattern of interrelationships. In terms of the cline of instantiation (see Section 2.5.2), Tang (2013, p. 24; based on Martin, 2006)) positions thematic patterns in what he calls “generalized instance” – an intermediate position between instance and instance type.

Thematic patterns are analytically generated through the identification of the roles or meanings that words have in relation to each other in a given text:

Words do not necessarily “have” meanings in themselves. A word in isolation has only a “meaning potential”, a range of various uses to mean various things. What it actually means as part of a sentence or paragraph depends on which *thematic item* in some particular thematic pattern it is being used to express (Lemke, 1990, p. 35, emphasis added).

In order to generate thematic patterns from texts, Lemke (1983, 1990, 1995b) drew on Halliday’s Systemic Functional grammar:

Essentially, the thematic formation abstracts from its instances in one or more texts the common lexicogrammatical semantic relations (mainly those of transitivity, nominal group structure, clause-complexing, and lexical taxonomic relations such as synonymy, antonymy, hyponymy, and meronymy) actually shared by the texts (Lemke, 1995b, p. 91)

To provide an example of how a thematic pattern is generated I use the clause “the atom absorbed the photon” (Schumacher & Westmoreland, 2010, p. 37) that I used in Section 2.5.1 to introduce some of the SFL terminology. Here, according to SFL’s analysis of language, “the atom” is Actor, “absorbed” is Process, and “the photon” is Goal. A thematic pattern, then, organises important words, “thematic items” (Lemke, 1990, p. 39), that have

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<sup>31</sup> In other words, a particular thematic pattern can be seen as a “blueprint” for such texts, although usually realized through different wording.

<sup>32</sup> The alternative would be a text with its own “*text thematic system*” (Lemke, 1983, p. 160).

been distilled out of the text. The link between each pair of thematic items would be labelled by the juxtaposed names of the roles/structural functions of the different items. (Conventionally, abbreviations for these role names are used). In this way the kind of relationship that is realised between two items is characterised. Consider the items “ATOM,” “ABSORB” and “PHOTON” from my example clause. The relationships between these items could be illustrated in a thematic pattern as:



where Ac = Actor, Pr = Process and G = Goal.

Lemke further elaborates the significance of the term thematic item by describing how a given thematic item can be realised by different words:

Because there is often more than one way to express the parts of a thematic pattern in words, the pattern itself has to be defined at a slightly more abstract level than that used to describe wordings. A scientific “concept” ... can always be expressed in different words: sound can be expressed as sound, sound wave, acoustic vibration, pulse, and so on at different points in the same text (or from one text to another). The element of a thematic pattern which can be expressed in all these ways is called a thematic item.... The web of semantic relationships among different thematic items form the thematic pattern or thematic formation of the topic (Lemke, 1990, pp. 202-203).

Texts that are analysed in terms of a thematic pattern can be, for example, transcriptions of spoken language in a classroom. Lemke (1995b) describes that, in the analysis, the text that one wishes to analyse can first be paraphrased, for example:

...a certain [Number] of [Electrons] are [Located] in certain [Types] of [Orbitals], the latter being considered parts of [Shells] in which the [Electrons] [Have] a certain [Amount] of [Energy]. In addition, certain [Elements] have [Particular-Numbers-of Electrons-in-Particular-Orbitals], known as their [Electron Configurations] (Lemke, 1995b, p. 93).

Lemke describes that in this paraphrase of the text, he has:

put principal thematic items in brackets, and glossed their thematic relations textually, in effect writing a more abstract, but still co-thematic text of the same formation I am describing (Lemke, 1995b, p. 94).

The analysis is then formalized in terms of SFL’s analysis of spoken and written language:

“...the relation of [Number] to [Electrons] is that of Numerative-to-Thing in the grammatical semantics of the nominal group..., and similarly [Type] is Classifier to [Orbital] as Thing. These two thematic relation units are themselves related by the semantics of transitivity, as Carrier of Attribute: Circumstantial: Location.” (Lemke, 1995b, p. 93)

In order to capture the meanings that are realised in longer stretches of text a linear pattern such as in the atom-absorption example earlier may not be sufficient. Therefore, thematic patterns often have a two-dimensional diagrammatical layout such as in Figure 2.4. Lemke states:

Thematic patterns [...] are best expressed in the form of diagrams that can show the interconnected semantic relationships among several terms or thematic items. (Lemke, 1990, p. 35)

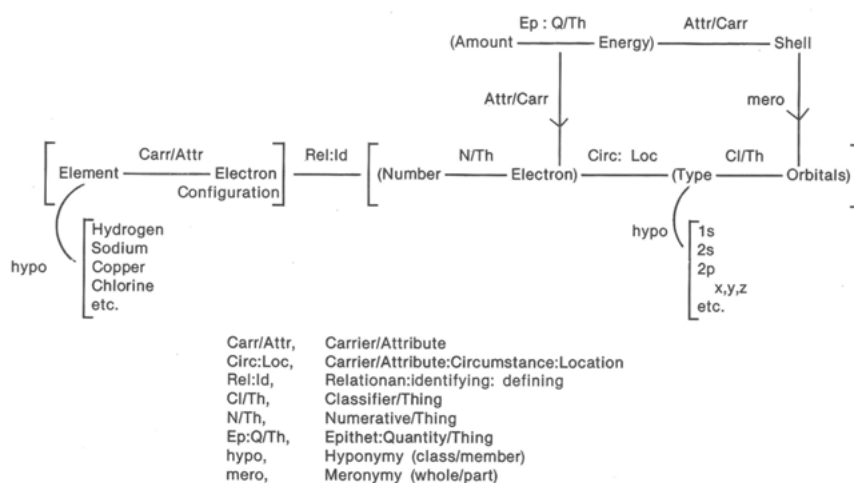


Figure 2.4. A typical thematic pattern. Republished with permission of Elsevier, from Intertextuality and text semantics, Lemke, J.L., in P.H Fries & M. Gregory (Eds.), *Discourse in society: systemic functional perspectives*, Volume L, 1<sup>st</sup> edition, 1995, p. 94; permission conveyed through Copyright Clearance Center, Inc.

A two-dimensional thematic pattern such as the one in Figure 2.4 with its thematic items and the labelled links between those items can be seen to have similarities to “concept maps” (see, for example, Novak & Cañas, 2008). However, thematic patterns are different in that they constitute an analysis of empirical data, and that they add an extra layer of theory provided by SFL’s analysis of text on top of the diagrammatic organisation. On the other hand, the complexity of and the theory that lies behind thematic patterns simultaneously renders them better suited as research tools than as a tool for teaching (Lemke, personal communication, 12 September, 2014). I wanted to be able to both capture the meanings that were realised in student discussions and to build on thematic patterns to create a tool that could

potentially be used by teachers. The result was my patterns of disciplinary-relevant aspects (see Section 4.2.3).

In the next section I turn to describing different ways that the meaning potential of language can be increased, including an alteration of the typical ways that semantic elements (especially processes) are realised in the lexicogrammar. Although this produces powerful linguistic resources for physicists, it simultaneously produces learning challenges for physics students (see, for example, Brookes, 2006; Brookes & Etkina, 2007, 2009).

## 2.7 Increasing the meaning potential of language

An important point in relation to meaning-making in physics is that the meaning potential of language can be expanded through different “semogenic” processes (Halliday & Matthiessen, 1999, p. 17). These processes also have in common that they involve an increased “packing” (Halliday, 2004b, p. 28) of text. What follows is a review of the literature that describes these packing-processes, including rankshift, nominalisation, and technicalisation. I also discuss the power of packing for physicists, and the challenges that it creates for students.

The first process I review is known as “rank shift” (Halliday & Matthiessen, 1999, p. 261). Through a rank shift, a higher rank, for example, a clause, is shifted towards a lower rank – a phrase, group or a word<sup>33</sup>. Although this implies a loss of information (see Halliday & Matthiessen, 1999, p. 231), it enables the rank-shifted unit to be further elaborated on by the language around it as it becomes “embedded” (Halliday & Matthiessen, 1999, p. 592; Halliday & Matthiessen, 2004, p. 426) in the surrounding language. Consider the following example from a physics textbook. The clause “kinetic energy ... is conserved” (Young & Freedman, 2004, p. 300) can be rank shifted to a nominal group as in “conservation of kinetic energy” (p. 300), which no longer contains a verb. This rank shift makes it possible for the original clause to function on the rank below that of the clause, and thus to become a part of a new clause. An example from Young and Freedman of a new clause is: “From the conservation of kinetic energy we have ...” Here, the rankshifted original clause has become embedded in the new clause.

Note that while increasing the meaning potential of language, rankshift is simultaneously one of the ways that scientific language becomes increasingly compact, abstract and opaque (Martin, 1992; Martin & Veel, 1998). This makes language a powerful semiotic resource for physicists. (Compare also with the mathematical modelling of the relationship between

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<sup>33</sup> SFL does not consider rankshifts in the other direction, that is “upward rankshift” (Halliday, 1966; McGregor, 1991).



ambiguity and efficiency in communication in Corominas-Murtra, Fortuny, & Solé, 2011; Fortuny & Corominas-Murtra, 2013.) However, rankshifts may at the same time pose significant learning challenges for science students.

Two related processes that increase the meaning potential of (scientific) language are “nominalisation” and the closely related “technicalisation” (Halliday, 1998a; Halliday & Martin, 1993; Matthiessen et al., 2010). Nominalisation is the process by which nouns (or generally nominal groups), which usually realise grammatical participants such as Things and Qualities, are instead used in order to realise processes and thus replace verbs that typically fill that function. SFL therefore characterises nominalisation as a form of “grammatical metaphor” (Halliday, 1998b; Halliday & Matthiessen, 2004) since it creates a tension between the two strata lexicogrammar and semantics.

For an example of nominalisation, consider the noun “conservation” that is used instead of the verb group “is conserved” in the sentences from Young and Freedman (2004, p. 300) that were referred to earlier. Another example of nominalisation is the noun “refraction” that replaces the verb “refracts” (see the discussion in Halliday & Martin, 1993, pp. 14-15). In SFL, the typical realisation of processes by a verbs is called “congruent construal,” whereas the metaphorical realisation by a noun it is termed a “metaphorical reconstrual” (Halliday & Matthiessen, 1999, p. 272).

When a nominalisation (metaphorical reconstrual) gets accorded a taken-for-granted meaning by the community that makes up the discipline, the term becomes “*technical*” within that discipline (Halliday & Martin, 1993). This process is called technicalisation. Technicalisation is thus another process that changes the meaning potential of language. Such changes usually take place in “the time frame of evolution in the species or a social group” (Matthiessen et al., 2010, p. 197), which is referred to in SFL as a “phylogenetic time frame” (Halliday & Matthiessen, 1999, p. 17).

Like rank shift, nominalisation is very useful for physicists. This is because the nominal group that is the outcome of nominalisation becomes “a textual ‘package’, a packed and compacted quantum of information ready to take on its role in the unfolding of the argument” (Halliday & Matthiessen, 1999, p. 239). This means that through nominalisation, processes can become thematised<sup>34</sup> in spoken or written language and given a foregrounded position in the clause (Halliday, 1996; Halliday & Matthiessen, 1999). Nominalisation also allows processes that are realised as nominal groups to be further elaborated and/or specified, thus enabling a more diverse taxonomy of processes (see Section 2.5.2).

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<sup>34</sup> Similar thematisation has recently been investigated in mathematics (Doran, personal communication, 2012).

The effect that nominalisation and technicalisation have on science learning has been explored in Brookes' (2006) and Brookes and Etkina's (2007) work with students' difficulties with language in quantum physics. Particularly, Brookes and Etkina (2007) investigated cases where, in everyday life, the grammatical use of a word (for example, "heat") signalled that it was referring to "matter" (pp. 4-5), whereas in physics, the meaning of that word would be thought of as a process.

Halliday (1993b, p. 74) similarly discusses the challenges that result from nominalisation and exemplifies it with the clause "Lung cancer death rates are clearly associated with increased smoking." Here "lung cancer death rates" and "increased smoking" are both nominalisations. With respect to these (nominalised) nominal groups, Halliday asks about their congruent construal (cf. what Brookes, 2006, p. 137, calls their "denominalized" form):

What is **lung cancer death rates**: how quickly lungs die from cancer, how many people die from cancer of the lung, or how quickly people die if they have it? What is **increased smoking**: more people smoke, or people smoke more? (Halliday, 1993b, p. 74, emphasis in original)

Halliday (1998a) claims that the result of nominalisation:

...is not loss of semantic distinction but ambiguity: the different possible meanings are still discrete. This may – indeed it often does – create problems for the learner, who has to guess right, often without realising there is more than one possible interpretation. (p. 228)

Therefore, the introduction of grammatical metaphors in a text, although powerful for disciplinary insiders, risks making it less transparent.

A special case of nominalisation is what Lemke (1990, p. 101) calls "condensation." Condensation means that a nominal group comes to realise "a whole little thematic pattern" – in other words, a whole configuration of meaning. (For a similar argument, see Lemke, 1995a.) Accordingly, condensations can be seen to contribute to "packaging the knowledge that has developed over a long series of preceding arguments" (Halliday, 1993a, p. 131).

With respect to nominalisation Halliday & Matthiessen (1999) point out that:

Usually the configurational pattern will have been built up over long stretches of text, or (especially if it is a technical form of discourse) over a great variety of different texts – for example, a series of textbooks used in teaching a science subject throughout a school. Very often the learner has to construct the configurational relations from various sources without their being made fully explicit in any one place; and in the limiting (but by no means unusual) case they have never been made explicit at all, so that the figure has to be *construed from the metaphor* – a very difficult task indeed.

So the more the extent of grammatical metaphor in a text, the more that text is loaded against the learner, and against anyone who is an outsider to the register in question. (pp. 271-272, emphasis theirs)

Thus, considering that physics texts are amongst the most technicalised of texts, and have large amounts of nominalisations, the need for “unpacking” (Halliday & Matthiessen, 1999, p. 256) – the construction of a congruent construal – can be seen as highly relevant from an educational point of view. In my work I have extended this discussion on the need for unpacking to also include semiotic resources other than language (see Section 4.3). In a similar way, I adapt the term rankshift to apply not just to language but, analogically, to the full range of semiotic resources and I go on to problematize teaching and learning in terms of “reverse rankshift” (see Paper III and Section 4.3.2). As a necessary preamble to this use of the term rankshift, and to the way I have used thematic patterns in my work, I introduce multimodality in the next section.

## 2.8 The multiplicity of semiotic resources - Multimodality

In this section I will introduce how the social semiotic perspective has developed from dealing almost exclusively with language, to dealing with the multiplicity of semiotic resources, a perspective referred to as multimodality (Kress, 2010).

From a linguistic perspective, language has a privileged position for making meaning and construing experience. Therefore, when discussing meaning-making with semiotic resources other than spoken or written language, these other resources can be referred to as those to which exophoric references<sup>35</sup> are often made (see, for example, Martin & Rose, 2007). From a multimodal perspective, however, the other semiotic resources, such as images to which the wording refers, become resources for meaning-making in their own right. So, some meaning is realised by the written language and other may be realised by another semiotic resource, such as an image. Van Leeuwen (2011, p. 169) argues that: “what is marginal and what is central will depend on the cultural and situational context.” Lemke (1998) takes this further and argues that entirely different meaning may be made by the interrelation of, for example, the two semiotic resources language and image, rather than with, for example, image alone.

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<sup>35</sup> I want to remind the reader that in SFL an exophoric reference refers to something outside written or spoken text (see Section 2.5).

One of the central aspects for this thesis is characterised by Martin and Rose (2007) as “how semantic patterns at the level of discourse<sup>36</sup> are realised as visual patterns at the level of image” (p. 322; for a similar argument, see also Tang, 2013). A similar argument can be seen in Halliday and Matthiessen’s (1999) discussion regarding weather forecasts, where:

*...isotherms on the map and clauses such as high temperatures will range from 60s in the northern Rockies to 100s in Arizona could be construed as alternative realizations of the same semantic figure, or sequence of figures.*  
(pp. 354-355, emphasis theirs)

It is the “orchestration” of a multiplicity of semiotic resources that is collectively referred to as multimodality (see, for example, Kress, 2010; Kress, Jewitt, Ogborn, & Tsatsarelis, 2001; Kress & Van Leeuwen, 2001, 2006).

Broadly speaking, the accounts of social semiotics in the literature differ widely in terms of the details that are focused on and/or omitted. This can be seen to be a result of its inclusive character (see, for example, Section 2.3.4). Different social semiotic theories about multimodality can be divided according to whether they are closer to SFL and Systemic Functional Grammar, or whether they put less emphasis on the grammar, and take a more general social semiotic stance. An example of a multimodal theory that is closer to SFL is Systemic Functional-Multimodal Discourse Analysis (SF-MDA), to which O’Halloran (2005), working in mathematics, and Lim (2011), working in the English language, adhere. The multimodal approach proposed by Kress (for example, 2010), builds on the social semiotic part of Halliday’s work, but essentially ignores grammatical aspects. (See Jewitt, 2009, for an elaboration on the different theoretical “flavors” of multimodality.)

It should also be noted here that different constructs that pertain to social semiotics are sometimes used interchangeably. And there appears to be no wide consensus regarding the way certain terms are used. For example, “mode” is often used instead of “semiotic resource”; Kress (2010, p. 28, emphasis his) exemplifies modes as “*speech; still image; moving image; writing; gesture; music; 3D models; action; [and] colour.*” Another example of the terminological ambiguity in social semiotics is the term “modality.” This term is often used in a similar way to the term mode (in the sense of different kinds of semiotic resources; for an example of this use of the term modality, see Tang et al., 2011). However, modality can also be taken to mean “the truth value or credibility of (linguistically realized) statements about the world” (Kress & Van Leeuwen, 2006, p. 155). Thus, according to

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<sup>36</sup> By discourse (short for “discourse semantics”), Martin and Rose (2007) are referring to what Halliday calls “semantics” in his model of stratification of language described in Section 2.5.1.

Kress and van Leeuwen, statements can have “low” or “high” modality, and they extend this concept to “visual modality” (p. 158). In my view, this latter sense of modality is not directly related to my use of multimodality, which rather follows the former sense of modality, that is, as a multiplicity of different kinds of semiotic resources.

Social semiotics describes language as a semiotic system (see Section 2.5.2). In essence a semiotic system is a system of possible options that are chosen among in order to make meaning. From a multimodal point of view it is possible to identify “semiotic systems other than language such as gesture, facial expression and vocal paralinguistics in face-to-face conversation” (Halliday & Matthiessen, 2014, p. 46, by vocal paralinguistics is meant, for example, “voice quality” p. 33; see also Muntigl, 2004). Different semiotic systems may differ in terms of, for example, stratification, rank, and metafunctions (Martin, 2011), but more research is needed in order to specify the characteristics of each semiotic system. (For pioneering work that suggests rank scales in semiotic resources other than language see O’Halloran, 2005, for mathematics ; and for visual rank, see O’Toole, 1994; 1995).

The “division of labour” (Halliday & Matthiessen, 2014, p. 38) between different semiotic systems and how integrated the different semiotic systems are, might vary between different contexts. An example of less integration between semiotic systems is images in early books that only fill decorative functions (Halliday & Matthiessen, 2014, p. 47), whereas gestures and speech are often highly integrated. (See also Royce, 2007, for discussions about “intersemiotic complementarity”). In Section 2.8.6 I develop this idea of the ‘division of labour’ between different semiotic systems in physics.

This discussion about different semiotic systems is also related to a multimodal interpretation of the term *text*. Contemporary multimodal literature often talks about “multimodal text” (Bezemer & Kress, 2008; Bowcher, 2007; Halliday & Matthiessen, 2014; Jewitt, 2005; Kress, 2010; Royce, 2002; Van Leeuwen, 2005). Bowcher (2007, p. 630) describes “multimodal texts” as “those in which more than one modality converge in a situation to produce meaning.” As described in Sections 2.5.1 and 2.5.2, in Systemic Functional Linguistics text is simultaneously an *instance* of language and the highest rank in the semantic stratum (that of meaning). For this reason, in this thesis I analogically consider instances of written and spoken language, mathematical formalism, gestures, pictures, diagrams and so on, as *text* (see Figure 2.5), which is simultaneously the realisation of a certain context (see Figure 2.3, showing the cline of instantiation).

The multimodal perspective on text also has consequences for referencing (see Section 2.5) – different semiotic resources might reference the same thing. Thus, different semiotic resources could also be seen to contribute to the cohesion of texts (see, for example, Tseng, 2008)

At this point I will sum up the terminology I use in this thesis. I use “semiotic resources” synonymously with “signs” and “representations”<sup>37</sup>. I use “semiotic system” to mean different kinds of semiotic resources that to some degree can be seen to be describable as a system of choices. By text I mean text in its widest sense (i.e. the same thing as multimodal text). And, as mentioned in Section 2.5, in this thesis I focus on the ideational content<sup>38</sup> of the texts produced in physics education.

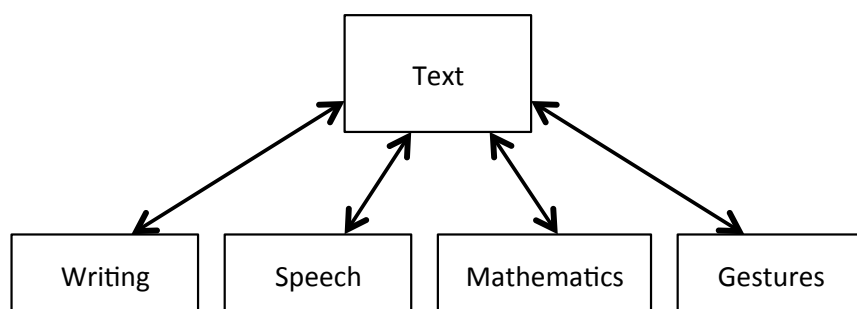


Figure 2.5. The relationship between semiotic resources (the bottom row) and multimodal text.

In the following sections I introduce other concepts related to semiotic resources that are important for this thesis.

### 2.8.1 Persistent and non-persistent semiotic resources

As indicated by Kress (2010, p. 165) it is possible to distinguish between a semiotic resource that “persists” and one that does not. I have referred to these options as “persistent” and “non-persistent” semiotic resources (see Section 4.2.5 and Paper I). By persistent I mean a semiotic resource that leaves a persistent “trace” (Woolgar, 1988) of its production in the medium in which it is produced. Thus, examples of persistent semiotic resources<sup>39</sup> are images, diagrams, equations, and written language. Examples of non-persistent semiotic resources are gestures and spoken language, which

<sup>37</sup> In particular, I have used the term *representations* in the papers that make up this thesis, since it is the term conventionally used in the PER literature.

<sup>38</sup> Lemke (1990, 1992) has generalized the metafunctions of language from Halliday’s work to other semiotic resources. The three kinds of meaning that Lemke proposes are “Presentational” (corresponding to the ideational metafunction of language), “Orientational” (corresponding to the interpersonal metafunction) and “Organizational” (corresponding to the textual metafunction of language). For this thesis, however, following Kress (2010), I have used the names initially given to the metafunctions of language also for other semiotic resources. The ideational metafunction relates to the who, what, where and when, etc. in the text (see Section 2.5)

<sup>39</sup> A different word that has been used to mean essentially the same thing is “inscriptions” (see, for example, Roth & McGinn, 1998, p. 35).

‘vanish’ from the medium in which they are produced directly after their production.

## 2.8.2 Typological and topological meaning

In Section 2.5.1 the terms typological meaning and topological meaning were introduced. Lemke (1999, pp. 174-175; 2004, p. 37) argues that meaning can be categorised into “meaning-by-kind” (typological meaning) and “meaning-by-degree” (topological meaning). Typological meaning refers to the kind of meaning that language has become specialized to communicate. For example, when we write we make choices that are distinct and discrete (such as whether a wave is mechanical or electrical). In science, however, topological meaning is particularly important, for example, when we deal with quantities that can vary continuously, such as speed. In order to make topological meaning, it may be more appropriate to use semiotic systems other than language – for example, mathematics or gestures. So, in order to optimize meaning-making and communication in physics, both kinds of meaning need be made, and therefore different kinds of semiotic resources are needed (Airey & Linder, 2009). (For a discussion of cases where the two kinds of meaning interact (which is not uncommon), see Lemke, 2000b.) The implications for physics education that these ideas might have will be further discussed in Section 4.4.2 in relation to the Variation Theory of Learning.

## 2.8.3 Semiotic resources as motivated metaphors

Semiotic resources can be characterised as metaphors. From a multimodal perspective Kress (2010, p. 55, emphasis his) claims that “[i]n a social-semiotic take on representation and communication, all *signs* are *metaphors*.” Here, metaphor is taken to mean *seeing something as something else*<sup>40</sup>. Signs as metaphors are achieved, Kress claims, in a two-step process, in which there is first an analogy: for example, a drawing of a tree is *like* a tree (i.e. they share some aspects or features). Next, one goes on to say that what has been drawn *is* a tree.

Kress (2010) further claims that a sign is always “motivated”<sup>41</sup> (as opposed to Saussure's "arbitrary" sign, see Chandler, 2007). In this way, calling something a bus and not a car depends on what characteristics of the thing we want to name are present, and to what extent these characteristics

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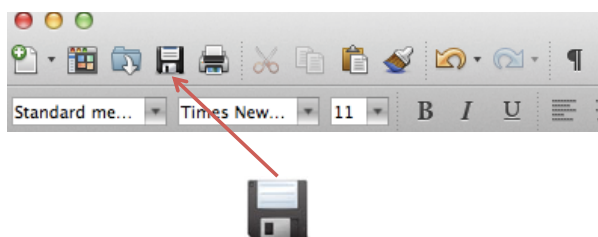
<sup>40</sup> This can be seen to be similar to Saussure's description of language in Section 2.4.1: the signifier is “dissimilar” (Saussure, 1959, p. 115) to the signified. Also, compare with what Bateson (1972, p. 323) calls a “difference which makes a difference” (see also Lemke, 2000a) and the discussion about reference in Section 2.5.

<sup>41</sup> However, there is no general consensus in this matter in the social semiotics community (see, for example, Lim, 2004).

are typical for what we know as buses and cars respectively. A similar argument for the motivation of signs in language is given by Hasan (1999):

the categories of context, meaning and lexicogrammar are related realisationally, not arbitrarily: a meaning exists by virtue of its activation by context *and* its construal by some lexicogrammatical form, which is not to deny that the categories of linguistic meaning bear a necessary relation to the categories of speakers' subjective experience. Subjective experience is a necessary, but not sufficient, condition for the significance of linguistic meaning (p. 223, note the use of the term "meaning" for the stratum of semantics).

Signs that were once overtly motivated (or "transparent", Hodge & Kress, 1988, p. 23; that is, that it was easy to see why it is used as a sign) by, for example, being iconic<sup>42</sup> can, with time, change to become more "opaque" (in a similar way to how scientific language may change, see Section 2.7). For a common example, consider the icon for saving a document in Microsoft Word, which is the iconic symbol for the now obsolete diskette (see Figure 2.6; Aamoth, 2010). The motivation for this icon may still be transparent to some people (those who have used or at least seen this type of back-up/transfer media), but may be opaque to others (those who have only ever used CDs, DVDs, USB drives or 'the Cloud' to save/transfer their work. From the point of view of the development of the sign, the "save this document"-icon is, however, motivated.



*Figure 2.6.* The motivation for the icon for the "save this document" option in Microsoft Word may be transparent for some people, but may not be for others.

For illustrative examples from physics consider the symbols used to denote common quantities. For example, the vector quantity force is denoted by the symbol ***F***. The motivation for this may be obvious if one is English speaking (***F***orce). If one instead is Swedish speaking, the word for force is "kraft," and the symbol motivation is immediately less transparent. In both cases the emphasis (bold) aspect that symbolises the vector nature of force is not obvious at all, but is used by convention. This convention, which applies

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<sup>42</sup> See the discussion about Peirce's triadic categorisation of signs in Section 2.4.1.



to all vectors in print, is useful for disciplinary insiders. To an outsider, on the other hand, the motivation for a semiotic resource may be veiled for different reasons, for example, (1) that the semiotic resource does not resemble what it means, or (2) that the semiotic resource communicates a distinction that is specific to a certain culture (such as a particular scientific discipline), and that is not well known outside these cultures (compare with Halliday's, 1978, discussion about "antilanguages" among prison inmates).

An important point for this discussion is that regardless of whether the materiality of a semiotic resource *is* motivated or not, the possible motivation is often hidden to students who are learning to use the semiotic resources, and their meanings, in particular contexts. For these students, the relationship between the semiotic resource and its meaning may *appear* to be arbitrary. Then, any semiotic resource could work just as well. For a physics example, consider the following story told by Feynman:

While I was doing ... trigonometry, I didn't like the symbols for sine, cosine, tangent, and so on. To me, "sin f" looked like s times i times n times f! So I invented another symbol, like a square root sign, that was a sigma with a long arm sticking out of it, and I put the f underneath. For the tangent it was a tau with the top of the tau extended, and for the cosine I made a kind of gamma, but it looked a little bit like the square root sign....

I thought my symbols were just as good, if not better, than the regular symbols—it doesn't make any difference *what* symbols you use—but I discovered later that it *does* make a difference. Once when I was explaining something to another kid in high school, without thinking I started to make these symbols, and he said, "What the hell are those?" I realized then that if I'm going to talk to anybody else, I'll have to use the standard symbols, so I eventually gave up my own symbols. (Feynman & Leighton, 1992, p. 24)

This example shows that the shared nature of the semiotic resources is important for successful communication. In Paper I, I draw on Wittgenstein's notion of *standing fast*<sup>43</sup> (e.g. Wittgenstein, 1979, §152 and §234) to denote those aspects that are presupposed in a discussion in order to make the discussion possible. I have taken the term standing fast to mean those parts of the discussion that are not questioned; they are, or become, taken for granted.

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<sup>43</sup> After reading Wickman and Östman's (2002) use of Wittgenstein's notion of standing fast for words that are used "without hesitation or without further questioning" (p. 608), I decided to use a similar approach in my Paper I.

## 2.8.4 Increasing the meaning potential of semiotic resources other than language: semiotic metaphor, intersemiotics and intrasemiotics

Closely related to the discussion about metaphor above, and to ways of increasing the meaning potential of language described in Section 2.7, is O'Halloran's (2005) discussion of "semiotic metaphor" in multimodal text<sup>44</sup>. Semiotic metaphor is introduced in relation to intersemiotics (that which goes on between different kinds of semiotic resources, such as translation<sup>45</sup>) and intrasemiotics (that which goes on within a single kind of semiotic resource based upon its 'grammar'). O'Halloran (2005) describes semiotic metaphor as "the potential of intersemiotic processes to produce metaphorical construals" (p. 12), whereby an "expansion of meaning" (p. 16) is produced. This claim is similar to that made by Lemke (1998), who argued that in science, meaning is "multiplied" when several semiotic systems are used together. Liu and Owyong (2011) also make a similar argument in the area of chemistry. Thus, in addition to the processes that were introduced in Section 2.7, the interrelation with other semiotic resources also increases the meaning potential of language.

From a multimodal point of view, semiotic resources other than language can also be seen to participate in the "packing" (Halliday, 2004b, p. 28) of text that contributes to making new meaning possible. For an explicit example of packing in mathematical notation, consider Einstein's introduction of what has become known as his "summation convention":

A glance at the equations of this paragraph shows that there is always a summation with respect to the indices which occur twice under a sign of summation (e.g. the index  $\nu$  in...

$$\left[ dx'_\sigma = \sum_\nu \frac{\partial x'_\sigma}{\partial x_\nu} dx_\nu \right],$$

and only with respect to indices which occur twice. It is therefore possible, without loss of clearness, to omit the sign of summation. In its place we introduce the convention:—If an index occurs twice in one term of an expression, it is always to be summed unless the contrary is expressly stated (Einstein, 1952, p. 122).

In other words, under these particular circumstances Einstein suggested that the summation sign could be omitted so that  $\sum_i a_i x_i$  could be written as

<sup>44</sup> I am using the term multimodal text here to emphasize that I refer to text that is realised by different kinds of semiotic resources and not only spoken or written language.

<sup>45</sup> Note that Kress and Van Leeuwen (2006) have suggested the term transduction for translation between different kinds of semiotic resources, and Duval (2008) has suggested the term conversion.

$a_i x_i$ . In Section 4.3.2 and Paper III, I discuss such “rationalisation” further, and give an example of how the rationalised nature of a different semiotic resource – a circuit diagram – leads to learning challenges for students.

In the following section, I will describe some of the more recent multimodality research that uses Lemke’s thematic patterns as an analytical tool.

### 2.8.5 Application of thematic patterns to multimodal science text

Tang, Tan and Yeo (2011) made use of Lemke’s thematic patterns in the analysis of a discussion between school students about the “work-energy concept.” Particularly, they were not only interested in how students used scientific terminology, but how “students construct meaning of a scientific concept through the integration of different modalities”<sup>46</sup> (p. 1778). In order to do so Tang, Tan and Yeo (2011) applied thematic patterns to analyse the multimodal text that a group of students produced. Here, the ways that different semiotic resources realised meanings was illustrated in a collage-like manner. The Tang, Tan and Yeo study concludes, in particular, that equations can provide quantitative relationships for students, whereas qualitative cause-effect relationships require further corroboration using a variety of semiotic resources. More generally, their study concludes that teachers need to explicitly point out the relationships between different semiotic resources to students.

This development of social semiotics towards the analysis of the realisation of thematic patterns through different semiotic resources was continued by Tang (2013), who positioned thematic patterns in a “multimodal instantiation hierarchy” (p. 34). This work is interesting given the aim of my research work given in Section 2.3.6: to investigate the ways that a social semiotic perspective can inform the teaching and learning of undergraduate physics. In Section 3.3.3, I illustrate my own way of building on thematic patterns to analyse meanings that are made with different semiotic resources.

In the next section I introduce a new construct – *disciplinary affordance*, which is a construct that I use when answering and discussing Research Question 2.

### 2.8.6 Disciplinary affordance

I have defined the disciplinary affordance of a given semiotic resource as “the inherent potential of that [semiotic resource] to provide access to

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<sup>46</sup> “Different modalities” here refers to different kinds of semiotic resources, see the discussion in Section 2.8.

disciplinary knowledge” (Paper I, p. 658). This construct builds in important ways upon Gibson’s (1979) notion of *affordance* that he introduced in his “ecological approach to perception.”

Gibson (1979) described affordance as a potential that is inherent in the environment regardless of its perception. In Gibson’s argument an animal would at times perceive this affordance – “to perceive an affordance means to perceive some potential environmental resource and a means of action that will lead to attainment of it” (Gibson & Pick, 2000)<sup>47</sup>. Therein lies a challenge with the way that Gibson used the term affordance – it is a relationship between an object (the environment) and a perceiving subject and, at the same time, a potential inherent in the object itself. Norman (1988) had a seemingly different interpretation of affordance. He considered only those affordances that had already been perceived by an animal (including humans) to be affordances. Eventually these seemingly conflicting views held by Norman and Gibson were resolved when Norman agreed that his view could be called “perceived affordance”, and could be seen to constitute a subset of the affordance of an object (environment), which could in fact never be exhaustively described.

Drawing on Gibson (see, for example, 1979) the field of multimodality talks about the affordance of different semiotic resources in a way that is almost identical to the way the term *meaning potential* is used in SFL (see, for example, Jewitt & Kress, 2003). For example, Bezemer and Kress (2008, p. 182) say, with regard to *moving image* that “[i]t combines the affordances of still image, spatial organization, with temporal organization: It unfolds in time.”

In Section 2.8 I mentioned the division of labour between different semiotic resources that are used in physics. I see affordance as a different way of describing this division of labour. Thus, in order to emphasize the discipline-specific affordance of a given semiotic resource, I created a new construct, *disciplinary affordance*<sup>48</sup>, which was introduced in Paper I. I will return to why and how I consider disciplinary affordance to be a useful analytic construct when I discuss the results in Section 4.2.5.

Having discussed semiotic resources and the idea that they have different disciplinary affordances, I will now go on to introduce the Variation Theory of Learning. This is a theoretical perspective I started to explore after seeing the links that could be made to my social semiotic framing.

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<sup>47</sup> Note that this quote comes from James Gibson’s wife, Eleanor Gibson.

<sup>48</sup> Anyone who finds the term affordance problematic for, in particular, its psychological connotations pointing at, for example, “direct perception,” (Gibson, 1979, p. 147) may consider thinking of it in terms of Brunswik’s “discriminanda”, “manipulanda”, and “utilitanda” properties (Tolman & Brunswik, 1935, pp. 52-53) – which, however, may carry other psychological connotations.

## 2.9 The Variation Theory of Learning

### 2.9.1 Introduction

As described in the previous section, my construct of disciplinary affordance builds on Gibson's (1979) work on affordance. There is another way in which Gibson's ideas are relevant for my thesis work, namely by suggesting that one learns to see the world in new ways by coming to "discriminate" or "differentiate" one's "perceptions of the world" (Gibson & Gibson, 1955, pp. 38, 40). Marton and Pang (2006) state:

According to differentiation theories, initially vague percepts become more and more differentiated through perceptual learning: That is, more and more differences are discerned in what is perceived. Those differences lie both within what is perceived and between what is perceived and what has been perceived earlier. From this theoretical standpoint, perceptual learning is a process of discrimination and discernment. (pp. 198-199)

Discernment is thus critically important to classroom learning. Here, to discern something means to be able to differentiate amongst the various aspects of some given phenomenon and hence be able to focus on the most relevant aspects. What does it take to discern something in a holistic and differentiated manner? The fundamental starting point for the Variation Theory of Learning is that without variation there can be no discernment and without discernment there can be no learning (Bowden & Marton, 1998; Marton, 2015; Marton & Booth, 1997; Marton & Pang, 2006; Marton & Tsui, 2004). The Variation Theory of Learning has become one of the most successful and widely used contemporary theories of learning (Marton, 2015). There is extensive literature about student learning that deals with the Variation Theory of Learning and topics range from pricing (Pong, 2000) to Cantonese opera (Lo & Marton, 2011). Many studies have been made in science education contexts, especially in the form of learning studies (see Lo, 2012, and references therein). However, most work has been carried out at school level, and examples of the few studies that have been made in higher education are given in Section 2.2.4. In what follows, I present those parts of the Variation Theory of Learning that are most relevant for my thesis.

The Variation Theory of Learning was introduced by Marton and Booth (1997) as a new perspective on learning, which characterizes learning in terms of the differentiation of awareness. As such, variation theory deals with how, in terms of awareness, "learning proceeds from a vague undifferentiated whole to a differentiated and integrated structure of ordered parts" (Marton & Booth, 1997, p. 138). Marton and Booth further propose that:

To an increasing degree we see the world in terms of patterns of a shared culture through a shared language. Our own world becomes increasingly the world of others as well, and the latter world, the world as already experienced, is a constitutive force in learning just as the individual's constitutive acts are. (Marton & Booth, 1997, p. 138)

Here, Halliday's (2004d) view that language learning contributes to shaping experience (see Section 2.5.2) can be seen to form an essential part of coming to experience the "world as already experienced" (Marton & Booth, 1997, p. 138).

In the next section I will introduce how the Variation Theory of Learning describes awareness.

## 2.9.2 Awareness according to the Variation Theory of Learning

Awareness plays a central role in the Variation Theory of Learning. Drawing on Gurwitsch (1964), Marton and Booth (1997) and Booth (1997) describe awareness as being structured in terms of degree of focus. Some aspects of the world form the "theme," which is in focal awareness, other more peripheral aspects form a "thematic field" that surrounds the theme, and those aspects that are considered irrelevant form the "margin." Teachers and students often differ with respect to the structure of their awareness and Booth (1997) points out that:

When presented with a situation, a problem, that requires that thinking to be applied, ...[the teacher] becomes rapidly aware of the important factors, the relations between them, where the difficulties might lie, and a number of ways to reach a solution. The students have, collectively, a wide but not necessarily differentiated understanding of the same field. Individually, they are aware only partially of the factors involved in the field and, when they are faced with a problem, there is not the same clarity of what is central to the problem nor the same awareness of a variety of ways of tackling it. (p. 140)

Thus, for the teacher, some immediately critical aspects of a particular object of learning that may be defined, for example, by a particular problem that has been posed, quickly become the "theme of awareness" (Booth, 1997, p. 141). More peripheral aspects, on the other hand, become the thematic field (see also Cope, 2000). Here, the thematic field is related to the theme through relevance, and will thus be subject to a shift in its content as the theme is changed (for example, when a different aspect of the problem is focused on). As indicated earlier, those aspects of the awareness characterization that are irrelevant to the theme make up the margin.

For the student, those aspects relating to a posed problem that are relevant from a disciplinary point of view might not become thematic because the overall awareness still needs to be further differentiated in terms of

discerning those aspects. A key condition for accomplishing a differentiated awareness is therefore, according to the Variation Theory of Learning, the existence of variation within those aspects that need to be noticed (for a recent example of work in this area, see Marton & Pang, 2013, and for examples from physics and engineering, see Section 2.2.4).

### 2.9.3 Variation

According to the Variation Theory of Learning, there are three interrelated and inseparable conditions that must be met in order for learning to take place (Marton & Booth, 1997; Marton & Tsui, 2004). The first of these is variation. The theory states that learning has an enhanced possibility to take place when students encounter situations where:

...some particularly critical feature of the material they are learning can be brought out of a taken-for-granted background by meeting variation around that feature ... opening dimensions of variation. (Booth & Hultén, 2003, p. 70).

The variation around a particular critical feature opens up a critical aspect (a “dimension of variation,” Marton & Booth, 1997, p. 186). Lo (2012) describes the difference between a critical feature and a critical aspect as:

the latter refers to a dimension of variation and the former is a special value on that dimension of variation. (p. 61)

Variation is a necessary condition for making an aspect noticeable, and thereby for enhancing the possibilities for learning (see Marton, 2015). For an everyday example, consider the two bolts in Figure 2.7. In order for someone to come to understand what “pitch” is in the context of bolts it is necessary to experience the kind of variation that exists between those two bolts. (Of course, showing an image is not the only way that this variation can be brought about.)



Figure 2.7. Two similar bolts with a difference in pitch (from paper V).

The important thing is that there is variation to be experienced. In this respect Marton and Booth (1997, p. 100) distinguish between “implicit” and “explicit” variation. Implicit variation is when an aspect that *could* have been varied in a given situation was *not* actually varied. For example, a single instance of a bolt presents implicit variation since a range of aspects could potentially vary. However, two simultaneous instances of bolts (or two instances of bolts experienced in sequence) have the potential to make that variation explicit. For example, if one bolt that has a short distance “between two adjacent thread roots or crests” (Bickford, 2008, p. 479) is contrasted with one that has a long distance, there is an explicit variation in the aspect of pitch. No claims can however be made about a persons’ actual discernment of a given aspect of bolts on the basis of this explicit variation. But it is the variation of this aspect that makes discernment possible. In other words, explicit variation of a certain aspect suggests a higher degree of probability that the aspect will be discerned.

#### 2.9.4 Discernment

In order for learning to take place, variation must be experienced so that critical aspects can be discerned. Discernment is therefore the second of the three necessary parts in the characterization of learning provided by the variation theory. Discernment refers to the experience of a particular feature, aspect, part or whole. However, Marton and Booth (1997, p. 89) point out that “to experience something is not only to pick it out of its context, but also to relate it to its context, and even to other contexts as well at the same time.” Thus, a particular aspect of an object of learning needs to be discerned against the background of, and in relation to, other aspects of the object of learning. And the object of learning as a whole also needs to be discerned in a given context. In order to articulate how learning is made possible through the experience of variation, simultaneity is the third critical part.



## 2.9.5 Simultaneity

Simultaneity is the third interrelated condition that makes learning possible through the experience of variation. Simultaneity here refers to:

1) The simultaneous *presence* of contrasting options – in other words, variation. Here, different instances that differ in an aspect that should be noticed, but that are otherwise the same, are juxtaposed synchronically (at the same time).

2) The simultaneous *experience* of contrasting options, so that the dimension of variation at hand is discerned. Here it is possible to draw on previous experience in a “diachronic” fashion, whereby “[e]xperiencing variation... is contingent on the simultaneous awareness of instances that appear at different points in time” (Marton et al., 2004, p. 18).

3) The simultaneous experience of several aspects of a whole, and/or a whole in a context. An important aspect of the Variation Theory of Learning that is related to simultaneity is that, although simultaneity is a necessary condition for learning, too much variation is also detrimental for learning. Thus, variation theory argues that in cases where several different aspects need to be noticed and related to each other, each aspect needs to be varied and experienced individually before different aspects can be varied simultaneously in order to get related to each other as parts of a larger whole (Lo, 2012; Marton & Pang, 2013).

A systematic way in which variation is created in order to make possible the experience of different aspects and how they are related to each other is referred to as a “pattern of variation” (Pang & Marton, 2013, p. 1067). The Variation Theory of Learning identifies four different patterns of variation (Marton & Tsui, 2004). These are introduced in the next section.

## 2.9.6 Four patterns of variation: Contrast, Separation, Generalization, and Fusion

Marton and Tsui (2004, pp. 16-17) consider four different patterns of variation that are useful in order to make classroom learning possible. These patterns are 1) contrast, 2) separation, 3) generalization, and 4) fusion.

The first pattern of variation, contrast, is the variation that was illustrated by the bolts in Figure 2.7. It is the contrast in a particular aspect of a learning objective that makes it possible to discern that aspect.

The second pattern of variation, separation, is about separating one aspect of a learning objective from another. Thus, varying the bolt’s length while keeping all other aspects constant will bring out this aspect while varying the bolts width while keeping all other aspects constant will bring out that aspect. Having only one aspect that varies while keeping all other aspects constant has the potential to separate the aspect that varies from other aspects of the whole.

The third pattern of variation, generalization, involves discerning the applicability of a particular aspect in new situations. For example, discerning that length applies to bolts, boats, and (metaphorically) to time. For an undergraduate physics example, consider the generalisation of vector addition to a new situation such as when learning, for example, about the propagation of a pulse in a string. Here, the net force on a part of a string is the sum of the tension forces acting on that part of the string. The discernment of the applicability of vector addition in a new situation such as this is an instance of generalization.

The fourth pattern of variation is fusion. Here, the initial differentiation of awareness through the experience of variation around critical aspects is followed by a “restructuring of awareness” (Booth, 1997, p. 147), where the different aspects are related to each other in such a way that they form a new whole. This “fusion” (Marton & Tsui, 2004, pp. 16-17) is an outcome of the experience of several aspects simultaneously. For example, consider the “plane electric wave” depicted in Figure 2.8. For a given value of the  $y$ -coordinate, the electric field is specified by the curve. Thus, a disciplinary way of knowing involves discerning that the electric field remains invariant irrespective of the values of the  $x$ - and  $z$ -coordinates. Research has shown that it is often difficult for students to obtain such discernment. (Ambrose, 1999; Ambrose et al., 1999; Podolefsky & Finkelstein, 2007b). Coming to experience the image in Figure 2.8 in a disciplinary way can therefore be seen as an example of *fusion*, where the different aspects of the illustrated situation are experienced holistically.

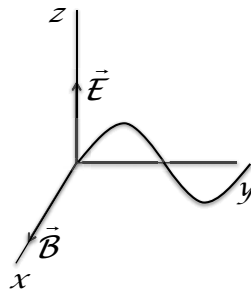


Figure 2.8. A plane electric wave.

### 2.9.7 The object of learning

In the Variation Theory of Learning, a well-defined area within a field of subject matter that makes up the content for some unit of teaching and learning is called an “object of learning.” An object of learning is different from a “learning target” (Marton, 2015, p. 24) in that it provides a more

detailed picture of what needs to be learned in order to meet the learning goal:

Assuming that there are necessary conditions of learning that can be defined in terms of patterns of variation and invariance, we can in every single case determine what varies and what is invariant, and hence also state what can be learned and what cannot, if the object of learning is novel to the students. (Marton, 2015, p. 176)

The object of learning can in turn be divided into three parts (Marton & Tsui, 2004): (1) an intended object of learning; (2) an enacted object of learning; and, (3) a lived object of learning.

- 1) The intended object of learning is that which the teacher expects the students to learn within some unit of teaching and learning.
- 2) The enacted object of learning is the whole of the different ways that the intended object of learning is actually materialized in a given unit of teaching and learning – something to which both the teacher and the students make contributions.
- 3) The lived object of learning is each student's experience of the object of learning. This can, according to variation theory, be investigated through, for example, interviews.

An object of learning can also be divided into its constituent parts. For example, in the context of student group work around a given object of learning, Ingeman, Berge, and Booth (2009) propose that an object of learning can be described as consisting of partial objects of learning. They use Newtonian mechanics to illustrate how students themselves partition an object of learning: in order to “focus on ‘smaller’ learning objects ... certain themes were pursued for a period of time in the conversation until there was a clear shift” (p. 352). Using a social semiotic perspective, Tang (2013) takes a similar approach arguing that a given field in physics is constituted by a number of thematic patterns.

### 2.9.8 The space of learning

The Variation Theory of Learning provides a way to talk about the possibilities for learning that are created in a given instance of teaching and learning: “the space of learning” (Marton et al., 2004). “Creating a space means opening up a dimension of variation (as compared to the taken-for-granted nature of the absence of variation)” (Marton et al., 2004, p. 21). This essentially means that the enacted object of learning *is* the space of learning (see Marton et al., 2004). In other words, the different ways that teachers and students enact the object of learning in a given learning situation determines what learning can possibly take place.

Marton, Runesson and Tsui (2004) also point out the importance for teaching of ensuring a “shared space of learning” in terms of a “common ground”:

...what the teacher presents as ground should be shared common ground between himself and the students, so that what he presents as figure can be made sense of by the students in relation to the ground. (p. 32)

That a common ground is often not established between the teacher and the students in undergraduate physics education can be seen in the PER work on representations referred to in Section 2.2.2, which says that teachers often underestimate the challenges students experience when working with different semiotic resources in physics. The use of interactive engagement methods in physics teaching can be a step towards minimizing this problem, by making “communication in the classroom ... bi- or multi-directional” (Marton, 2015, p. 236) between teachers and students.

## 2.9.9 The role of the teacher according to Variation Theory

Pang and Marton (2013, p. 1080) point out that “powerful teaching must take as its point of departure that which students need to learn.” One consequence of this is that the teacher needs to find out what the educationally critical aspects of the object of learning are (Lo, 2012). However, even for experienced teachers this is not always straightforward:

...although we may have already discerned these critical features and grasped the relationships among them as a whole, resulting in a state of ‘fusion’ in which the features and the whole are experienced as an undivided entity, we may not be able to identify certain individual critical features unless our natural attitude is suspended and we attempt to analyse the object of learning carefully (Lo, 2012, p. 66)

Wood (2013, p. 58) similarly points out that “[i]dentifying an object of learning, its critical aspects and appropriate dimensions of variation, is not a simple process.”

A second responsibility of teachers is, according to Booth and Hultén (2003), to create situations in which variation around the critical aspects can be experienced, and whereby learning can be made possible. For example, in a physics context, Ingeman, Linder, and Marshall (2009) investigated the dimensions of variation that a group of students dealt with while working with a computer simulation of the Bohr model. The dimensions of variation that they identified were: finite vs. infinite number of energy levels; difference between orbit radii; difference between energy levels; and, wavelength of spectral lines. The variation within and across these

dimensions of variation had been built into the simulation, and could therefore be experienced by the students.

In Section 4.4 (and Paper IV) I draw on the social semiotic perspective I constituted for this thesis to propose an analysis to support the identification of critical aspects of an object of learning. In Section 4.5 (and Paper V) a thought experiment is undertaken that builds on the Variation Theory of Learning and the insights from my analysis of the student discussion in Paper I. This thought experiment introduces three factors that systematically help to create variation within critical aspects. Finally, in Section 4.6 (and Paper VI) I attempt to operationalize these ideas in a problem solving setting.

In this chapter I have presented an overview of my conceptual framework and in the following chapter I describe how I collected and analysed the data needed in order to answer my research questions.

## 3 Methods

### 3.1 Introduction

In this chapter I describe the methods for data collection and analysis that I used for my thesis work. The chapter ends with a section on how credibility, transferability, dependability, confirmability and a potential limitation of the work were dealt with in the thesis.

The sections dealing with the data collection and methods of analysis relate to the four different datasets that I collected to answer Research Questions 1-4, and 6, as presented in Section 1.4 (see also, Table 3.1). Research Question 5 has no specifically related dataset as it is what I term a ‘thought experiment’ and is discussed in Section 3.6.

Datasets 1, 2 and 4 consist of audio and video data of student action in different interactive engagement physics settings, with the fourth dataset also containing field notes. The third dataset consists of a well-known physics text by Feynman, Leighton and Sands (1963). Thus, four separate datasets are analysed. These datasets deal with three separate areas of physics, namely refraction, electrical circuits (laboratory work with RC-circuits), electric potential and electric potential energy. These were chosen because they are widely recognised as presenting significant learning challenges to students at the introductory university level (for refraction see, for example, Kryjevskaja et al. 2012; for electric circuits see, for example, Stetzer et al., 2013; for electric potential and electric potential energy see, for example, Planinic, 2006).

There are two datasets that deal with refraction: the first dataset, which consists of a discussion between students who were given a task to explain why the refraction of light takes place; and, the third dataset, which is made up of a text extract taken from a highly regarded physics textbook: the Feynman’s Lectures on Physics (Feynman et al., 1963).

The second physics content area is laboratory work with electric RC-circuits. Here, the setting was a laboratory exercise where a group of three students were engaging to experimentally study the charging and discharging of a capacitor using an oscilloscope (see the laboratory instruction in Paper III).

The third physics content area chosen was electric potential and electric potential energy. The teachers in the electromagnetism courses that I studied were using interactive engagement teaching methods and were very positive

to my being present in the classroom, thus making it an ideal setting for my data collection. The data from the electromagnetism courses was collected in two similar interactive engagement problem solving settings, which gave me the possibility to collect authentic data where students used a range of semiotic resources in their interactive engagement.

The relationship between the different physics areas, research questions, datasets and published papers that make up this thesis are indicated in the table below.

*Table 3.1.* The relationships between the different physics education areas examined, research questions, datasets and papers that make up this thesis. (This table is a repeat of Table 1.1 in Chapter 1.)

Physics education area	Research Question	Dataset	Paper
Refraction	1-2	1	I, II
Electric circuits	3	2	III
Refraction	4	3	IV
	5	—	V
Electric potential and electric potential energy	6	4	VI

In the following sections I present the methods for data collection and analysis of the four different datasets in these three areas of physics content and a description of the methods used for answering Research Question 5.

## 3.2 Data collection

The data that I collected for this thesis mainly consists of audio and video data, supplemented by still images and printed teaching materials. I was present during all stages of data collection. Besides being an important source of data, the field notes that I took also assisted greatly with data analysis.

The equipment used to collect the data varied in terms of which video cameras and sound collecting devices were deemed most appropriate for the different research settings. For example, sometimes video cameras were positioned on tripods, but at other times they were hand-held. With respect to the positioning of video cameras, I took note of Goodwin's (1994, p. 607) comment on their use:

...I require as data records that preserve not only sequences of talk but also body movements of the participants and the phenomena to which they are attending as they use relevant representations. I use videotapes as my primary source of data, recognizing that, like transcription, any camera position constitutes a theory about what is relevant within a scene—one that will have

enormous consequences for what can be seen in it later—and what forms of subsequent analysis are possible. A tremendous advantage of recorded data is that they permit repeated, detailed examination of actual sequences of talk and embodied work practices in the settings where practitioners actually perform these activities. Moreover, others can look at—and possibly challenge—my understanding of the events being examined.” (Goodwin, 1994, p. 607)

As did Goodwin, I had to make decisions about what to focus on and what to ignore both before and during data collection - capturing an overview of a situation might mean having to leave out detail and vice versa. When more than one group of students were involved, then more than one video camera was used. Depending on the setting either the camera microphone or iPads, which produced high quality recordings and could be positioned at the students’ desks, were used to record the audio data.

### 3.3 Method for the first dataset (Research Questions 1-2, Papers I and II)

#### 3.3.1 Data collection

In order to start exploring how a social semiotic perspective can inform the teaching and learning of undergraduate physics, I set up a data collection scenario where three highly regarded third-year university physics students were asked to provide a physics explanation of why the refraction of light takes place. All three students volunteered to participate in my research<sup>49</sup>.

The task initially given was as follows (translated from the original Swedish version):

One day one of your friends, who had not studied physics since high school, comes with you to the physics laboratory. She asks a question that she has been thinking about. When she was standing on a jetty trying to use a stick to pick up a ring from the bottom of the lake, she discovered that she could not point [the stick] straight towards the place where the ring was seen to be lying, if she wanted to connect with it. How would you, from a physics perspective, help her to get a reasonably holistic understanding of the physics in the situation? Discuss.

This task was then repeated a second time with ‘the friend’ changed to another physics student asking for help in order to get a good understanding

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<sup>49</sup> The students signed an ethical consent form – “participation agreement” (Rundgren, 2008) – in which they granted me permission to use the video data in my research so long as their anonymity was guaranteed. A copy of the consent form is provided in Appendix B.



of the physics involved. The discussion was allowed to develop and eventually led into a discussion of *why* the refraction of light takes place.

The research setting was a student physics laboratory where the students had access to different kinds of equipment and a blackboard and chalk. In a very limited way I, in my role as researcher, also participated from time to time in the students' deliberations, but only for non-intrusive clarification purposes. In total the time that the students spent on this discussion was 45 minutes.

The students' discussion was video recorded and later analysed. A single video camera with a built-in microphone was used to make the recording. The video camera was fixed to a tripod behind a desk, as shown in Figure 3.1. It was positioned in such a way as to be as unobtrusive as possible; at no stage of the recording did the students either look at the camera or remark on its presence.

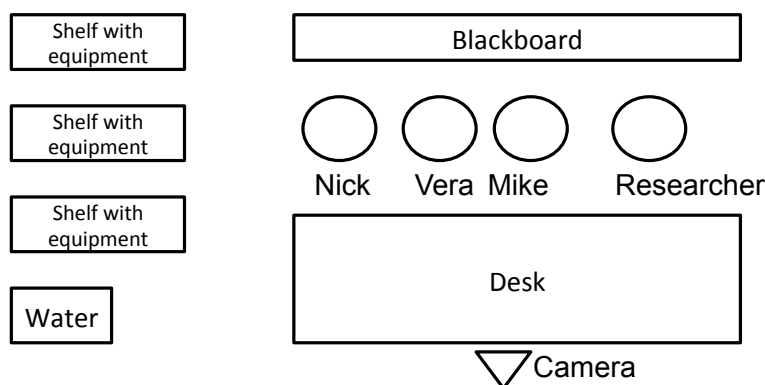


Figure 3.1. The physical organisation of the laboratory where the first data set was collected.

### 3.3.2 Transcription

The first step in my engagement with the data was the verbatim transcription of all the spoken text during the student discussion into an Excel™ spreadsheet. This transcript is presented in Swedish in Appendix A<sup>50</sup>. In this initial period of engagement with the data a number of sequences of the video data that appeared to have particular significance for the task were identified. One sequence appeared to be particularly important for the agreement reached amongst the students that they had produced a satisfactory explanation for the phenomenon of refraction. This sequence was subsequently chosen for deeper analysis, which included a verbatim transcription and analysis of *all* semiotic resources employed by the students

<sup>50</sup> This excludes the preamble presentation of the tasks to the students.

– spoken and written language, mathematical notation, images, gestures and the like (see Section 2.3.2). In other words, a complete multimodal transcript derived from Baldry & Thibault (2006); Bezemer & Mavers (2011), and Jewitt (2006) was produced. Selected extracts of this transcript are presented in Section 4.2.1, where the sequences used are translated from the original Swedish transcripts. The multimodal transcription of these sequences allowed the actions performed by the participating students with semiotic resources other than language, such as drawings or gestures, to be described carefully in the same spread sheet alongside that of the spoken text. Here, gestures were described in detail in written language rather than reproduced as still images. The drawings that the students produced on the blackboard were also carefully reproduced (see, for example, Figure 3.2).

An analysis was later made using the multimodal transcription in tandem with the video footage so that the roles of the different semiotic resources could be fully appreciated. The analysis was conducted iteratively, comparing each step in the analytical process with the video data itself, until a refined analysis was reached.

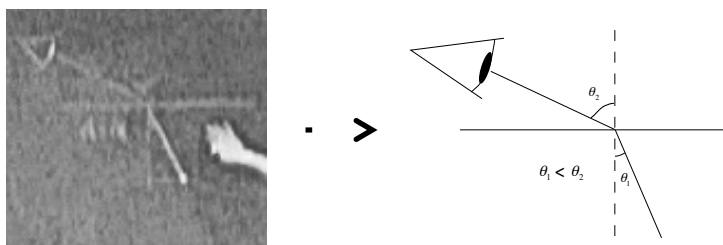


Figure 3.2. An illustration of the reproduction of the students' drawings.

### 3.3.3 Synoptic analysis

I will now describe how I undertook my synoptic analysis of the first dataset (see Section 2.5.1). This includes my formulation, development and use of patterns of disciplinary-relevant aspects as a research tool, in relation to the theoretical background presented in Chapter 2.

A traditional thematic pattern displays the analysis of spoken or written language in a diagrammatic form (see Section 2.6). Tang and colleagues extended thematic patterns to enable their multimodal analysis of student work in a physics setting (see Tang, 2011; Tang et al., 2011). Building on the general thrust of their work, I created a synoptic, time independent, description of the multimodal transcript, which I characterise as a “multimodal pattern”, as shown in Figure 3.3.

In the blue boxes towards the top of the multimodal pattern in Figure 3.3, the terms *Part* and *Hits* can be found. The relationship between these two words in this original transitive model analysis was thus *Actor/Process*, shown in the brown shaded box in the figure. The crossed out *Faster* (blue box on the right hand side of the figure) remains in the pattern in order to draw attention to the fact that this was one of the paradigmatic choices available to the students and indeed was the first choice of one of them during the discussion. However, the word *Faster* could not be incorporated “conceptually” into the coherent, logical explanation for the phenomenon of refraction that the students were seeking. Consequently, it was quickly substituted by *Slower* by another student (see the transcript in Table 4.3 in Section 4.2.1). In other words, my multimodal pattern was not intertextual in Lemke’s (1983) sense of the term (see Section 2.6).

This first analysis also considered the meanings being made with semiotic resources other than spoken language. This included action (such as gestures), mathematical notation and images. The multimodal pattern in Figure 3.3 shows these different kinds of semiotic resources – each identified by a different colour.

The constitution of the pattern then underwent an iterative process that included a reordering of the items that were chronologically presented in the discussion, whilst still retaining their original functional meanings and relationships. In this way an increasingly focussed diagrammatic description of the discussion emerged in my analysis.

During the iteration process, the references to whether speech, gestures or different kinds of actions had been used were phased out from my pattern formulations. Thus, what remained was a characterisation of the content that had been realised in the student discussion. The information about the type of semiotic resource that realised different content ended up being juxtaposed with the identified pattern in written text. The patterns were organised in such a way that finally three different disciplinary-relevant aspects emerged in the form of contrasting pairs. I decided to characterize this analytical approach in terms of *patterns of disciplinary-relevant aspects*. These are presented in the results chapter in Figures 4.6-4.8.

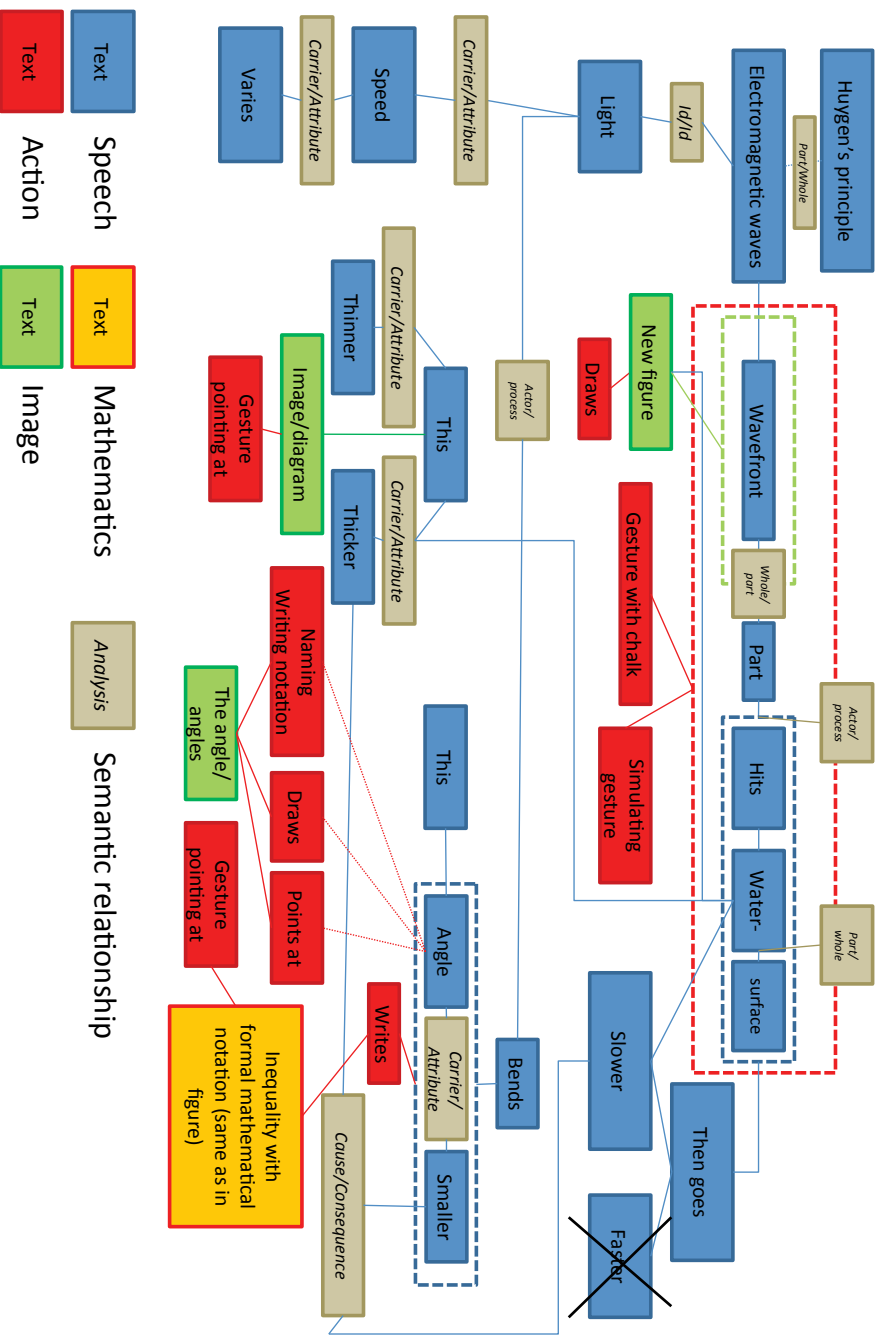


Figure 3.3. My multimodal pattern (Fredlund & Linder, 2010b), which was the first step towards the formulation of a pattern of disciplinary-relevant aspects. Different colours show different semiotic resources. Refer to the key at the bottom for how the different kinds of semiotic resources are encoded.

### 3.3.4 Dynamic analysis

Whilst the patterns of disciplinary-relevant aspects produced a synoptic analysis, a dynamic analysis (see Section 2.5.1) of the student discussion was also done as it examines meaning-making as it develops with time. The dynamic analysis provides the possibility at each point in time to look back at what went before and to identify what contextualised each new action or utterance.

For the dynamic analysis of the student discussion I drew on the work of Bloom and Volk (2007) – in particular what they call a “metapattern analysis of complexity in students’ argument” (p. 56). My focus in the dynamic analysis was the chronological development of the students’ discussion. At the same time, I was looking for the different meanings that emerged in the discussion. These have been included in Figure 4.4 where the different meanings are used as labels. The analysis also shows which kind of semiotic resource was used to realise a given disciplinary-relevant aspect. In this way I used my adaptation of Bloom and Volk’s “metapatterns” to show where in the students’ discussion the new meanings emerged, and through the use of what semiotic resources this emergence took place. The results of the analysis using this method are given in Section 4.2.2.

## 3.4 Method for the second dataset (Research Question 3, Paper III)

### 3.4.1 Data collection

My second set of data was collected in the electronics laboratory where a group of students (different from the first data set) from an introductory electromagnetism course were working on connecting an circuit (a resistor and a capacitor connected in series) together with a signal generator and an oscilloscope according to a given circuit diagram (see Figure 3.4). The students worked on the problem for approximately one hour. The purpose of the exercise was twofold: (1) to illustrate on an oscilloscope the form of the capacitor charge and discharge as a function of time; and, (2) to use this illustration to measure the charging and discharging characteristics of capacitors with different capacitance for different values of the resistance. The laboratory instruction can be seen in full in the Appendix of Paper III.

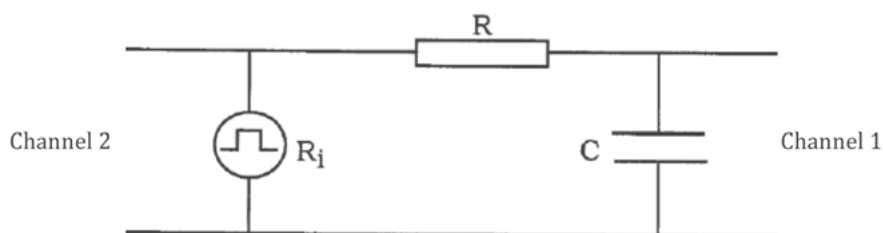


Figure 3.4. The circuit diagram (from Paper III).

Video data and still footage was collected with a handheld camera, and audio data was collected both with the video camera and an iPad that was positioned on the laboratory bench. The iPad was positioned in such a way so as to ensure that I would be able to obtain the best audio quality at all times. Data was collected over a period of approximately one hour, and efforts were made to collect the data as unobtrusively as possible while still being able to gather sufficient analytic detail. The physical organisation of the laboratory where the second dataset was collected can be seen in Figure 3.5.

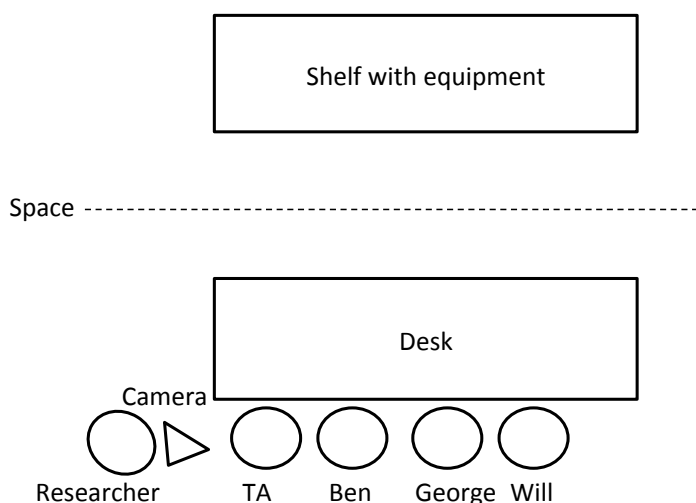


Figure 3.5. The physical organisation of the electronics laboratory where the second data set was collected.

### 3.4.2 Transcription

The first step in my engagement with this data was to go through the video data looking for sequences that appeared to be particularly interesting for answering Research Question 3. A laboratory Teaching Assistant's (TA's) intervention in the students' attempts to make meaning of the circuit diagram

that they had been given was one such instance. Thereafter I went on to consider the students' engagement with the circuit diagram prior to them having to ask the TA for assistance.

The next step in my engagement with the data was the verbatim transcription of the selected audio recordings. The audio quality varied dependent on the relative positioning of the iPad and video camera. On occasion, the video camera provided a clearer recording, seeing as it was moving around, and was thus sometimes closer than the iPad to the person speaking.

### 3.4.3 Analytic method

The video data was analysed in a chronological manner by carefully reconstructing in the laboratory the different ways that the students connected the oscilloscope and the signal generator into their circuit. Comparisons were made with the video data to make sure that the oscilloscope outputs obtained accurately matched those obtained by the students - the photographs presented in Section 4.3.1 were taken from the reconstructed connections. The transcripts and the video data (including any pointing gestures that were captured in the video – see, for example, Figure 4.13), and the matched reconstructions were brought together to ensure as clear an understanding of the sequence of events as possible. The approach was similar to that used by other researchers in PER (see, for example, Heath, Hindmarch, & Luff, 2010; Lindwall & Lymer, 2008; Rehn, Moore, Podolefsky, & Finkelstein, 2013; Scherr, 2008; Tang, Delgado, & Birr Moje, 2014).

Different ways to present the relationships between the students' connections and the circuit diagram were tested. For instance, the insertion of red and black coloured dots into the circuit diagram in Figure 3.4 was found to be the best way to capture the connections of the red and black coloured connectors that the students used; resulting in, for example, Figure 4.11.

## 3.5 Method for the third dataset (Research Question 4, Paper IV)

### 3.5.1 Data collection

The third set of data is an extract from a canonical physics text taken from Feynman, Leighton and Sands' (first printed in 1963) explanation of refraction. This consists of the following semiotic resources: written text, mathematical equations, and a wavefront diagram. While this is not the most

common explanation of this phenomenon given in undergraduate physics textbooks (see, for example, Hüttenbräuer, 2010; and for alternative explanations see Mahoney, 1994; Young & Freedman, 2004, pp. 1272-1273), their explanations are widely considered to be exemplary in physics education. For example, Kryjevskaja, Stetzer, and Heron (2012) used a similar explanation in a contemporary discussion about student understanding of wave behaviour at a boundary in terms of wavelength, frequency, and propagation-speed relationships. The analysed extract is presented in Section 4.4 and consists of written language, mathematics and an image.

### 3.5.2 Analytic method

The third dataset was analysed by systematically interrogating the different semiotic resources in order to identify instances where disciplinary-relevant aspects were explicitly varied, and by attempting to foreground instances of implicit variation. This was done by analytically separating the written text, the mathematical equations and the wavefront diagram and then looking at the intersemiotic relations (see Section 2.8.4) and what the different semiotic resources analytically convey both individually and jointly. The disciplinary-relevant aspects thus identified constitute the analysis outcome.

## 3.6 Method for Research Question 5 (Paper V)

The method for answering Research Question 5 builds on undertaking a “thought experiment”. The constitution of the thought experiment is based on: (1) my own extensive experience of teaching and learning physics; (2) the three parts of my conceptual framework – PER, social semiotics, and the Variation Theory of Learning; and, (3) the analyses of the three first datasets and the answers to Research Questions 1 - 4. In this way the social semiotic perspective constituted for this thesis in relation to the Variation Theory of Learning underpins the method for this research question. As such, the answer to this research question makes up part of my discussion about the potential implications for teaching and learning that stem from my research (see Section 4.5.2).



## 3.7 Method for the fourth dataset (Research Question 6, Paper VI)

### 3.7.1 Data collection

The research context for the fourth dataset is students from an introductory electromagnetism course attending an interactive engagement tutorial. In this tutorial the students were asked to solve a problem that required them to make a distinction between electric potential and electric potential energy. The dataset consisted of two groups of students, a year apart, engaging with the given problem:

A metal sphere with radius 2,0 cm has an electric charge 1,0 nC. An electron is released from a point 1,0 cm from the surface of the sphere. What is the velocity of the electron as it hits the sphere?<sup>51</sup>

The students involved in the first year study are referred to as the first year data-group and the students in the second year study, as the second year data-group. The educational difference between these two data-groups is that the second group had their introduction to the problem start with an “intervention.” This “intervention” (see Section 4.6) was built on the outcome of Research Question 5, which specified three essential factors that physics teachers need to incorporate into their teaching practice to optimize learning outcomes. These are:

- the identification of the disciplinary-relevant aspects for a given object of learning;
- the selection of appropriate semiotic resources to help students discern disciplinary-relevant aspects and to relate them to each other in meaningful ways; and,
- the creation of variation around each disciplinary-relevant aspect against an unchanging background.

The first year data-group had six groups of three to four students (N=20) and the second year data-group three similar groups (N=12). Each dataset spanned 45 minutes of tutorial time. For the first year data-group, field notes were taken and both audio and video data were collected. For the second year, only field notes were taken. The physical organisation of the tutorial was the same for both years. Figure 3.6 gives the organization for the first data-group by virtue of including the pseudonyms used in the analysis transcript.

Building on this background, the analytic method used for answering Research Question 6 involved four stages.

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<sup>51</sup> Note: In Sweden, when writing numbers a comma is used instead of a decimal point.

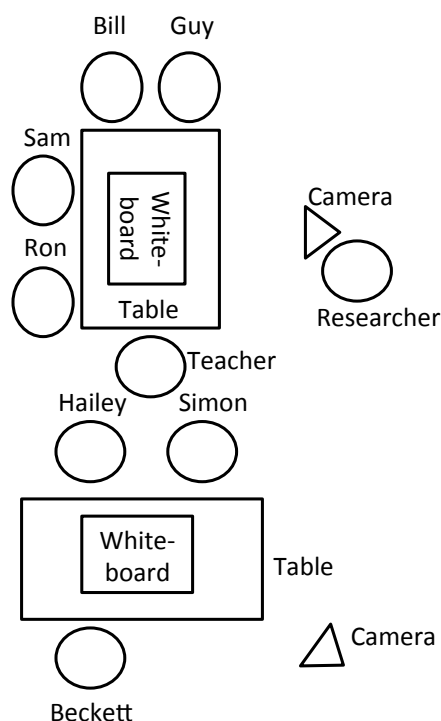


Figure 3.6. The physical organisation of the classroom where the fourth dataset was collected. Pseudonyms are used. They are included for the data discussion in the Results Section 4.6.

### 3.7.2 Analytic method

#### *The first stage*

The first stage involved transcribing the audio data from the first year data-groups' work on the problem, and analysing the transcript alongside the actual video recordings of the students' actions.

These transcripts were needed to ascertain the nature of the learning challenges that students face when needing to draw distinctions between the concepts of electric potential and electric potential energy, and to use this analysis to frame the identification of the associated disciplinary-relevant aspects.

The analytic method included a continual cross-referencing to other semiotic resources that the students employed, such as pointing and gesturing around the images and equations that were captured by the video.

#### *The second stage*

The analyses done for the first stage were used to produce a multimodal pattern that, via the method used for Research Question 1 (see Section 3.3),

led to the identification of the disciplinary-relevant aspects (the first factor needed).

#### *The third stage*

This stage involved looking for an optimal set of semiotic resources to help students discern the disciplinary-relevant aspects and relate them to each other in meaningful ways (the second factor needed).

#### *The third stage*

This final stage was a design stage. It involved looking for ways to create patterns of variation around the disciplinary-relevant aspects set against an unchanging background (the third factor needed).

#### *The fourth stage*

The fourth stage involved making a comparison between the first year data-group and the second year data-group students (the group that had the “intervention”). The comparison was made in terms of the amount of help the student groups from the different years needed in order to distinguish between electric potential and electric potential energy in their solving of the given problem.

### 3.8 Establishing quality

The methods that I describe earlier in this chapter are of a qualitative nature. Thus, I sought to establish what Gee, (2005), in his discussion of quality in qualitative research refers to as “validity.” Gee describes validity as when “some aspects of convergence, agreement, coverage, and linguistic details” are met (p. 114). Here, “convergence” means that different aspects of the text production in the situation that was analysed point in the same direction. “Agreement” means that the more people who support the analysis (especially those who are insiders to the disciplinary discourse), the more valid it can be considered. “Coverage” is how appropriate the analysis is for describing other instances of similar situations. As for the “linguistic details”, Gee (2005) argues that the analysis is more valid if the functions of the grammar of the language have been paid due attention. From here, I propose that the inclusion of a focus on the different semiotic resources employed by the participants in the studies in this thesis further adds to its validity. The agreement aspect is to some extent provided by the co-authors of the published papers and the peer review process accrediting my analysis. It is also important to note that the authors of the published papers, including myself, have experience of being both students and teachers of physics. The coverage aspect is considered by the recognition that the re-formulations of the detailed explanation given by the participating students did not affect the patterns found in the analyses, “but rather served to confirm and cement the

relationships between the physics concepts that had already been fruitfully established” (see Paper I, p. 663). The linguistic details in parts of the analyses of the student discussion in the thesis can thus also be seen to contribute to the quality of the analysis.

Regarding generalizability, I have sought to provide sufficiently detailed descriptions (compare with what Geertz, 1973, calls a “thick description”) to allow a reader to understand the problem and follow how the data and the analyses have been dealt with. This detail, then, provides the basis for “naturalistic generalization” (Stake & Trumbull, 1982) to take place. In other words, the detail that I have provided should be sufficient for a reader to discern parallels to their own similar situation(s) in a “vicarious experience” (Lincoln & Guba, 1985, p. 359) to generalise the results for their circumstances.

### 3.8.1 Potential limitation

The participation of the researcher in the situation where the data is collected is common in qualitative research (Kvale & Brinkmann, 2009; Robson, 2002). As I pointed out in Section 3.2, I feel that this was in fact a major strength of my research design. However, I was also very aware of my presence possibly being a potential limitation when I collected the data. I thus made a special effort to behave like a “physics test charge” (which carries the notion in physics that the charge is so small that placing it at a point in a electric field has a negligible affect on the field around it), in other words, to limit the effect of my participation.

In the next chapter I present and discuss the results of my analyses and the answers to my research questions.

## 4 Results and discussion

### 4.1 Introduction

This chapter is divided into five further sections. In each section I present the relevant research questions and show how the methods of analysis described in Chapter 3 are used before I answer the research questions. Discussions and implications are included. As mentioned in Section 1.4, the detail given has either been completely or partially reported in the Papers that form part of this thesis. This means that at times parts of these papers have been extracted and/or modified without further reference.

The table below is a repeat of Tables 1.1 and 3.1, given here to help make the links between the different parts of the thesis and the results and discussion in this Chapter.

*Table 4.* The relationships between the different physics education areas examined, research questions, datasets and papers that make up this thesis.

Physics education area	Research Question	Dataset	Paper
Refraction	1-2	1	I, II
Electric circuits	3	2	III
Refraction	4	3	IV
	5	—	V
Electric potential and electric potential energy	6	4	VI

### 4.2 Research Questions 1 and 2 (Papers I and II)

Research Questions 1 and 2 are presented together in this section because they are both answered using analyses of the first dataset, which was collected from a scenario where three highly regarded third-year university physics students were asked to provide a physics explanation of why the refraction of light takes place (see Section 3.3).

*RQ 1. In what ways can thematic patterns be developed as an analytical tool in order to analyse meaning-making in introductory undergraduate physics?*

*RQ 2. A distinction is made in the literature between semiotic resources that “disappear” almost immediately after they have been produced, such as spoken language and gestures, and those which do not, such as written language and images. With respect to these non-persistent and persistent semiotic resources:*

*During interactive engagement dealing with the refraction of light, what roles do these non-persistent and persistent semiotic resources play in terms of the following facets:*

- *what are these roles and how can they be characterised;*
- *which persistent semiotic resources are used by a group of students when engaging interactively in explaining the refraction of light;*
- *what differences in disciplinary affordances of the persistent semiotic resources used by the students can be observed in such an explanation;*
- *what aspects of persistent semiotic resources can account for disciplinary affordance differences in an explanation of the refraction of light;*
- *to what extent can the different persistent semiotic resources that the students used be seen to present the disciplinary-relevant aspects that learners would need to be aware of in order to explain why the refraction of light takes place in a disciplinary manner?*
- *how do students select a persistent semiotic resource around which to interactively engage; and,*
- *how can the answers to the above facets be related to “Vision I” scientific literacy (Roberts, 2007a, 2007b)?*

Throughout their discussions the students used a range of semiotic resources to make meaning about why the refraction of light takes place. These included a bottle brush, and a glass tank of water that the students used to illustrate the way they saw refraction being manifested in terms of the apparent bending of a partially immersed straight object (see Figure 4.1).



*Figure 4.1.* The bottle brush that the students immersed partially in the tank of water to illustrate the manifestation of the refraction of light (from Paper I).

The students also attempted to use a laser pointer, adding milk to the water in order to make the light from the laser visible. However, the students did not have enough milk for this to work. At a later stage one of the participating students drew wheels that roll from one surface condition to another on the blackboard (see the transcript in Swedish in Appendix A), which is a common explanatory analogy for the refraction of light (see Section 2.2.6). In the particular extract of the video data that I have chosen for further analysis a sudden insight appears to take place. In the next section I present this illustrative extract from the student discussion in a form of multimodal transcript (see Tables 4.1-4.3). (The Figures 4.2, 4.3, 4.6-4.8, and parts of the transcript in Tables 4.1-4.3 appear in Paper I.)

#### 4.2.1 Multimodal transcript

In the first part of this extract the three students, who I have given the pseudonyms Vera, Mike and Nick, are looking at a ray diagram (a persistent semiotic resource) that Mike has just finished drawing on the blackboard (see Figure 4.2).

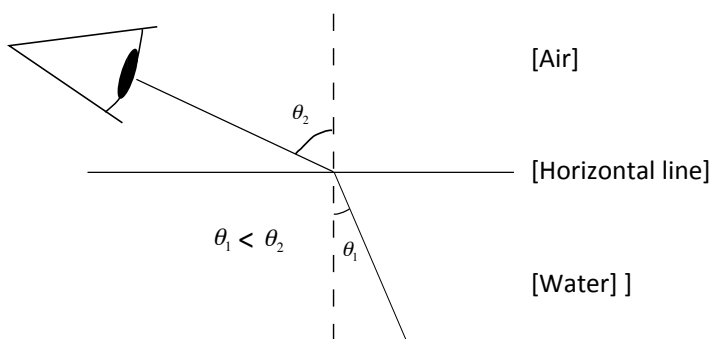


Figure 4.2. A reproduction of the ray diagram that was produced by the students. I have added the labels in square brackets for clarification (from Paper I).

At this point, the discussion given in the multimodal transcript in Table 4.1 took place. The way I have used multimodal transcripts was derived from Baldry and Thibault (2006) and is introduced in Section 3.3.2 as a way to describe how meaning is made with different semiotic resources.

Table 4.1 My multimodal transcript of the first part of the student discussion on why the refraction of light took place. Descriptive notes are given in square brackets.

Transcript-line	Interlocutor <sup>52</sup>	Semiotic resource	
		Spoken language	Other
1	Vera:	But, isn't the point that we want to describe it as a wavefront? ...coming in?	Holding the chalk, moves her hand, from up to the right and down to the left across the ray like a wavefront would be drawn in the ray diagram in Figure 4.2.
2	Mike:	Yes, but I... I usually don't think of it as wavefronts, I usually kind of just think that:	Has just finished his drawing of the ray diagram in Figure 4.2 and takes his hand down from the black board.
3	Mike:	"Well, this is thinner and this..., is thicker." So when the light... I don't know [voice fading].	Points first above the horizontal line (see Figure 4.2) then below the horizontal line.

<sup>52</sup> Interlocutor, here, means the person doing the acting and/or talking.



4	Vera:	But, why, why, why does it bend, why is the angle...	Points at the “crosshair” where the ray meets the surface.
5	Researcher:	But you just know it's like that.	Pointing at the ray diagram.
6	Vera:	...this angle...	Puts the arcs and the mathematical notation $\theta_1$ and $\theta_2$ as in Figure 4.2.
7	Nick:	...smaller than the other and not the other way around?	Sits down, finishes the sentence for Vera.
8	Researcher:	That's what I never can, well...	Vera writes mathematical notation, $\theta_1 < \theta_2$ below the horizontal line in Figure 4.2.
9	Vera:	Why is it, why is this smaller and not bigger?	Points at the $\theta_1$ in the inequality she just drew.
10	Nick:	Well, because this is denser, kind of.	Points at the area below the horizontal line.
11	Vera:	Why, why does that happen because it is denser?	Shrugs her shoulders

In the extract given in Table 4.1 the students reference and produce both persistent semiotic resources (the ray diagram and the mathematical notation) and non-persistent semiotic resources (spoken language and gestures).

At this point, approximately 30 minutes<sup>53</sup> into the discussion, the students apparently reached a dead end, a stalemate. Next, the following exchange occurred (see Table 4.2).

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<sup>53</sup> Note that a considerable portion of this time was used for illustrating refraction using the glass tank of water etc.

*Table 4.2.* Multimodal transcript of the second part of the extract from the student discussion. This extract ends with the group agreeing on the wavefront as a viable description of light, although its identification with light is still only implicit (and indicated through the referencing use of “It’s” in Transcript-line 15).

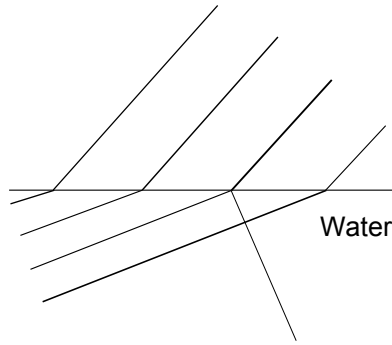
Transcript-line	Interlocutor	Semiotic resources	
		Spoken language	Other
12	Mike:	Well, then one has to start thinking of Huygens’ principle or...	Looks at the blackboard, then at Vera.
13	Vera:	Yes, I think we have explained it that way some time.	
14	Researcher:	What does that mean then?	
15	Nick:	It’s electromagnetic...	
16	Mike:	Yes, or kind of just, or, electromagnetic waves.	
17	Nick:	...waves at... yes.	
18	Researcher:	But try a little bit.	
19	Vera:	But somehow we’re thinking of it as a wavefront.	
20	Mike:	Yeah...	

The part of the extract presented in Table 4.2 was then followed by a sequence where the students started to explore the properties of wavefronts (see Table 4.3). Here, the students again used non-persistent semiotic resources such as gestures and speech whilst referring to the persistent ray diagram drawn on the blackboard (Figure 4.2).

Table 4.3. Multimodal transcript of the third part of the extract from the student discussion. Here, the properties of wavefronts are explored. In Transcript-line 28 a direct link between light and wavefronts is made. Descriptive notes are given in square brackets.

Transcript-line	Interlocutor	Semiotic resources	
		Spoken language	Other
21	Vera:	And then, kind of, a part of the wavefront will hit, I can't do that explanation myself, but a part of the wavefront will kind of hit the water... [referring to the area below the horizontal line]	Uses gesture to show how a wavefront would be drawn in the ray diagram, without actually drawing one
22	Mike:	...before, and then it goes faster.	Makes a waving gesture with his hand, simulating the movement of a wavefront.
23	Vera:	...before, and it goes <i>slower</i> in the water.	Pointing at the area below the horizontal line
24	Nick:	Yes.	
25	Mike:	Yes, that's right! It's denser which means it's going slower there.	Pointing at the area below the horizontal line (water).
26	Vera:	And then it won't kind of...	
27	Researcher:	What is going slower then? I don't understand.	
28	Mike:	The light is going slower!	[Equating "a part of the wavefront" with light]

This part of the extract ends as Mike is about to draw a new diagram, a wavefront diagram (see Figure 4.3).



*Figure 4.3.* A reproduction of the detail given in the wavefront diagram eventually drawn by the students. Here, the word “Water” was written below the horizontal line in the diagram (from Paper I).

In the next section I present my dynamic analysis of the discussion.

#### 4.2.2 Dynamic analysis

Figure 4.4 shows my dynamic analysis of the student discussion in the form of a diagrammatic construction of the interplay and the intersemiotic references between the different semiotic resources that were used in the discussion. The analytic approach used to obtain Figure 4.4 was derived from Bloom and Volk (2007) and is described in Section 3.3.4.

Figure 4.4 shows who is acting or saying something, what is said, which aspect of the content of the discussion that the action is contributing to, the actions that are taken, and what semiotic resources are referenced and produced.

Extracts taken from the spoken language used in the student discussion are given in the first column of Figure 4.4, labelled ‘Speech’. Filled circles indicate explicit references to the different meanings labelled across the top of the middle columns and unfilled circles indicate implicit references and/or references to one of the contrasting options that constitute the disciplinary-relevant aspects. For example, the unfilled circle in the ‘Speed’ column in line 22 shows where the students first introduced the speed of light into the discussion. The ‘Action’ column gives the different actions taken by the students. The letters in the ‘Image’ column refer to the different positions indicated with the corresponding letters in Figure 4.5.

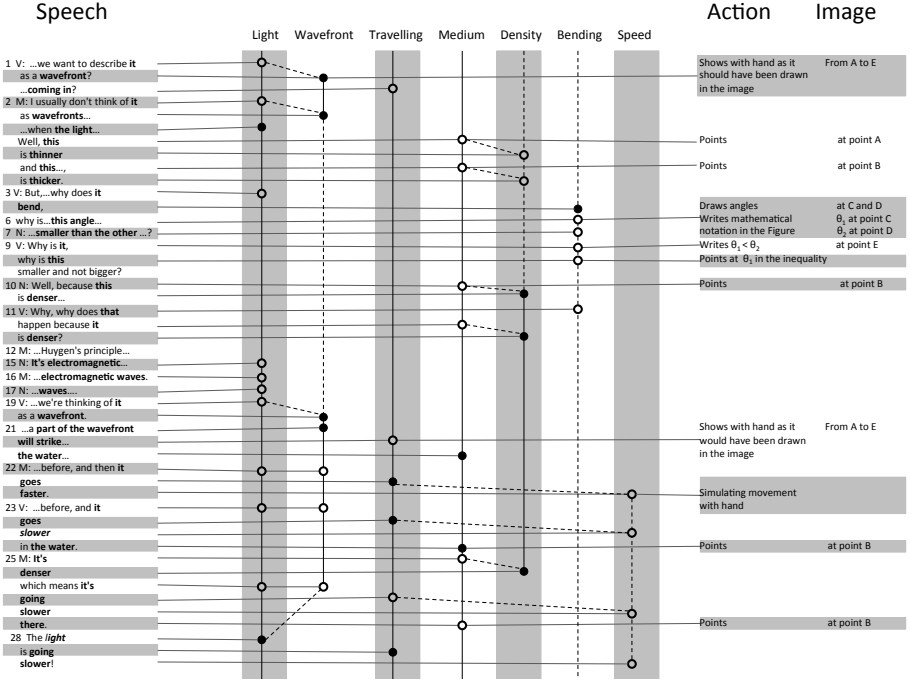


Figure 4.4. A visual illustration of the dynamic analysis.

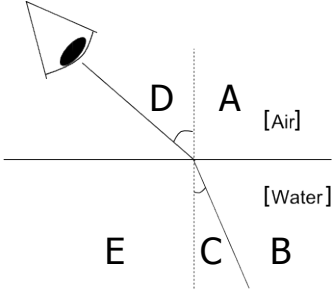


Figure 4.5. Letters showing positions in the ray diagram referred to in Figure 4.4 (Fredlund & Linder, 2010a, see Appendix C).

My analysis suggests that the most important point in the discussion extracts is in Transcript-line 22 in Table 4.3. This is when Mike says that the (semantic) participant “a part of the wavefront”, which was agreed upon in Transcript-line 20 in Table 4.2, “goes *faster*” (semantic) process + circumstance; (“goes” is Process, “faster” is the circumstance role Manner, similar to a quality in the nominal group). In Transcript-line 22 it can also be seen that Mike accompanies his words with a hand gesture (a non-persistent semiotic resource), which shows the movement of a wavefront increasing in speed. Mike’s “goes *faster*”, indicates a culmination of insight of the relevance that the change in *speed* of light has for the explanation of why the refraction of light takes place. The change in speed stays in focus as Vera quickly corrects Mike’s “goes *faster*” to the contrasting option “goes *slower*.” Figure 4.4 presents the dynamic development of the discussion leading up to Mike’s drawing of the (persistent) wavefront diagram in Figure 4.3.

In Transcript-line 2 the contrasting attributes “thicker and thinner” are associated with the different illustrative media, water and air. This is done through intersemiotic references between the spoken attributive relational process “is” and the pointing gestures.

In summary, my dynamic analysis of the students’ discussion shows the development of the student discussion that led up to the emergence of the speed of light as a relevant aspect for the students’ explanation of refraction. By looking at which semiotic resources were used I was able to identify the important role that the wavefront diagram played in the students’ meaning-making.

#### 4.2.3 Synoptic analysis – the patterns of disciplinary-relevant aspects

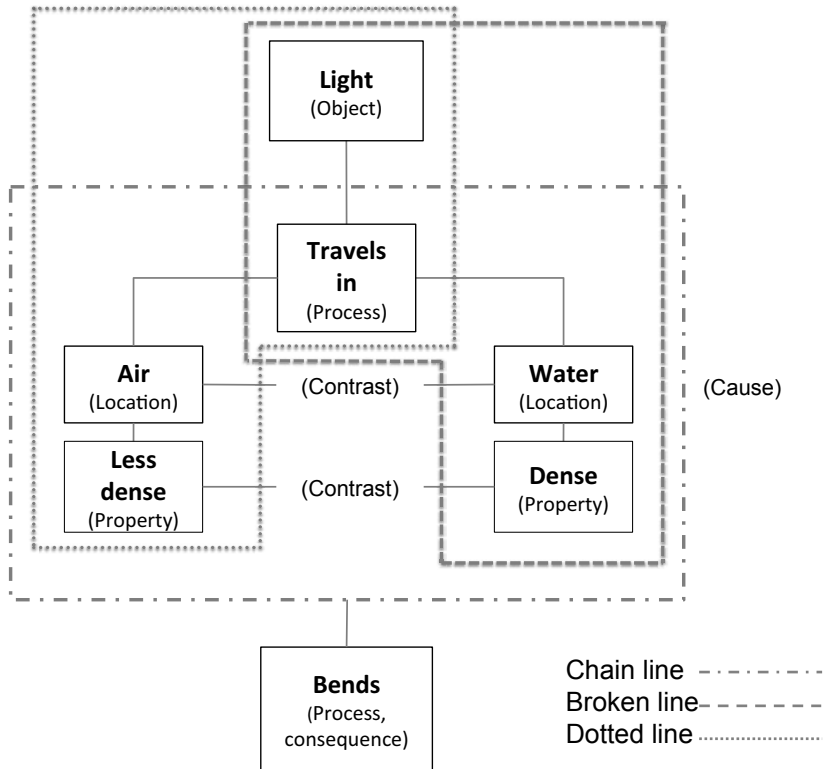
Here I present my synoptic analysis in the form of what I term patterns of disciplinary-relevant aspects<sup>54</sup>, shown in Figures 4.6 to 4.8. These patterns of disciplinary-relevant aspects emerged from an iterative process during the analysis described in Section 3.3.3. The patterns of disciplinary-relevant aspects show the relationships between the different thematic items that were analytically distilled out of the students’ discussion in the multimodal pattern in Figure 3.3.

The different patterns of disciplinary-relevant aspects represent different sequences in the thread of the students’ discussion. The first pattern (Figure 4.6) captures what happened before the identification of speed of light as a disciplinary-relevant aspect (Table 4.1); the second pattern (Figure 4.7) deals

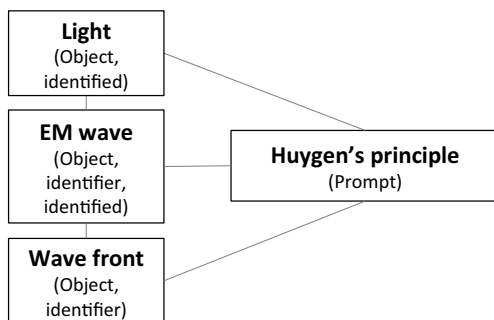
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<sup>54</sup> Note that at the time of writing Paper I, I had not yet settled on the name *pattern of disciplinary-relevant aspects* for the diagrams I had created and so, in the paper, I mainly refer to the diagrams as “my thematic patterns.”

with how light is related to electromagnetic waves through Huygens' principle (see Table 4.2); and, the third pattern of disciplinary-relevant aspects (Figure 4.8) displays a synoptic analysis of the whole student discussion, which adds the dimension of the speed of light (see Tables 4.1-4.3).

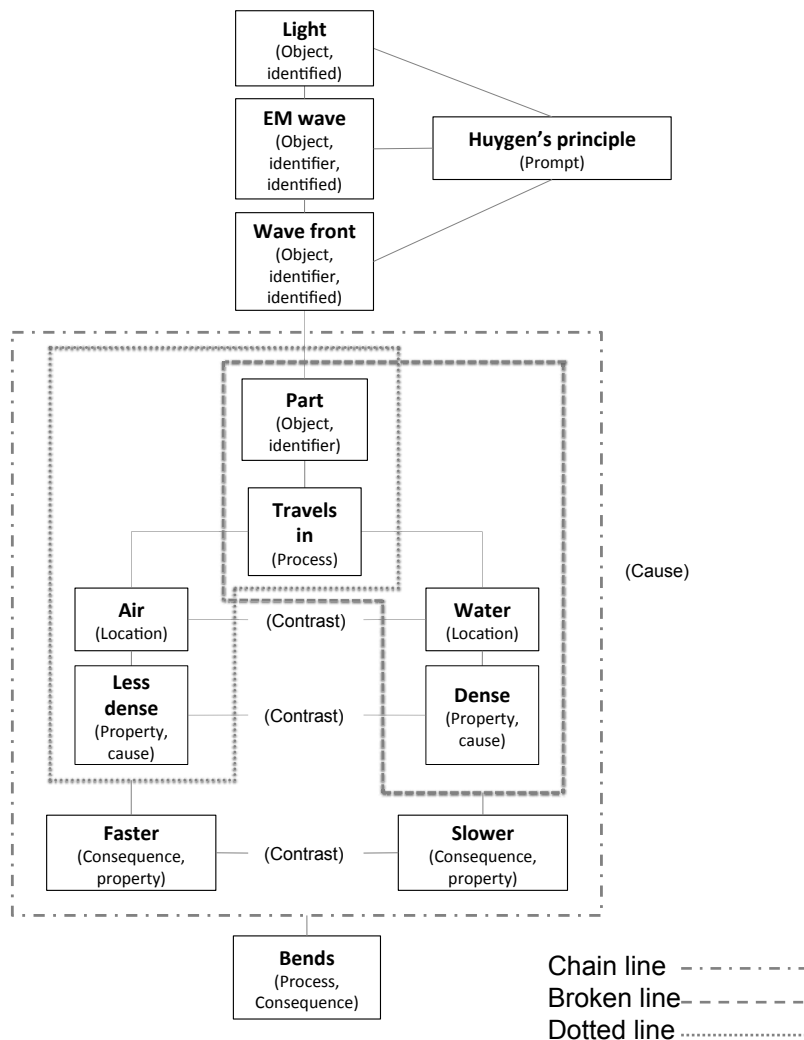


*Figure 4.6.* The pattern of disciplinary-relevant aspects for the first part of the discussion extract (see Table 4.1). The chain line encapsulates the cause of refraction as it appeared in the students' explanation. The broken and dotted lines encapsulate the physics meanings that were contrasted in the discussion (see Paper I).



*Figure 4.7.* The pattern of disciplinary-relevant aspects for the students' transition to a wave model of light (see Table 4.2 and Paper I).





*Figure 4.8.* The pattern of disciplinary-relevant aspects for the whole extract of the students' discussion (see Tables 4.1-4.3) after the speed of light has been identified as a disciplinary-relevant aspect for the refraction of light. The chain line encapsulates the cause of refraction, as it appeared in the students' explanation. The broken and dotted lines encapsulate the physics meanings that were contrasted in the discussion (see Paper I).

A comparison between Figure 4.6 and Figure 4.8 shows how the introduction of wavefronts affected the discussion – it enabled the students to agree on the importance of the aspect of the speed of light for the development of their explanation and eventually enabled them to agree that they had provided an appropriate explanation.

It should finally be noted that after the particular extract of the discussion presented above, as part of their interactive discussion each of the students

went up to the blackboard and drew, pointed, and in detail described with words how the wave could change direction as it changed speed in passing from one medium to another. This did not affect the construction of the pattern “but rather served to confirm and cement the relationships between the physics concepts that had already been fruitfully established” (Paper I, p. 663).

After all of these “twists and turns” in the discussion, Vera continued to pursue a viable explanation of refraction by questioning the ‘spread-out’ nature of light, and how refraction of light could be explained if light was seen as a point particle. However, the other students did not take this up.

This brings me to where I can answer the first two research questions individually.

#### 4.2.4 Answer to Research Question 1

*In what ways can thematic patterns be developed as an analytical tool in order to analyse meaning-making in introductory undergraduate physics?*

Following Tang, Tan, and Yeo (2011) I built on the concept of thematic patterns as reported by Lemke (1990) in order to capture meanings that have been realised through the production of a range of different semiotic resources. To do this I initially worked on a colour-coding system that made it possible to trace which semiotic resources were used to realise which meanings throughout the student discussion. Then, through an iterative process, I rationalised this form of multimodal pattern into a form that systematically displays the meanings that were realised in the student discussion (patterns of disciplinary-relevant aspects). The restructuring of the different parts of the initial pattern (given in Figure 3.3 in Section 3.3.3) led to my disciplinary-relevant patterns becoming useful analytical tools. I have used this analytical tool to display each disciplinary aspect that the students found to be relevant for an explanation of why the refraction of light takes place as a contrast pair, e.g. faster – slower, air – water. The three different patterns of disciplinary-relevant aspects in Figures 4.6-4.8 together make it possible to show the effect that the introduction of wavefronts had on the progression of the student discussion. This, in turn, led to the introduction of the term disciplinary affordance of a semiotic resource (see Section 2.8.6 and Paper I).

From my analysis, I saw patterns of disciplinary-relevant aspects as having two important attributes:

1. *as an analytical tool.* The final pattern of disciplinary-relevant aspects given in Figure 4.8 is a way to analytically and synoptically

- capture disciplinary-relevant aspects realised in the text that was produced dynamically in the interactive engagement; and,
2. *as a “model” of an essential part of the learning process.* Theoretically, the pattern of disciplinary-relevant aspects can be seen to capture those meanings that need to be realised through the produced and referenced semiotic resources in order to, in my example, constitute an explanation at an undergraduate physics level of why the refraction of light takes place.

The social semiotic perspective I constituted for this thesis provides a theoretical framework that facilitates a deep analysis of the physics content as it is realised through the production of different semiotic resources in a physics discussion. As an analytical tool my patterns of disciplinary-relevant aspects provide a graphical synoptic overview of the different aspects of the text that is dynamically produced. The content is realised in different ways through the production of different semiotic resources. Different semiotic resources realise different aspects of the patterns of disciplinary-relevant aspects according to their different disciplinary affordances.

### *Discussion*

My patterns of disciplinary-relevant aspects explicate relationships (a structure) between different disciplinary-relevant aspects (in terms of meaning). I see a wider usefulness of these analyses in terms of how they open links between my social semiotic perspective and the Variation Theory of Learning, which has proved to be a very successful theoretical underpinning for interventions aiming at enhancing possibilities for learning (see Section 2.9; and for a discussion about the relationship between structure and meaning, see Marton & Booth, 1997). The similarity that I began to notice between the Variation Theory of Learning's notion of critical features and my pattern of disciplinary-relevant aspect analysis led to the development of Research Questions 4-6 and is further discussed in Section 4.4.2.

The patterns of disciplinary-relevant aspects also furthered my description of the meanings that were realized through the different semiotic resources that were produced in the student group explanation about why the refraction of light takes place.

In ways similar to how Lemke (1990) described the meaning of a word as being dependent on its relationship to other words in a thematic pattern (see Section 2.8.6), each disciplinary-relevant aspect that is part of a pattern of disciplinary-relevant aspects gets its meaning from their relationships to one another. In other words, the relevance of each of the disciplinary-relevant aspects stems from its relation to the other disciplinary-relevant aspects; the pattern of disciplinary-relevant aspects has a built-in structure of relevance

for the particular content that it characterizes. Consequently I propose that different aspects may have different degrees of relevance for some particular content (object of learning).

An essential part of physics learning could therefore be described as: (1) coming to notice those aspects that the discipline of physics considers being relevant for some particular object of learning; (2) coming to experience the aspects as relevant; (3) becoming able to relate different relevant aspects to each other; and, (4) coming to experience the degrees of relevance that different aspects might have for the object of learning.

#### *A note on disciplinary-relevant aspects*

The pattern of disciplinary-relevant aspects analysis shows three contrast-pairs, namely: – Air–Water, Less dense–Dense, and Faster–Slower. A fourth contrast, which is given by the angles  $\theta_1$  and  $\theta_2$ , is indicated in the pattern of disciplinary-relevant aspects through the process “bends.” These contrasts are distinctions that the students find relevant for explaining why the refraction of light takes place. Here, the different contrast pairs have been realised in different semiotic resources, from which they have been analytically extracted. Each of the contrast pairs is qualitatively different from the other contrast pairs, and each pair could be given a separate name, such as speed, density, and medium. In this spirit, Maxwell (1871) points out in a letter to the London Mathematical Society that the distinctions made in physics often are “quantities”:

The first part of the growth of a physical science consists in the discovery of a system of quantities on which its phenomena may be conceived to depend.  
(p. 224)

I argue that the different quantities of such a system would have to be qualitatively unique. For example, temperature is a qualitatively unique quantity. The attributes cold and hot (which are essentially qualities) also point at temperature, and can therefore make distinctions both within the quantity temperature and across different quantities such as temperature and pressure. These are the kinds of distinctions that are displayed in my patterns of disciplinary-relevant aspects. Each of these distinctions then is what I call a disciplinary-relevant aspect, which, as such, becomes an important analytical unit.

The reason for inventing and naming this new analytical unit is that, as my patterns of disciplinary-relevant aspects and my semiotic analysis in Paper IV show, distinctions that are relevant to a particular physics object of learning need not be quantities (e.g., the medium is not a quantity). A disciplinary-relevant aspect has both a certain degree of importance for the object of learning that it characterizes, and it is important for the discipline that deals with it and that initially made the associated distinctions.

### *Implications for teaching and learning*

Lemke (1990) suggested that teachers should attempt to create thematic patterns for the content that they are teaching. However, it does not seem very realistic to expect teachers to be able to easily learn about the theory on which thematic patterns are based in order to be able to create them. In any case, Lemke (personal communication, 12 September, 2014) recently pointed out that thematic patterns are principally a research tool. Despite this it might be possible for teachers to start thinking about the content to be taught in terms of, for example, contrasts – both within and between qualitatively different aspects of meaning; what I have called disciplinary-relevant aspects. Teachers who attempt to describe the content they intend to teach in the form of a pattern of disciplinary-relevant aspects – or who simply list the disciplinary-relevant aspects of the content they are going to teach – would be better placed to select the semiotic resources that are the most useful in the teaching. Further implications of this for the teaching and learning of physics are discussed later under the results of Research Questions 4-6 (See Sections 4.4-4.6).

## 4.2.5 Answer to Research Question 2

Each of the seven facets of Research Question 2 are presented individually:

### **Facet 1:**

*During interactive engagement dealing with the refraction of light, what roles do non-persistent and persistent semiotic resources play in terms of what these roles are and how they can be characterized?*

For the purpose of this thesis the distinction between persistent and non-persistent semiotic resources was found to be educationally important. My analysis shows that the persistent semiotic resources (the ray diagram, the wavefront diagram, and the mathematical notation) and non-persistent semiotic resources (spoken language and gestures) that the students used played different roles in the realisation of the pattern of disciplinary-relevant aspects. The results indicate that in interactive engagement persistent semiotic resources radically affect the meaning-making by serving as the hub around which non-persistent semiotic resources are coordinated. In this respect, persistent semiotic resources affect which meanings can be made. Non-persistent semiotic resources play a more provisional role. In other words, they are used to negotiate meanings before these meanings are realized in a persistent form (see, for example, Kress, 2010). Once meaning has been realized in persistent form, non-persistent semiotic resources can be used in interactive engagement to either reinforce or re-negotiate meanings.

Thus, the choice of persistent semiotic resource is found to be central for the outcome of interactive engagement.

**Facet 2:**

*Which persistent semiotic resources are used by a group of students when engaging interactively in explaining the refraction of light?*

These students proved to be fluent in a large number of semiotic resources that could be used for discussing the refraction of light. The answer is best given by the following list:

The students produced a ray diagram; a wavefront diagram; a drawing of wheels that turn; and, mathematical notation. They also used a water tank; water; and, a bottle brush as a linear object that they immersed in the water. The students also attempted to use a laser pointer, adding milk to the water in order to make the light from the laser visible.

**Facet 3:**

*What differences in disciplinary affordances of the persistent semiotic resources used by the students can be observed in such an explanation?*

The ray diagram and the wavefront diagram were found to have different disciplinary affordances – in other words, they have different potential to provide access to disciplinary knowledge. The ray diagram was found to afford access to the direction of propagation of light and the various angles of refraction. However, the ray diagrams could not afford the students access to the (changing) speed of light. The wavefront diagram, on the other hand, did afford access to the difference in the speed of light and for this reason the wavefront diagram appears to be particularly important for the explanation of why the refraction of light occurs.

*Implications for teaching and learning*

In relation to the answer to this question I would like to suggest that teachers' knowledge about which semiotic resource is the most appropriate one for dealing with a particular part of physics content (object of learning) – in other words, teachers' appreciation of disciplinary affordance – might often be tacit (Polanyi, 1967). However, teachers who become sensitive to the differences between different semiotic resources in terms of their disciplinary affordances are more likely to become able to produce more powerful learning experiences for their students.

#### **Facet 4:**

*What aspects of persistent semiotic resources can account for disciplinary affordance differences in an explanation of the refraction of light?*

To answer this question each of the semiotic resources are dealt with in turn.

##### *(i) Ray diagram*

A ray diagram geometrically/spatially illustrates the direction of propagation of light in relation to the surface between two different media. The ray diagram is specialised in showing this direction, which is often disambiguated by an arrow. The different media involved are not given directly other than that they are named and labelled through the use of other semiotic resources (such as spoken and written language, pointing gestures, etc.). Furthermore, it is possible to insert different angles and other constructs, such as the normal to the surface, as parts of the ray diagram. However, there are no visible aspects of the ray diagram as such that can afford access to the speed of light, which thus remains ambiguous.

##### *(ii) Wavefront diagram*

Wavefronts in a wavefront diagram are perpendicular to the direction of propagation. The distances between the wavefronts are proportional to the speed of light. In this way, the wavefront diagram can provide access to the speed of light. However, the actual travelling of the wavefronts is not well presented by the static wavefront diagram. Here, gestures can be used to complement the wavefront diagram in order to present the movement dynamically, and this movement can be further referenced through verbal language. It is also common that the wavefronts get combined with the ray diagram in order to disambiguate the direction of propagation of light.

##### *(iii) Mathematical notation*

Mathematical notation is specialized in making quantitative meaning (what Lemke, 2003, p. 226, calls "topological meaning"). In the case of refraction, mathematics gives access to the quantitative relationships between the different physics aspects and provides the possibility to calculate their values – what Duval (2006, p. 103) terms "treatment."

##### *(iv) Equipment*

The water tank, the water and the straight object provide access to a "real" situation where refraction takes place, of which certain aspects are in turn translated into the ray diagram and the wavefront diagram. There is nothing in the water tank, the water or the straight object that directly brings the focus to light, the speed of light, light rays or wavefronts. Only the *observable effect* of the concept of refraction of light on the apparent position of objects that are immersed in water can be illustrated.

### *Discussion and Implications*

For each of the persistent semiotic resources used by the students there are disciplinary conventions that govern how they should be interpreted (compare with grammar). These conventions are important for the disciplinary affordances of the semiotic resources. Becoming aware of these conventions can be seen as an integral part both of coming to appreciate the disciplinary affordance of a semiotic resource; and, of becoming fluent in the use of the particular semiotic resource. Thus, it is often not just the material aspects of the semiotic resource that provide the disciplinary affordance of a semiotic resource, but rather these aspects together with the conventions that have been established for their application and interpretation for a particular context.

### **Facet 5:**

*To what extent can the different persistent semiotic resources that the students used be seen to present the disciplinary-relevant aspects that learners would need to be aware of in order to explain why the refraction of light takes place in a disciplinary manner?*

From the analysis presented so far I would argue that a single semiotic resource only presents a subset of the disciplinary-relevant aspects of the refraction of light. In other words, the different semiotic resources have different disciplinary affordances. This means that the different persistent semiotic resources that the students used would be expected to provide access to different aspects of disciplinary knowledge. That is, the different persistent semiotic resources are useful to different degrees for the realisation of different aspects of an explanation of why the refraction of light takes place. At the same time, the meanings made with different semiotic resources reciprocally contextualize each other. For example, the ray diagram can be seen to contextualize the mathematical notation, which could mean different things depending on the context in which it is produced.

### *Discussion and Implications*

Because different semiotic resources have different disciplinary affordances, the choice of an appropriate semiotic resource becomes important in meaning-making in physics. Learning physics therefore involves learning to make appropriate choices of semiotic resources. In other words, learning physics involves “coming to appreciate the disciplinary affordances” (Paper I, p. 658) of the semiotic resources. A goal of physics education must therefore be to help students develop an appreciation of the disciplinary affordances of different semiotic resources. Such appreciation would help



students to choose those semiotic resources that best provide access to the disciplinary knowledge that is needed for the purpose at hand.

**Facet 6:**

For the given situation, *how do students select a persistent semiotic resource around which to interactively engage?*

In my analysis of the student discussion to formulate an explanation for the refraction of light I found some evidence that the extent to which students perceive the relevance and usefulness of different semiotic resources for providing access to disciplinary knowledge in interactive engagement can be related to the frequency of use of these semiotic resources in, for example, lectures and physics textbooks.

*Discussion and Implications*

A reason why the students in the extract presented in Section 4.2.1 first chose to produce a ray diagram could be that it is the most often used semiotic resource in physics textbooks dealing with the refraction of light (see, for example, Hüttebräuker, 2010). Van Leeuwen's (1999, p. 29) argument that choices might also "result from a convention followed unthinkingly, a habit acquired unreflectively, or an unconscious impulse" can be seen to point at a similar idea. Furthermore, Airey's (2009, p. 111) contention that "repetitive practice is the means by which students become fluent in disciplinary discourse" can be seen to be a result of a similar argument.

If students' choice of a particular semiotic resource is based on the frequency of use of that semiotic resource there is a risk that they do not make appropriate choices based on their appreciation of the disciplinary affordances of different semiotic resources. This is a potential area for future research (See Chapter 6).

**Facet 7:**

*How can the answers to facets 1-6 of Research Question 2 be related to "Vision I" scientific literacy (Roberts, 2007a, 2007b)? (For detail of what is meant by Vision I – see Section 2.2.5 and Paper II).*

As described in Section 2.2.5, Airey (2009) has claimed that students become scientifically literate with respect to a given physical phenomenon through repetition, and that this repetition is needed in order to become fluent in a critical constellation of semiotic resources. Airey (2009) essentially equates fluency in using semiotic resources with scientific literacy. While answering facets 1-6 of Research Question 2 above, I suggest that students need to know which persistent semiotic resource has the

appropriate disciplinary affordance for solving a problem at hand. I argue that this could be seen as an important complementary aspect of scientific literacy (see Paper II).

### *Discussion and Implications*

It is not sufficient to become fluent in a set of semiotic resources – some appreciation of which persistent semiotic resources are called for in a given situation is also an essential component of scientific literacy (see Paper II).

I now turn to Research Question 3, first showing the results of the analytic methods described in Section 3.4 before answering the research question.

## 4.3 Research Question 3 (Paper III)

The analysis of the second dataset was used to answer Research Question 3. The scenario involved a group of students from an introductory electromagnetism course working in the electronics laboratory attempting to connect an RC-circuit appropriately so that they could make measurements with an oscilloscope (See Section 3.4.1).

*RQ 3.* Given that the social semiotic perspective constituted for this thesis has been used to problematize the access to disciplinary knowledge that different physics semiotic resources present:

- 3.1. What is the nature of the learning challenges associated with physics aspects that have been rationalized out of a typical semiotic resource used in physics education (an RC-circuit used in a student laboratory learning situation)?*
- 3.2. How can the results of 3.1 be theorized in terms of enhancing students' appreciation of the disciplinary affordances of physics semiotic resources?*

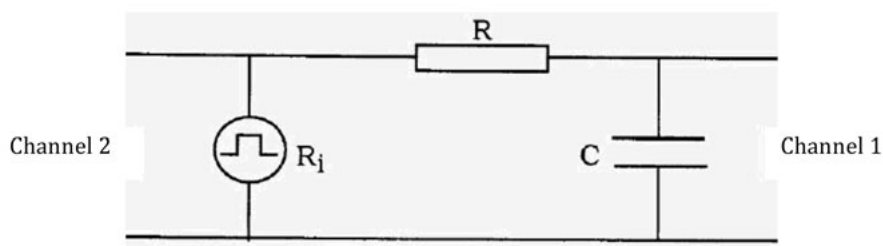
The analysis of the first dataset (see Sections 4.2.1-4.2.3) showed that the meanings of certain semiotic resources were taken for granted by the students and not unpacked further. For example, the students mentioned “*Huygens’ principle*” without any further unpacking – it “stood fast” (Paper I, p. 664). “*Huygens’ principle*” can be seen as an example of a “condensation” (see Section 2.7) of text into a nominal group that is used for a “whole little thematic pattern” (Lemke, 1990, p. 101).

In what follows I will use my second dataset to illustrate how the phenomena of taking-for-granted and packing (for which I have used the term “rationalisation” – see Section 2.8.4 and Paper III) exist not only in language, but also in other semiotic resource systems that students often

encounter in undergraduate physics. As such, they potentially create learning challenges for the students.

### 4.3.1 Analysis

Here I present my illustrative data analysis of a part of the students' engagement with the laboratory exercise. The aim of the exercise was to measure the charging and dis-charging characteristics of a capacitor. My analysis has focused on the part of this exercise where the students had to connect an RC-circuit according to a circuit diagram provided in the laboratory instruction (see Figure 4.9).



*Figure 4.9.* The circuit diagram of the RC-circuit the students were asked to connect. (From Paper III)

It can be seen that one of the disciplinary-relevant aspects that is necessary in order to appropriately connect this circuit is an aspect that is not shown explicitly in the circuit diagram, namely the positioning of the grounding cables to the different devices used.

The apparatus available to the students in this case called for the use of cables that had BNC connectors (see Figure 4.10) in at least one end. This is a connector type that is usually used together with coaxial cables, which in turn is the preferred choice for electrical signals. The other end of the cables used could have two, what are known as, “banana plugs”. In order to separate the grounding and the signal lines from each other, student laboratory coaxial cables often have two banana plugs at the one end of the cable. By (student-laboratory) convention, these banana plugs are colour coded – black for grounding and red for the signal. Note again that there is nothing in the circuit diagram that indicates where the circuit ground (black coloured connector) should be connected for each oscilloscope channel, or for the function generator input.

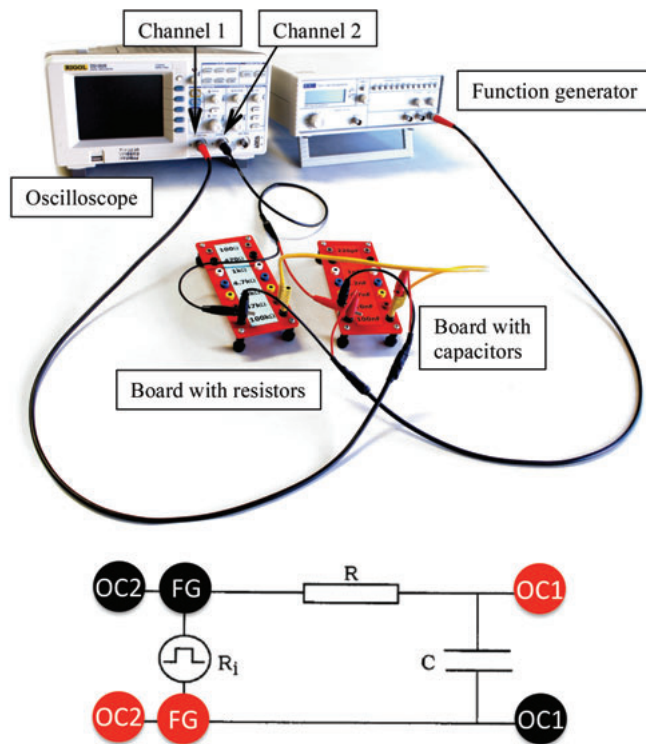


*Figure 4.10.* The coaxial cable used by the students to connect their circuit. The cable has black and red coloured banana plugs at one end (to the left of the image) and a BNC connector at the other end (to the right of the image) (from Paper III).

The analysis explicates the different iterations of connecting the circuit that the students went through in order to get to a stage where their circuit produced measurement outcomes on the oscilloscope screen that were useful for the task at hand. These illustrations (see Figure 4.11, 4.13, 4.15, 4.16, and Table 4.4) are given in terms of coloured dots inserted into the circuit diagram in order to show the positions where the students connected the different colour coded connectors. The letters inscribed in the coloured dots show which apparatus was connected and how it was connected: FG for function generator, OC1 for Channel 1 of the oscilloscope, and OC2 for the oscilloscope's Channel 2.

Next I present those parts of the students' discussion that illustrate the challenges that they experienced when connecting the circuit. This illustration is presented in chronological order.

The students first selected the equipment that they needed in order to connect the circuit. Two of the students, George and Ben (pseudonyms are used for the students' names), started by connecting Channel 1 and 2 of the oscilloscope, and the digital function generator, to a resistor and a capacitor. There was some initial confusion regarding which of the red/black colored banana plugs should be on which side of the capacitor. The perceived ambiguity in this decision is seen when Ben questions if it matters which way the coaxial cable gets connected. The first attempt at connecting the circuit is shown in Figure 4.11, and the resulting image on the oscilloscope screen can be seen in Table 4.4(a). Note that although this circuit is incorrect, the students could not see the reasons for this "incorrectness" in the circuit diagram given in the laboratory instructions.

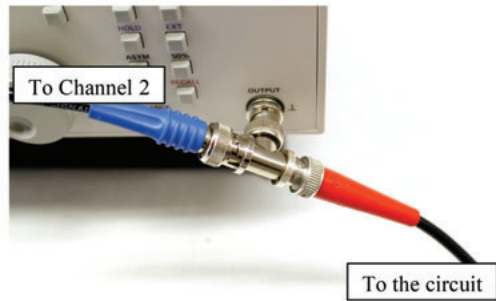


*Figure 4.11.* A pictorial and a diagrammatic illustration of the students' first attempt at connecting the circuit. FG refers to the function generator and OC1 and OC2 refer to the oscilloscope's Channel 1, and Channel 2 respectively. (From Paper III)

The students' circuit in Fig. 4.11 shows that the signal from the function generator (the red dot called FG) had been connected to the reference potential of the oscilloscope's Channel 1 (the black dot called OC1). It appears as if the students were treating the red/black coloured banana plugs as if they were connecting a voltmeter. Voltmeters do not have to be connected to a common reference potential, but should be connected across the component, i.e., to each end of the component across which the voltage is to be determined. Here, traversing the circuit in either direction would lead to the red and black connectors for both oscilloscope channels being encountered in the same order. However, voltmeters are not suitable for visualizing rapidly varying voltages and therefore the oscilloscope was used for this laboratory exercise. And, oscilloscopes need to have a common ground, as mentioned above.

Having completed this first attempt to connect the circuit, the students struggled with getting the oscilloscope screen to show anything meaningful by, for example, trying different frequencies of the square wave input signal. This prompted Will to ask: "Have we even connected it correctly?" whilst carefully examining their circuit. When the expected signals did not show on

the oscilloscope screen, the students attempted to simplify their connections by connecting the function generator directly to the oscilloscope's Channel 2 with a coaxial cable that had BNC connectors *at both ends*. They managed this by getting a BNC T-connector (see Figure 4.12) to simultaneously connect the function generator to the circuit with a split-end coaxial cable. The assumption apparently being that the correct connections would be built into the two BNC connectors by default! This was in fact the case and the cable substitution reversed the polarity of the connection (see Figure 4.13). Note, however, that this reversal was no longer directly observable since there were no longer any red and black coloured banana plugs to connect. Compounding this problem, the new circuit did not change the image on the oscilloscope either (see Figure 4.14 and Table 4.4b). This was due to the students' inappropriate oscilloscope settings.



*Figure 4.12.* The T-connector “solution” that was used to connect the function generator to the oscilloscope (Channel 2) and to the circuit. (From Paper III)

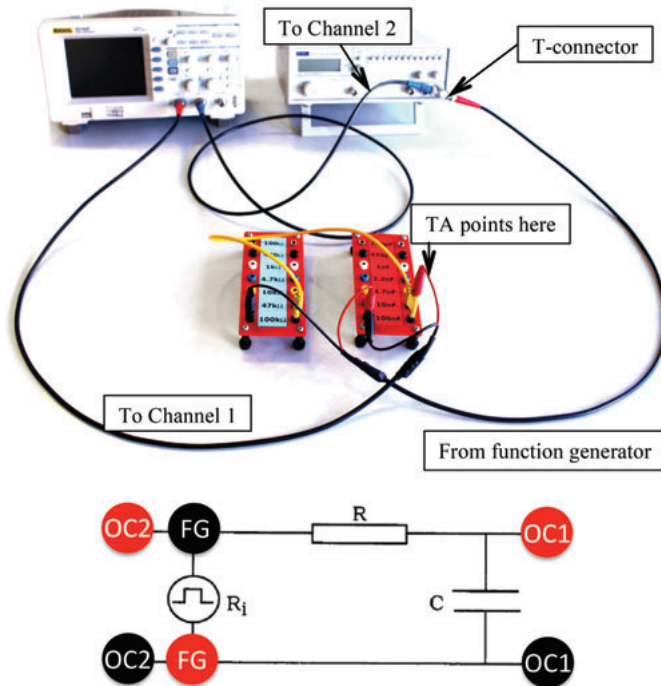


Figure 4.13. A pictorial and a diagrammatic illustration of the students' circuit after they had connected the oscilloscope's Channel 2 directly to the function generator. FG refers to the function generator and OC1 and OC2 refer to the oscilloscope's Channel 1, and Channel 2 respectively. As pointed out earlier, the OC2 connections took place by default through the use of the BNC T-connector (see Figure 4.12). (From Paper III)

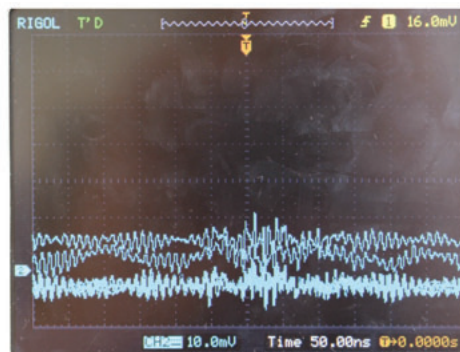


Figure 4.14. The image on the oscilloscope screen for the connection shown in Figure 4.13 above. (From Paper III)

Still not getting a good image on the oscilloscope screen, the students asked the teaching assistant (TA) for help. While waiting for the TA to arrive, Will and Ben had the following conversation:

Will: It is connected properly, right?

Ben: Yes, I think so.

Will: It's the capacitor, the resistor, then we complete it, and then...

Here, the word "it" is an implicit reference to the circuit. When the TA arrived, the following conversation took place.

TA: What's the problem?

Ben: First we would like to verify that we connected this correctly.

TA: Let me see.... Yes, now I see. I see one thing that is odd here. Ehm, it's like this, these [holding the cables entering the circuit from the function generator], have a grounding cable and a signal cable. The grounding in function generators and the oscilloscope...

Ben: They should be the same.

TA: [Still holding the cables entering the circuit from the function generator], ...it is the same. So, in principle, what you do here is that you take the signal from the function generator and you run it directly to the ground. Then nothing happens. There is no current in the rest of the circuit. So you have to start by changing, changing their places. Then I suppose it is easiest to change the polarity of this [pointing at the red coloured banana plug going to Channel 1; see Figure 4.13].

That the grounding in the different apparatus should be the same appears to stand fast (see Section 2.8.3) as soon as it has been pointed out by the TA. It is possible that the students had not seen it as relevant earlier because the grounding is not shown in the circuit diagram. However, the students never analyse explicitly in the circuit diagram how the identical location of the grounding can be achieved. Following their understanding of the TA's advice, the students therefore swapped the places of the red and black coloured banana plugs to Channel 1 across the capacitor, rendering the circuit connected as in Figure 4.15. Both the function generator and Channel 1 were now connected to the same place in the circuit with red banana plugs. At this point the TA also helped the students to get readable signals to show on the oscilloscope screen (see Table 4.4c).



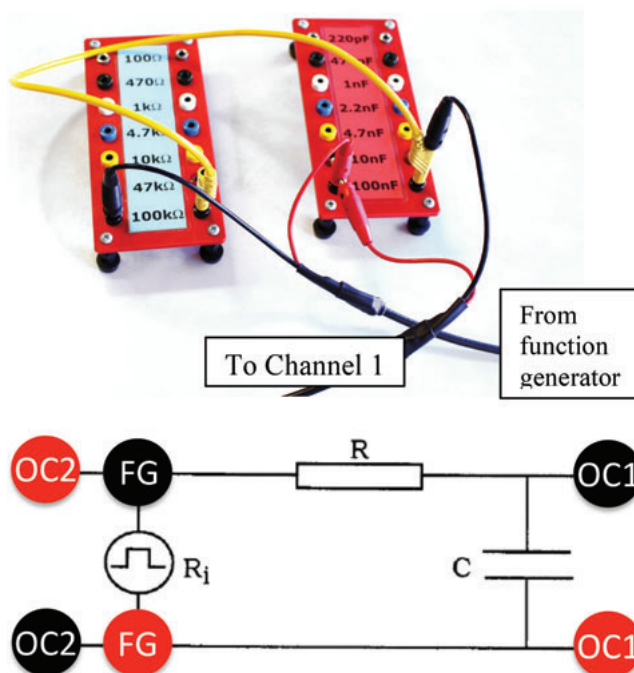


Figure 4.15. A pictorial and a diagrammatic illustration of the students' circuit after it had been corrected according to the TA's advice. Both "signal ends" of the cables were then connected to the same (equivalent) point in the circuit. FG refers to the function generator and OC1 and OC2 refer to the oscilloscope's Channel 1, and Channel 2 respectively. (From Paper III)

The signals from the two channels still did not look the way the students expected them to – they looked identical. Ben, referring to the images on the oscilloscope, said:

Ben: But, they are exactly the same.

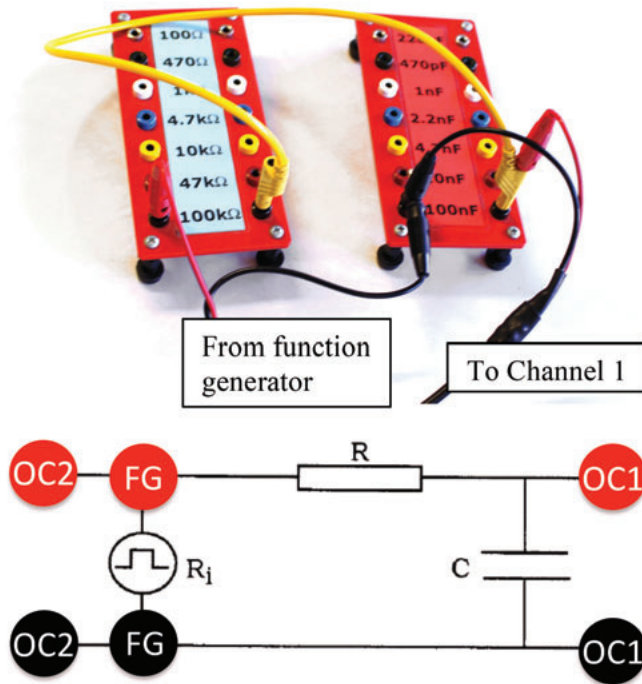
TA: Mm. That means that there is not so much going on in the circuit. Why does it not?

We can try either to change the capacitance, or we can change the frequency, and see if something happens.

After trying to change both the capacitance and the frequency, the two signals (input voltage and output voltage) still had identical forms on the oscilloscope screen (see Table 4.4d). The TA who had been observing this started to work on the circuit himself:

TA: We can try this. This can be... We'll let the signal go the other way so to speak – it can make a difference. Like so.

After the TA had completed the needed changes to the circuit; swapping the places of the red and black coloured banana plugs, the circuit then looked as shown in Figure 4.16.



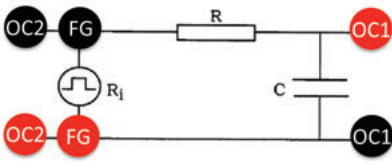
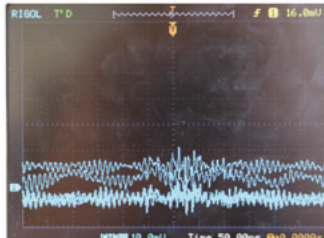
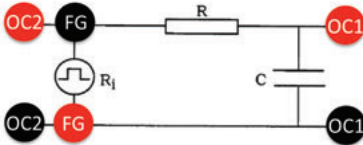
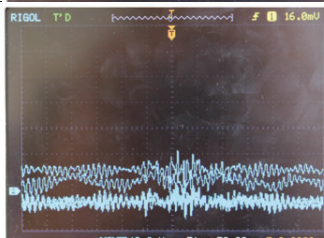
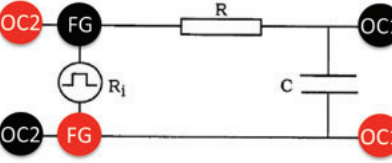
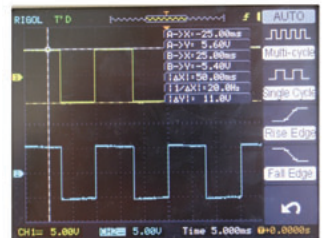
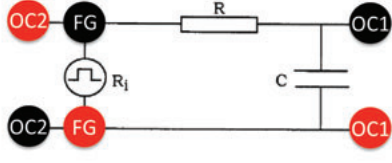
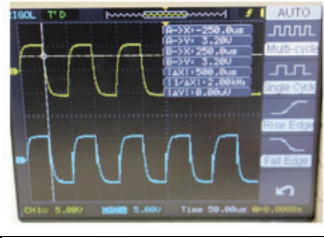
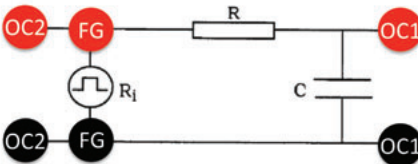
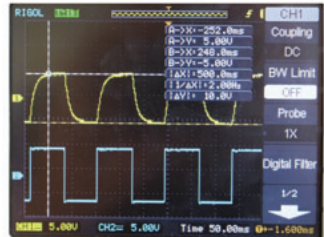
*Figure 4.16.* A pictorial and a diagrammatic illustration of the students' circuit after the TA's second intervention. Both "grounding ends" of the cables were connected to the same (equivalent) point in the circuit. FG refers to the function generator and OC1 and OC2 refer to the oscilloscope's Channel 1, and Channel 2 respectively. (From Paper III)

After making some input sensitivity adjustments to the oscilloscope that yielded images on the screen such as those in Table 4.4(e) the TA said:

TA: Now! Now it looks right. [Referring to what was seen on the oscilloscope.]

Table 4.4(e) shows the oscilloscope indicating a square signal from the function generator on Channel 2, and a characteristic charging and discharging curve from the capacitor on Channel 1. The students could then finally get on with their measurements.

*Table 4.4.* Summary of the illustrative vignette showing the sequence of connections and reconnections of the circuit that the students carried out and the oscilloscope images obtained at each stage. The signal from the function generator and the capacitor are shown in blue and yellow respectively. (From Paper III)

Description	Circuit connection	Image on the oscilloscope screen
(a) The students' first connection		
(b) The students' simplified connection		
(c) The circuit after the TA's first intervention		
(d) The same circuit after having increased the frequency		
(e) The circuit after the TA's second intervention		

### 4.3.2 Answer to Research Question 3

- 3.1. *What is the nature of the learning challenges associated with physics aspects that have been rationalized out of a typical semiotic resource used in physics education (an RC-circuit used in a student laboratory learning situation)?*

My analysis illustrates how the students struggled with connecting the RC-circuit appropriately, particularly with regard to the oscilloscope and the signal generator. Part of the reason for this may be that the location of the grounding was not directly indicated in the circuit diagram. Here, the RC-diagram can be seen to provide different details to a disciplinary insider (a teacher) and to the students in terms of the access to disciplinary knowledge that it provides. Put differently, students need to come to appreciate the disciplinary affordance of the semiotic resource.

- 3.2. *How can the results of 3.1 be theorized in terms of enhancing students' appreciation of the disciplinary affordances of semiotic resources?*

I propose, building on Halliday's description of "unpacking" (Halliday & Matthiessen, 1999, p. 256; see also Section 2.7), that unpacking the semiotic resources that are used in different educational settings so that more disciplinary-relevant aspects are made explicit could support students' appreciation of the disciplinary affordances of the semiotic resource at hand. I have described this as reverse rankshift (see Paper III).

#### *Discussion and implications for teaching and learning*

In order to see what unpacking is needed in each case the teacher should focus on those aspects that are relevant for the particular situation at hand. For example, realising the principle that the equipment needs a shared grounding in an actual laboratory setting involves considering that a subset of the points in the circuit diagram are actually directly connected to each other although this cannot be seen in the diagram – in other words, connections that are made inside the equipment (the grounding) cannot be directly seen. Essentially, the grounding cables are creating a "short circuit" between the points where their connectors are connected in the circuit. In my data, then, the TA and Ben had the following exchange of meanings:

TA: The grounding in function generators and the oscilloscope...

Ben: They should be the same.

Here, the TA's mentioning of "grounding" appears to have stood fast (see Section 2.8.3). Thus, it apparently provided a sufficient unpacking in terms

of which aspects are relevant for the situation at hand. Given this conclusion it is interesting how the students and the TA together failed to realise this meaning relationship in the circuit connections that followed. A possible reason is that the follow-up analysis of the circuit in terms of how it should be connected was not carried out in sufficient detail. Had this been done, for example, through using coloured dots for the differently coloured connectors (as I have illustrated in the different circuit diagrams in Section 4.3.1 it might have been easier to directly connect the circuit appropriately. Using coloured dots before connecting the circuit would be in line with the problem solving strategy used in Heller, Keith and Anderson (1992), where visualizing and planning the solution to the problem are important steps before the plan is executed.

Thus, the addition of the coloured dots in the circuit diagram results in a semiotic resource with a new disciplinary affordance that might be more powerful for students in that it enables further unpacking of the circuit – it can function as a more powerful hub around which meaning can be built (see Section 4.2.5). I argue that this new semiotic resource could help improve learning about circuit connections in a student laboratory setting (see Paper III).

This new modified semiotic resource could also potentially be used for creating explicit variation around the disciplinary-relevant aspect of grounding in electric circuits (see the discussion about the Variation Theory of Learning in Papers IV-VI).

## 4.4 Research Question 4 (Paper IV)

In this section I present my analysis of the third dataset for this thesis. The data here is a canonical text extract taken from Feynman, Leighton and Sands (1963) whose explanations are widely considered to be exemplary in physics education. This analysis has been reported on in Paper IV, from which parts of this section are taken, and is used to answer Research Question 4:

*RQ 4. What interconnections can be made between the analytic construct disciplinary-relevant aspects that was developed for this thesis and the Variation Theory of Learning's notion of critical aspects?*

To answer this question the third dataset was analysed using a systematic approach to explicate the disciplinary-relevant aspects that are referred to in the text (see Section 3.5.2). Below I present the text that I analysed:

...all that is required to understand refraction is to understand why the apparent wave *velocity* is different in different materials. The *bending* of light

rays comes about just *because* the effective speed of the waves is different in the materials. To remind you how that comes about we have drawn in... [Figure 4.17] several successive crests of an electric wave which arrives from a vacuum onto the surface of a block of glass. The arrow perpendicular to the wave crests indicates the direction of travel of the wave. Now all oscillations in the wave must have the same *frequency*. (We have seen that driven oscillations have the same frequency as the driving source.) This means, also, that the wave crests for the waves on both sides of the surface must have the *same spacing along the surface* because they must travel together, so that a charge sitting at the boundary will feel only one frequency. The *shortest* distance between crests of the wave, however, is the wavelength which is the velocity divided by the frequency. On the vacuum side it is  $\lambda_0 = 2\pi c/\omega$ , and on the other side it is  $\lambda = 2\pi v/\omega$  or  $2\pi c/\omega n$ , if  $v = c/n$  is the velocity of the wave. From the figure we can see that the only way for the waves to “fit” properly at the boundary is for the waves in the material to be travelling at a different angle with respect to the surface. From the geometry of the figure you can see that for a “fit” we must have  $\lambda_0/\sin \theta_0 = \lambda/\sin \theta$ , or  $\sin \theta_0 / \sin \theta = n$ , which is Snell’s law. (Feynman, Leighton & Sands, 1963, p. 31–2, emphasis in original)

My analysis aimed at foregrounding the disciplinary-relevant aspects in this text extract that are realised explicitly and/or implicitly through the different semiotic resources. This text extract contains a combination of written text, the mathematical equations and the image in Figure 4.17. These are located in the margin of the original 1963 book page to the left of the written text and in the centre of the page in the [www.feynmanlectures.caltech.edu](http://www.feynmanlectures.caltech.edu) edition which is the version I am referring to as the “text extract.” When I refer to “other texts,” these may be other parts of the text from which this extract is taken, or other texts altogether.

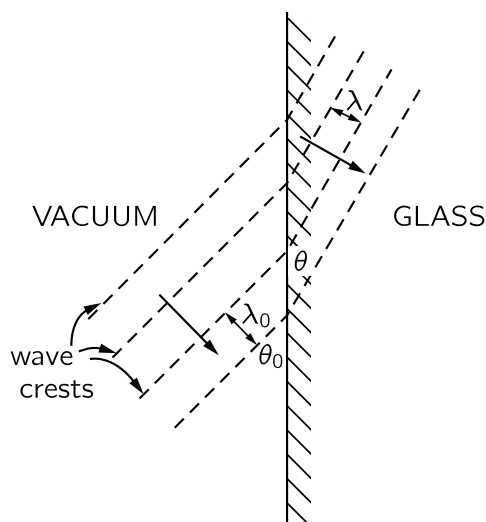


Figure 4.17. The image in the Feynman, Leighton and Sands (1963, p. 31-2) text. This image had the following caption in the original: “Relation between refraction and velocity change.” Copyright 1963, Feynman, Leighton and Sands, The Feynman Lectures on Physics : Volume I. Reprinted by permission of Basic Books, a member of the Perseus Books Group.

#### 4.4.1 Analysis

In the text extract, the first point to be emphasized is the “apparent wave *velocity*.” As a first step in my analysis I will therefore address the two entities “velocity” and “wave.” Both of these are names for wholes that consist of parts. Velocity can be unpacked into two constituent disciplinary-relevant aspects, namely speed and direction – both construed here as participants (“things”). The travelling itself is, however, largely taken for granted. In order for velocity to change, it suffices if the speed *or* the direction changes. However, the second sentence of the text extract describes how, as light travels from one material to the other, the change in the wave’s speed also causes a change in its direction. This is implicitly realised through the word “bending.”

This yields four critical aspects – the material (vacuum or glass), the travelling<sup>55</sup>, the speed (that differs), and the direction (that also differs). However, the detailed relationships between these aspects are absent at this point.

In the text extract, light is implicitly realised in terms of a “wave.” This wave has several disciplinary-relevant aspects that need to be unpacked<sup>56</sup>.

<sup>55</sup> Here I use “travelling” to label the disciplinary-relevant aspect as a whole and not just the option of travelling that stands in a contrast relation to “non-travelling.”

<sup>56</sup> For more about unpacking see Section 2.7.

One of these is related to the part of the wave that is called “crest<sup>57</sup>.” In Figure 4.17, crests are drawn as straight broken lines, suggesting that they are extended. This extension<sup>58</sup> is referenced implicitly in the written language (see what O'Halloran, 2005, p. 173, calls “intersemiotic reference”) when the arrow pointing out the “direction of travel” of the wave is described as being perpendicular to the crests. Once “direction” has been mentioned explicitly, the text goes on to explain why the direction changes when the speed of the “electric wave” changes. Here, the quality “electric” (a classifier, see Section 2.5.1) points implicitly to the characteristics that pertain to this particular kind of wave and its interaction with matter, such as its effect on electrons. The mentioning of this disciplinary-relevant aspect and several others that are common to different kinds of waves, including oscillation<sup>59</sup> and frequency<sup>60</sup>, suggest that the reader of this text extract is presumed to know them from other texts. These common aspects of waves together motivate why the crests of the wave need to have “the same spacing along the [glass block] surface” in both materials. This is the vertical distance between the crests of the wave in the image in Figure 4.17. And the implicit possibility to vary this spacing between crests makes it a disciplinary-relevant aspect. Having pointed out the necessity of this “same spacing,” and that the frequency of the wave (another implicitly variable disciplinary-relevant aspect) is the same in the materials, the text goes on to define the wavelength as “the *shortest* distance between crests of the wave....”

Via a chain of implicit intersemiotic references all remaining important constraints that a travelling wave is subjected to are then presented. For example, the mathematical equations showing that the wavelength  $\lambda_0$  is proportional to the speed of light when the frequency is constant (where the frequency mentioned in written language is realised in the mathematical equation as the constituent parts  $2\pi/\omega$  of “ $2\pi c/\omega$ ”), and the wavelength being pointed out in the image with a bi-directed arrow perpendicular to the crests. Consequently, the only geometric construction that still satisfies all those constraints is one where the wave’s direction, defined as a direction perpendicular to the crests, changes as the wave enters the glass block from the vacuum. This statement is expressed through the mathematical equation

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<sup>57</sup> A crest is the point of the wave where the entity constituting it has its maximum value, is never unpacked in the text extract and must be known from other texts.

<sup>58</sup> As with “travelling” I am here using “extension” to label the disciplinary-relevant aspect as a whole and not just the option of “extended” that stands in a contrast relation to “not extended.” Note that “extension” is a nominalisation.

<sup>59</sup> The nominalization “oscillation” is here used to label the disciplinary-relevant aspect as a whole and not just the option of oscillation that stands in a contrast relation to “non-oscillation.” Note that “oscillation” is a condensation in the sense of a name for “a whole little thematic pattern” (Lemke, 1990, p. 101; see Section 2.7; I use this term also for my patterns of disciplinary-relevant aspects).

<sup>60</sup> Which emphasize the process nature of the wave.



$\lambda_0 / \sin \theta_0 = \lambda / \sin \theta$ , where both the left hand side and the right hand side of the equation implicitly express “the same spacing along the surface” in terms of the different values of the wavelengths and the angles (which mathematically formalise the direction) in the different materials. The text extract leaves the reader to verify this statement by giving consideration to alternative options. Table 4.5 gives a summary of the analysis outcome.

*Table 4.5.* Summary of the analysis outcome. Implicit realisations given in square brackets. The ways that the disciplinary-relevant aspects are divided is given in brackets using the systemic functional linguistics (SFL) terminology for qualities: as continuous, binary, or taxonomic distinctions (see Section 2.5.1).

<b>Disciplinary-relevant aspect</b>	<b>Written language</b>	<b>Mathematical formalism</b>	<b>Image</b>
Travelling (Binary)	[Arrives, direction of travel, be travelling]		[Arrow pointing out direction of travel]
Speed (Continuous)	Speed, “different in the materials”	c [in vacuum], v [in other materials], proportional to $\lambda$ [wavelength] when $2\pi/\omega$ [frequency] is constant.	
Direction (Continuous)	Perpendicular to crests, from vacuum to glass; [angle]	$[\theta \text{ and } \theta_0 \text{ (angles)}]$ , indicated by index zero vs. no index e.g. in $\theta$ and $\theta_0$	Uni-directed arrows [perpendicular to crests], $\theta$ and $\theta_0$ [angles]
Material (Taxonomic)	Vacuum, glass		Vacuum, glass
Extension of crests (Binary)	[Has an arrow perpendicular to it]		Yes; straight (broken) lines
Spacing along glass block surface (Continuous)	Same in both materials	$[\lambda_0 / \sin \theta_0 = \lambda / \sin \theta]$	Same in both materials
Kind of wave (Taxonomic)	Electric		
Oscillation (Binary)	Oscillation		
Frequency (Continuous)	Frequency; constant	$[2\pi/\omega]$	
Wavelength (Continuous)	Wavelength; Shortest distance between crests	$\lambda, \lambda_0$	Bi-directed arrow
Refractive index (Continuous)		n [a material-dependent constant that is a function of wavelength; it is usually specified for a wavelength of 589 nm]	

#### 4.4.2 Answer to Research Question 4

*What interconnections can be made between the analytic construct disciplinary-relevant aspects that was developed for this thesis and the Variation Theory of Learning's notion of critical aspects?*

This question is answered in two parts. In Part 1, I bring to the fore the most significant theoretical links that I see existing between the social semiotic perspective of this thesis and the Variation Theory of Learning. These links build on the theoretical descriptions in Chapter 2. These were links that I started to notice when I created my patterns of disciplinary-relevant aspects for the analysis of the first dataset. These links are educationally relevant to physics education in the sense that although the literature continuously reports on new compelling evidence of the merits of the Variation Theory of Learning, it does not explicitly focus on the semiotic resources that are used to create the needed variation.

In Part 2, I then describe the particular interconnections that can be made between my construct – disciplinary-relevant aspects – and the Variation Theory of Learning's notion of critical aspects.

##### **Part 1**

Below I give the theoretical links that I identified and find to be the most significant for this thesis:

- *The need to experience contrast to constitute meaning.* Variation Theory focuses on creating the kinds of contrasts that make learning possible (patterns of variation). In a related way the social semiotic perspective of this thesis focuses on systems of contrasting meaning – that is, patterns of disciplinary-relevant aspects – the basis for meaning-making.
- *Focussing on parts and wholes and the relations between them.* Variation Theory describes the awareness of wholes and their parts and how these relate to each other. Similarly, my social semiotic analysis of the construal of experience through the production and use of semiotic resources as a social communicative practice includes the analysis of taxonomical relationships. Such relationships also include wholes and their parts (see Section 2.5.2).
- *The Variation Theory of Learning's "restructuring of awareness" and the evolution of semiotic resources.* The Variation Theory of Learning suggests that the experience of contrast should be followed by the experience of fusion of different aspects/parts into a whole. This is described as a "restructuring of awareness" (Booth, 1997, p. 147).

The social semiotic perspective of this thesis describes semiotic resources as evolving through “rationalization” (see Paper III) and “condensation” (Lemke, 1990, p. 101). There is a clear correspondence between these processes, where the first leads to the two latter. It is possible that the more comprehensive, differentiated and integrated a person’s awareness is, the less detail is needed in the semiotic resources.

- *The importance of prior experience.* The Variation Theory of Learning draws on prior experience, for example, in order to make diachronic variation possible (as described in Section 2.9.5). Social semiotics similarly describes previous experience as a potential for interpreting new ones.

## **Part 2**

After the analysis described in Section 4.2.3 I found that the analytical unit disciplinary-relevant aspects essentially has the same characteristics as the unit “critical aspects” that the Variation Theory of Learning uses to characterise those patterns of variation that are needed to enable classroom learning (see Paper IV). In the Variation Theory of Learning, identifying and enacting the critical aspects of an object of learning is fundamental for making learning possible (Lo, 2012; Marton and Booth, 1997; Marton et al., 2004). In this sense, the social semiotic perspective that I constituted for this thesis informed my analysis of this object of learning as it is realised in, for example, the text extract that I analysed in the previous section.

In the next chapter I provide a detailed example of how a pattern of variation to address several of the disciplinary-relevant aspects in Table 4.5 can be created. This relationship depends on the particular task at hand, and on the depth of the explanation to be provided.

Taking a broad overview, one can summarize how I got to see the relationship between my disciplinary-relevant aspects and the Variation Theory of Learning’s critical aspects: disciplinary-relevant aspects are the educationally important parts of an object of learning seen from the discipline’s perspective, and critical aspects are the educationally important parts of an object of learning seen from the students’ perspective. And both perspectives have the object of learning in focus.

### *Discussion and implications*

The enactment of objects of learning needs to provide a pattern of variation that allows the disciplinary-relevant aspects to be discerned. This is independent of whether the enactment is given in the form of a textbook, a lecture, or in interactive engagement among students.

Disciplinary-relevant aspects may, however, be realised implicitly and/or explicitly through the semiotic resources that are used. In order for learning

to take place it is therefore important to identify and explicate instances of implicit variation (Marton and Booth, 1997, p. 100). In this respect the distinction that Lemke (2003) makes between meaning by kind (typological meaning) and meaning by degree (topological meaning) has potentially important consequences for the creation of variation within disciplinary-relevant aspects. This is because the appropriateness of a semiotic resource for creating variation is likely to depend on whether the contrasts that need to be noticed are of a topological and/or typological character. For example, the difference between air and water is typological, which is the kind of meaning that language deals well with. Differences in speed or temperature, on the other hand, are topological, which is the kind of meaning that the number system or various diagrams are more appropriate for.

It is possible that a teacher who has made a preliminary analysis of the kind that was considered above will also be more attentive to students' questions and comments regarding the content of the teaching (see Section 4.2.4). The ways students talk, act, and use semiotic resources other than spoken language, can provide valuable indications of what the *students* consider to be the relevant aspects in a given physics situation, and what aspects they do not pay sufficient attention to in comparison to what is disciplinary relevant. This could help the teacher identify educationally critical aspects that were previously taken-for-granted and thus help students to discern new disciplinary-relevant aspects.

The analysis given earlier provides a potentially very powerful method to identify the disciplinary-relevant aspects of any object of learning and further to identify which critical aspects need to be varied to enhance the possibilities for learning. However, when undertaking such analysis it is important to pay close attention to both explicit and implicit variation; particularly in physics where implicit variation tends to be the rule rather than the exception. Here, there is the danger that the meaning of semiotic resources that is fully accessible to the disciplinary "insider" (such as the teacher), remain hidden from the disciplinary "outsider" (such as the student). In such instances it is important then that any implicit variation is unpacked (see Paper III and Section 2.7) during the analysis.

In relation to Research Question 3 about unpacking and in relation to the different disciplinary-relevant aspects that can be identified for a given object of learning, it should be noted that there is a continuum of degrees of relevance (see the answer and discussion for Research Question 1 in Section 4.2.4) of the different disciplinary-relevant aspects that are found in the analysis. The analysis used here does not, however, differentiate between these degrees.

In conclusion, an important goal for all teachers should be to enable their students to discern new disciplinary-relevant aspects of objects of learning. The Variation Theory of Learning suggests this can be achieved by opening

up variation around these aspects (creating patterns of variation). Consequently, what I am characterizing as disciplinary-relevant aspects can be seen to provide a powerful additional tool for physics teachers (see the results for Research Question 5 and 6).

In the next section I report on a thought experiment that addresses some of the possible implications for teaching and learning that stem from my research outcomes.

## 4.5 Research Question 5 (Paper V)

In this section I present a thought experiment that has been reported on in Paper V, from which parts for this section are taken. This “thought experiment” is used to answer Research Question 5:

*As a thought experiment, what are the implications of the answer to Research Question 4 for the teaching and learning of physics?*

Thought experiments constitute “an integral part of physics” (Helm & Gilbert, 1985, p. 131) and have been used both in special relativity and in quantum physics. Here, I use a didactic thought experiment in order to discuss the implications for teaching that I see stemming from the bringing together of theoretical parts of my social semiotics perspective with those of the Variation Theory of Learning. This thought experiment thus has the whole of my conceptual framing as its theoretical background.

### 4.5.1 A thought experiment

The starting point of this thought experiment is the insight that a pattern of disciplinary-relevant aspects can be realised through the production and use of a range of semiotic resources. The question then becomes which semiotic resource/s are most apt for providing access to certain meaning. As my illustrative example from the electronics laboratory in Section 4.3.1 shows, the answer may differ depending on a person’s level of appreciation of the disciplinary affordance of different semiotic resources. Students and teachers might find different semiotic resources to be more apt in the sense of providing access to an optimal amount of detail. For this reason the questions that the teacher needs to ask themselves is *not* about which semiotic resource will most aptly communicate what they want to share with students, but rather which details need to be communicated to them; in other words, firmly putting the object of learning in focus. Because each physics phenomenon is associated with a wide range of aspects, a choice needs to be made about which aspects are disciplinary relevant. For example, when

solving a problem related to the refraction of light a physicist might conceivably deem some of the aspects in Table 4.6 to be relevant.

Table 4.6. Potential disciplinary-relevant aspects in situations where the refraction of light takes place.

Angle
Direction
Distance
Frequency of light
Medium
Position
Refractive index
Sine of angles
Speed of light
Temperature
Time
Wavelength of light

In order to solve a particular problem, or to explain a given part of the phenomenon, only a subset of these aspects may be needed; what the intended object of learning is. As a teacher it is critical to know what the disciplinary-relevant aspects are for the learning goal at hand. Here, I will use the example of providing a *qualitative* explanation of why light “bends” at the surface between two media with different refractive indices, which is similar to the question that was given to the students that contributed to my first dataset. In the first dataset (see Section 4.2.4) I identified three disciplinary-relevant aspects to be direction, medium, and speed of light (see Paper I; and Kryjevskaja et al., 2012). I will therefore use these as the disciplinary-relevant aspects for this thought experiment.

Once the disciplinary-relevant aspects of the object of learning have been identified, those semiotic resources that best provide access to these aspects can be selected. As pointed out above, a number of semiotic resources can potentially fill this function. The question is *which* semiotic resource or resources are most apt for this purpose. Here, a ray diagram (see Figure 4.18), for example, could potentially be used to provide access to the change in direction of the propagation of light and the change in medium.

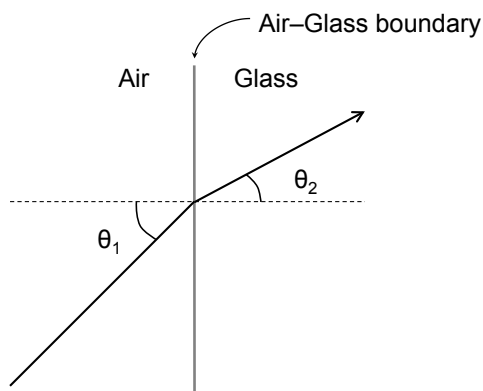
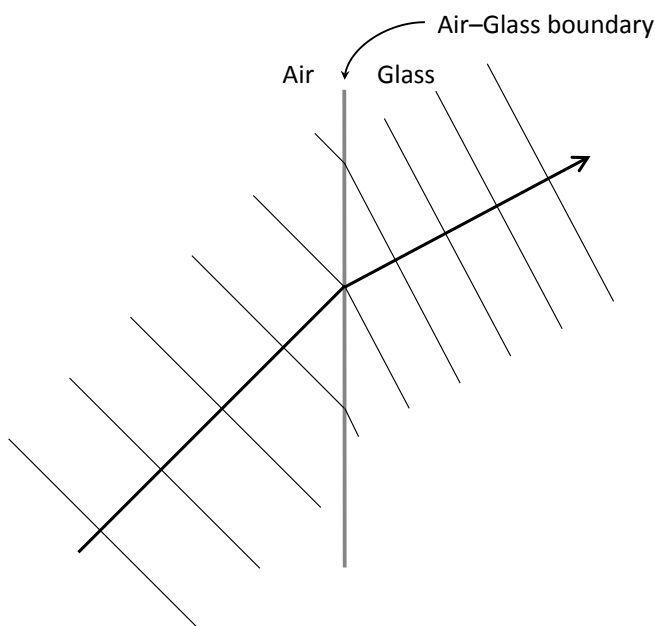


Figure 4.18. A ray diagram showing the refraction of light at an Air–Glass boundary and the angles of incidence ( $\theta_1$ ) and of refraction ( $\theta_2$ ) (Paper V).

A second candidate for an appropriate semiotic resource is Snell’s law ( $n_1 \sin \theta_1 = n_2 \sin \theta_2$ ). Here, the refractive index ( $n$ ) could be “unpacked” (see Paper III and Section 4.3) as  $n = \frac{c}{v}$  to provide explicit access to the speed of light, ( $v$ ). However, although Snell’s law presents the relationships between the different disciplinary-relevant aspects to be communicated, it is dependent on also having a ray diagram in order to identify the different angles involved. This is usually the case in physics – a number of semiotic resources need to be used together to make holistic meaning possible (see, for example, Airey and Linder, 2009). However, because of the difficulties that many students experience with translating between different semiotic resources (see, for example, Ainsworth, 2006; Schönborn & Bøgeholz, 2009) the *optimal* semiotic resource would be one that presented all the different disciplinary-relevant aspects. From this point of view Snell’s law is not an ideal semiotic resource to use on its own. Another issue with Snell’s law is that it is essentially quantitative i.e., its main function is to provide numerical values of the angles of incidence and refraction. Snell’s law together with the ray diagram essentially only shows *how much* light “bends” but not *why*. But in this thought experiment the goal is to provide a qualitative explanation of the refraction of light.

A third possible semiotic resource is the wavefront diagram (see Figure 4.19). This semiotic resource can be seen to bring together all three disciplinary-relevant aspects for a qualitative explanation of refraction – the direction (disambiguated by the arrow), the medium (indicated by the labels Air and Glass), and the speed of light (proportional to the shortest distance between the wavefronts). Thus, it has been shown to be an apt semiotic resource for the particular task of explaining why the refraction of light takes place (see Section 4.2.4, and Paper I).



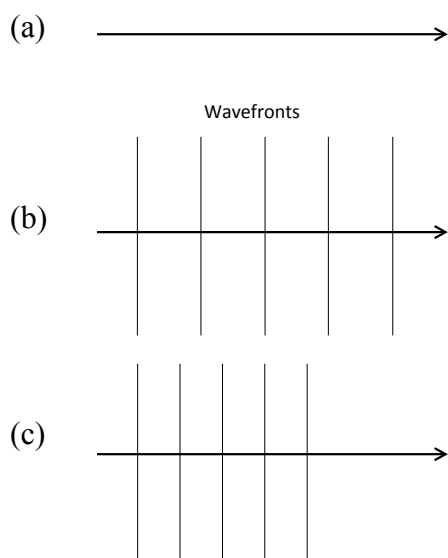
*Figure 4.19.* A wavefront diagram showing the refraction of light at an Air-Glass boundary when the angle of incidence is 45 degrees (Paper V).

I have described two factors that are important for successful introductory teaching of the refraction of light, namely 1) identifying disciplinary-relevant aspects (in this case direction, medium, and speed of light), and 2) selecting appropriate semiotic resources that provide students with access to these aspects (here, the wavefront diagram can be seen to be the most appropriate candidate). The final step in this thought experiment (the third important factor) brings in the Variation Theory of Learning, which says that a necessary condition for learning is to create variation around the disciplinary-relevant aspects in order to help students discern them and their relationships.

Here, a ray diagram can be an appropriate starting point in order to create variation in the first disciplinary-relevant aspect: direction. The direction can be disambiguated by the convention to draw rays of light as arrows in ray diagrams. The second disciplinary-relevant aspect is the medium, which can be varied by labelling different media that are juxtaposed to create a contrast. The third disciplinary-relevant aspect is the speed of light. Here, the wavefront diagram can be constructed by augmenting a ray of light (Figure 4.20 a) with wavefronts (Figure 4.20 b). The way that the distances between wavefronts relate to the speed of light can then be illustrated by contrasting a higher speed of light (larger distance between wavefronts) with a lower speed (shorter distance between wavefronts; compare Figure 4.20b



with Figure 4.20c). (In order to familiarise students with this relationship they could be asked to predict how the distances between the wavefronts in a wavefront diagram would vary for different speeds).



*Figure 4.20.* The effect of different speeds of light on the distance between wavefronts. (a) An arrow pointing out the direction of propagation of (a ray of) light. (b) Wavefronts travelling at a given speed. (c) Wavefronts travelling at two-thirds of the speed in 4.20b (Paper V).

So far in this thought experiment the relationship between the medium at hand and the speed of light in that medium has not been addressed. In order to give a qualitative explanation of why the refraction of light takes place, all three disciplinary-relevant aspects need to get to be related to each other by a student. Essentially, what needs to be understood here is the role that the speed of light in different media plays for the change in direction of propagation. In order to produce the necessary fusion (see Section 2.9.6) of the different disciplinary-relevant aspects, these aspects need to be co-varied. In order not to vary too much at a time, a starting point for the co-variation could be varying the medium and observing the effect on speed. Such a situation is depicted in Figure 4.21, where two media, air and glass, are juxtaposed so that light travels from one into the other. Here, students could be given wavefronts in one medium and asked to predict the distance between wavefronts in the other medium, based on the speeds of light in the different media (for an example table, see Table 20.1 in Oliviero & Woodward, 2014, p. 548). For example, the speed of light in air is approximately 300 000 km/s, in water 225 056 km/s, and in glass 200 000 km/s. Students' experiences of having carried out this step could also

contribute to reduce the risk that they think the speed of light in the first medium will affect the speed of light in subsequent media, which has been shown to be one of the potential problems that get encountered when learning about the refraction of light (see Kryjevskaja et al., 2012).

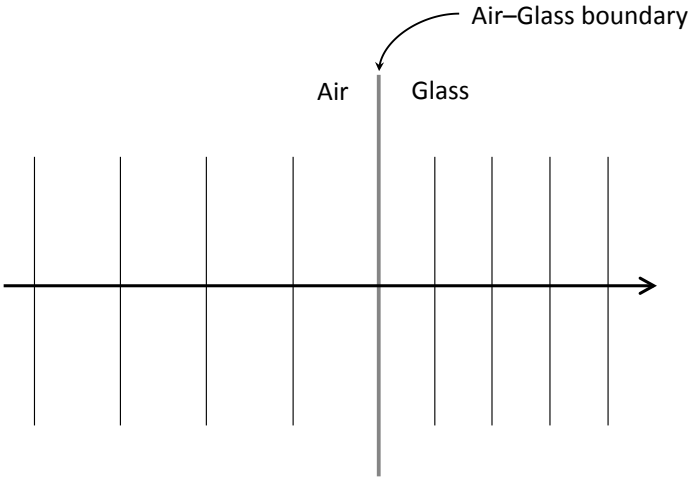


Figure 4.21. A diagram illustrating the speeds of light as proportional to the distances between wavefronts in air and glass, respectively (Paper V).

In the final stage of the Variation Theory of Learning model all the disciplinary-relevant aspects need to be varied together (as in Figure 4.19). Light comes in at an angle towards the Air-Glass boundary. Here, the wave is *compelled* to change its direction of propagation when the medium (and thus the speed of light) changes. This is the only way that the drawing of wavefronts in a continuous manner between the two media can be reconciled given that the shortest distances between the wavefronts are different in the different media (Kryjevskaja et al., 2012). As in the former step, students could be given the wavefronts in one medium and asked to draw them in the other. The information that is initially given to the students could also be varied, in terms of medium, direction, and/or speed of light, with students asked to fill in the gaps.

The pattern of variation (see Section 2.9.6) that was created can be given in tabular form as in Table 4.7, where the top two lines may be omitted if the students are found to be familiar with how the disciplinary-relevant aspects direction and medium are presented in the semiotic resources at hand.

Table 4.7. The pattern of variation created in this thought experiment.

	Direction	Medium	Speed
1	Variant		
2	Invariant	Variant	
3	Invariant		Variant
4	Invariant	Variant	Variant
5	Variant	Variant	Variant

## 4.5.2 Answer to Research Question 5

*As a thought experiment, what are the implications of the answer to Research Question 4 for the teaching and learning of physics?*

Following the analysis presented in the previous section, my answer to the question is constituted as follows:

This thought experiment has produced three factors that can be seen to be critical for enhancing the possibilities for learning from a semiotic resources point of view: (1) identifying disciplinary-relevant aspects; (2) selecting appropriate semiotic resources that provide the students access to the disciplinary-relevant aspects; and, (3) creating variation in the disciplinary-relevant aspects.

### *Discussion and implications*

First, the factor that involves identification of disciplinary-relevant aspects is intended to help teachers to pinpoint those aspects that students need to be aware of for a given task. This can be challenging since knowledge about *which* aspects are appropriate to focus on in a given situation, by and large, is tacit (Polanyi, 1967). For example, many physics teachers ‘just know’ which aspects to draw on in order to solve a given problem. Therefore, this (essentially trivial) first step towards sharing such tacit knowledge with students is critical but may often be overlooked. The importance of this factor cannot be overstated; students need to focus on the appropriate disciplinary-relevant aspects for the task before meaningful learning can take place.

Second, the selection of appropriate semiotic resources is intended to help students discern disciplinary-relevant aspects and to relate them to each other in meaningful ways. Choosing semiotic resources that bring these disciplinary-relevant aspects to the fore (see Paper III and Section 4.3) enhances the possibility that students notice them, but this, while necessary, is not sufficient on its own. This is because students often do not see semiotic resources in the same way that teachers do (for example, see Linder et al., 2014; and Meltzer, 2005, and Section 2.2.6). Here, the unpacking of

the semiotic resources (see Section 4.3, and Paper III) to a degree appropriate for the students in the given situation, and the development of fluency in a range of semiotic resources (Airey & Linder, 2009), are therefore essential complements to the appropriate selection of semiotic resources.

The final factor involves creating variation around each disciplinary-relevant aspect against an unchanging background. This further enhances the possibility for students to notice and focus on the disciplinary-relevant aspects (Marton & Booth, 1997; Marton & Tsui, 2004). Once students have discerned the disciplinary-relevant aspects they can be co-varied in order to support fusion. It is these three steps together that in this thought experiment lead to disciplinary learning.

The approach that this thought experiment proposes might be considered to be too time consuming to employ, and therefore seem to be impractical to use in classroom practice. Therefore, finding out what *students* find challenging is vital background for decisions about what to spend time on in class. Teachers might consider using clicker questions (see, for example, Crouch and Mazur, 2001), Just-in-Time Teaching (Novak, 2011) and/or other methods to interact with their students in a dynamic fashion to find out which topics should be given more time and attention.

Teaching strategies based around interactive engagement also have the possibility to enhance student learning using the three factors of this thought experiment. Here, groups of students themselves could (1) make judgements of relevance between different physics aspects, (2) select appropriate semiotic resources for dealing with these physics aspects, and (3) function as the “vehicle of variation” (Marton & Booth, 1997; Tao, 2001) that is needed to notice disciplinary-relevant aspects.

As pointed out earlier, a number of semiotic resources will usually be necessary in order to deal with the disciplinary-relevant aspects that are necessary in order to appropriately tackle a given physics problem (see, for example, Van Heuvelen & Zou, 2001). In other words, a particular constellation of semiotic resources is usually needed to appropriately deal with physics knowledge (Airey & Linder, 2009). As a consequence, a teacher would typically need to create variation both within and across different semiotic resources. In order to achieve appropriate physics understanding students need to simultaneously focus on variation of disciplinary-relevant aspects both within and across the semiotic resources. This variation is likely to be much more challenging for students to experience productively and requires that they have reached a high level of fluency with each of the semiotic resources involved. This is a potential area for future research.

The modification of an existing semiotic resource (such as the coloured dots in the electric circuit example in Section 4.3.1), or the creative process

of producing entirely new semiotic resources (such as the Feynman diagrams, for example, see Feynman, 1949) are also possible ways to select appropriate semiotic resources.

In conclusion, the results of my thought experiment suggests that when working with semiotic resources in physics, incorporating the three factors that have been pointed out as being educationally critical has the potential to significantly enhance student learning outcomes. An important implication of this thought experiment is that my social semiotic perspective and the Variation Theory of Learning resonate together to suggest a new strategy for physics education that neither of the frameworks alone fully encompasses.

## 4.6 Research Question 6 (Paper VI)

As described in Section 1.2, Research Question 6 explores the implications of Research Questions 4 and 5 empirically:

*As an exploratory case study using a physics tutorial where the assigned problem has the distinctions between the concepts electric potential and electric potential energy in focus, what kind of intervention can be created to illustrate how the answer to Research Question 5 could be successfully implemented?*

The answering of Research Question 6 involved the design of an exploratory case study that involved the stages described in Section 3.7.1.

The first stage involved analysing transcriptions of the students interactively engaging (groups of 3-4 using desktop whiteboards) with a problem that called for making an appropriate distinction between the concepts of electric potential and electric potential energy. The second used this analysis to formulate the disciplinary-relevant aspects relating to these two concepts through a process similar to that used for Research Question 1 (see Section 3.3.3). An illustrative transcript analysis is given below and the working multimodal pattern is given in Figure 4.23. The disciplinary-relevant aspects that resulted from this analysis are given in Table 4.8. The next phase was a design stage that involved looking for ways to create patterns of variation around the disciplinary-relevant aspects set against an unchanging background, and to use this to create an “intervention” as per the outcome of Research Question 5. The final stage involved drawing up a comparison of two data-groups of students (1 year apart) working on an identical problem that required a solution that needed an appropriate conceptual distinction between electric potential and electric potential energy.

*Illustrative transcript analysis for the first year data-group*

In the transcript given below I illustrate how I evaluated how the students in the first year data-group managed the needed distinction between electric potential and electric potential energy in order to solve the tutorial problem.

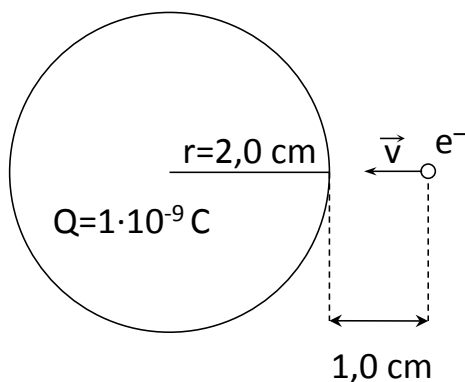


Figure 4.22. A reconstruction of one of the tutorial groups' pictures. (Paper VI)

Early in the students' solving of this problem the teacher suggested that they use the formula for electric potential,  $V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}$ , in their Physics Handbook (Nordling & Österman, 2006) to calculate the electric potential energy. The following two transcript extracts show how, when attempting to follow the teacher's advice, none of the groups made the distinction between electric potential and electric potential energy in an appropriate way.

Group 1:

Ron: The pot..., the potential difference is energy.

Bill: Ah.

Group 2:

Simon: And it is..., the potential..., is it..., that is the potential energy kind of?

Hailey: Yes, exactly.

The missing conceptual distinction between electric potential and electric potential energy also led both groups to write down formulae that inappropriately equated the difference in electric potential with the expression for the kinetic energy of the electron as it strikes the metal sphere

(see Equation 1 below). As a consequence the students were unable to solve the problem<sup>61</sup>.

$$V = \left| \frac{1 \cdot 10^{-9}}{4\pi\epsilon_0} \left( \frac{1}{6 \cdot 10^{-2}} \right) \right| = \frac{m_e v^2}{2} \quad \text{Equation 1}$$

However, these students did feel that the charge of the electron should have some bearing on their calculation. The conversation followed the following threads:

Group 1:

Bill: Well is it..., should..., do we really not need to count the contribution from that [pointing at the electron in their figure] to the whole thing [whistles with a falling pitch while moving his pointing finger towards the sphere]?

Guy: That's what I think that, because we use, we don't use... We only use one, one charge, we don't use...

[...]

Guy: But I'm talking about the electron's charge.

Bill: Yes exactly, we don't have it.

Group 2:

Beckett: Have we had the charge of the electron anywhere?

Hailey: No, I don't think we need to. Or, I don't know if we need to.

And so neither of the student groups could immediately see how to include the electron's charge in their mathematical expression. However, they felt that it should be somehow related to the electric potential:

Group 2:

Guy: Well, it's the electron's, erh, charge we need in the potential. That's where we should have it.

[...]

Guy: It is plus and minus, they pull each other together, and then we can't just count with that one. [Pointing at the centre of the sphere.]

The frustration experienced by the students led Bill in Group 1 to propose that the force acting on the electron be used instead to calculate the energy transformation:

---

<sup>61</sup> Note that although the equation was a hub in the student discussion (see Section 4.2.5) and the teacher looked at this equation when helping the group, the students' mistake appeared not to be noticed immediately. It can be seen, however, that this is an example of a persistent semiotic resource that potentially could have provided the teacher with valuable information about what the students were finding challenging (see the answer to Research Question 2).

Group 1:

Bill: You use that [pointing at Coulomb's law in their Physics Handbook (Nordling & Österman, 2006)] to calculate the force.

Ron: It calculates the force.

Guy: Yes.

Bill: We have a distance [tracing the distance between the electron and the sphere surface in their figure with index finger] to go.

Ron: Mm.

Bill: Force times distance is...? Energy!

Ron: Yes, energy.

Bill: Energy. There is a formula for energy that gives us the velocity. Isn't it that we should use?

Ron: But we want speed.

Bill: Yes! If we get the energy it... [pointing repeatedly from the electron towards the sphere in the figure] gets, or...

Ron: This is energy [circling with his index finger around Equation 1, see below.]

Bill: Yeah, yeah.

Guy: But the thing is that...

Bill: There we have two charges [pointing again in physics handbook.]

Ron: Yes.

Bill: That charge, that charge [pointing by turns at the electron and the sphere in the figure.]

Guy: ...also this force changes the closer it gets [tracing the path from the electron towards the sphere with a pen].

Bill: Integrate! [Laughter.]

Sam: Yes.

The teacher then had to specifically instruct the students to multiply the potential difference by the charge of the electron in order to reach the correct answer:

Group 2:

Teacher: You need a  $q$  here as well [referring to the students' equation], because this is... This is just the potential. To get the energy you have to take this times the charge that is moving in the potential. [Pointing at the electron in the figure.]

Group 1:

Teacher: We must have the charge of the electron here [writing  $e \cdot \Delta V$  on the students' whiteboard].

Sam: Oh, does that come in?



Teacher: Yes, because this, this [pointing at  $e \cdot \Delta V$ ] is... the change in potential energy.

Ron: Oh.

Bill: Times... then we should multiply by...

Teacher: Yes, because this is only the potential difference [pointing at Equation 1].

Bill: [Laughter.]

Teacher: You could remember this unit – electron volt.

Ron: Electron volt?

Guy: Mm.

Bill: Precisely.

Teacher: Then you have a charge times a potential difference.

Ron: Potential....

Despite leading the students to calculate the correct value for the electron speed when striking the sphere, Hailey was not satisfied with their mathematical expression:

Group 2:

Hailey: I don't really understand why, how I should think that it should be a small  $q$  there too.

Simon: No.

Hailey: I kind of don't get it.

Simon: No, because I thought we had a good argument before.

Here, it is clear that Hailey had not yet discerned the difference between electric potential and electric potential energy. It is also clear that the teacher expected the students to be familiar with the distinction between the two concepts and use the concepts in order to solve the problem.

Figure 4.23 gives the working multimodal pattern used to attain the disciplinary-relevant aspects needed to distinguish between the concepts of electric potential and electric potential energy. And Table 4.8 gives the resultant disciplinary-relevant aspects.

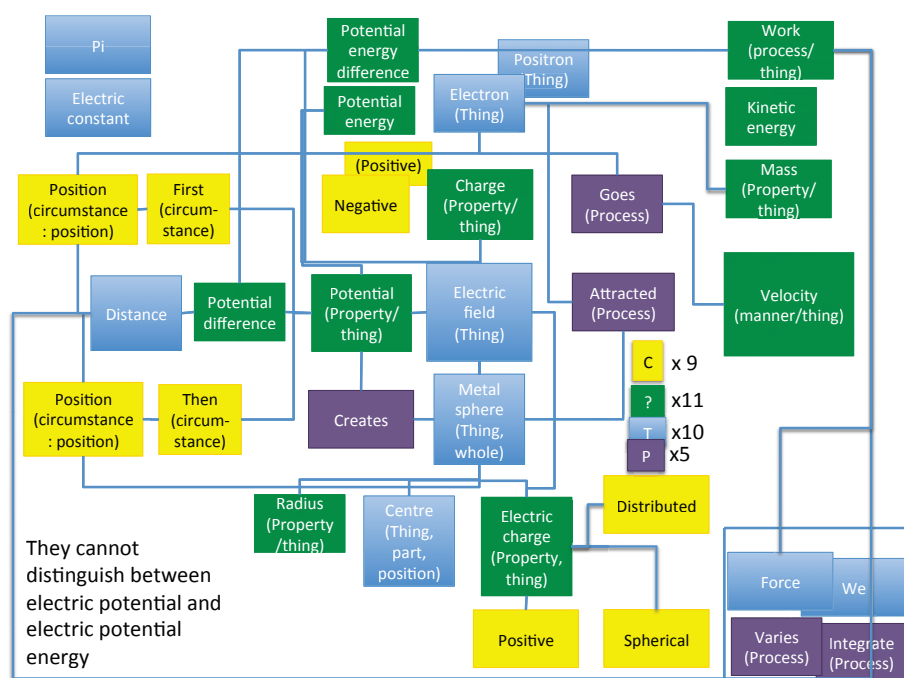


Figure 4.23. The working multimodal pattern used to attain the disciplinary-relevant aspects needed to distinguish between the concepts of electric potential and electric potential energy.

Table 4.8. The disciplinary-relevant aspects identified to distinguish between the concepts of electric potential and electric potential energy.

Physics content	Disciplinary-relevant aspect 1	Disciplinary-relevant aspect 2	Disciplinary-relevant aspect 3
Electric potential	Charge, Q, that creates the potential	Distance, r, from the Charge, Q, in [1]	
Electric potential energy	Charge, Q, that creates the potential	Distance, r, from the Charge, Q, in [1]	The charge, q, located at the distance, r, [2] from the Charge, Q, [1]

The most important parts of the disciplinary-relevant aspects for dealing with the conceptual distinction between electric potential and electric potential energy that was identified was the number of charges – that is, it is sufficient to have only *one* electric charge to create electric potential at a point; and, that for there to be electric potential energy at least *two* electric charges are needed (one being located at the electric potential created by the other).

The selection of an optimal semiotic resource or set of resources to give students access to the disciplinary-relevant aspects was obtained from a review of many physics textbooks and online educational resources that made the distinction between the concepts electric potential and electric potential energy easily discernable. During this process I came across an 11-minute video clip that used a multiplicity of semiotic resources in a very effective way – see Khan Academy (2014) – that I chose to use together with two clicker questions (see Section 2.2.1) to create the “intervention”.

Although not an explicitly given design feature, I saw the video clip as being effective because I could see that it enacted variation in different disciplinary-relevant aspects in ways that I could relate to what the Variation Theory of Learning called for (see answer to Research Question 4). Thus, the third essential factor needed for creating an “intervention”, namely to “create variation” (see Section 3.7), was satisfied by the video clip. In the video clip the following aspects were varied within and across disciplinary-relevant aspects.

Variation created *within* disciplinary-relevant aspects included:

- The charge creating a potential (e.g., zero vs. non-zero).
- The distance between a point and the charge creating an electric potential in that point (e.g., near vs. far; 3 cm vs. 4.5 cm vs. 9 cm).
- The potential at different distances from the (positive) charge creating the electric potential (big when near vs. small when far away; 100 J/C vs. 200 J/C vs. 300 J/C at decreasing distances).
- The electric potential energy at different distances from the charge creating the electric potential (e.g., “a lot” vs. “not quite as much” vs. “even less” at increasing distances).
- The electric potential energy for different charges located at a given potential (no charge – no potential energy vs. charge – potential energy).

Variation created *across* disciplinary-relevant aspects included:

- Electric potential vs. electric potential energy.

- Electric potential vs. electric potential difference (voltage).
- Potential energy vs. kinetic energy.

The resulting pattern of variation of the identified disciplinary-relevant aspects (see Table 4.8) that were created in the video clip are presented in Table 4.9. This meant that I saw the video clip containing all three of the essential factors that physics teachers need to incorporate into their teaching practice to optimize learning outcomes, which the results of Research Question 5 give as:

- the identification of the disciplinary-relevant aspects for a given object of learning;
- the selection of appropriate semiotic resources to help students discern disciplinary-relevant aspects and to relate them to each other in meaningful ways; and,
- the creation of variation around each disciplinary-relevant aspect against an unchanging background.

Table 4.9. The pattern of variation created in the Khan Academy video clip.

	Q (Charge)	R (Distance)	q (charge)	U (Electric Potential Energy)	V (Electric Potential)
1	Variant				Variant
2	Invariant	Variant			Variant
3	Invariant	Invariant	Variant	Variant	Invariant
4	Invariant	Variant	Invariant	Variant	Variant

In the following list I describe the different semiotic resources that were used in order to create the variation specified in Table 4.9.

1. Varying Q and V: *Speech*: There are empty points in space, no charges, V zero in different points. V not zero when charge is added. Positive Q yields positive V, negative yields Q negative V. *Drawing*: Adding “+Q” inscribed in a circle at the centre of the screen.
2. Q kept constant (positive). Varying r and V: *Speech*: [The potential] is big near the Q, small farther away. *Pointing in different places on the screen with cursor*: first close to the encircled + Q, then in the corners of the screen.
3. Q, r and V kept constant. Varying q and U: *Speech*: When there is nothing in the corner, the point’s V-value is 100J/C. If there is a charge of +2 C there are 200 J of energy. *Drawing*: draws a point in the corner of the screen (in other words, r kept constant). Draws a point charge “+2C” and moves it to the point in the corner. *Writing*: the point’s V-value is “100 J/C.”

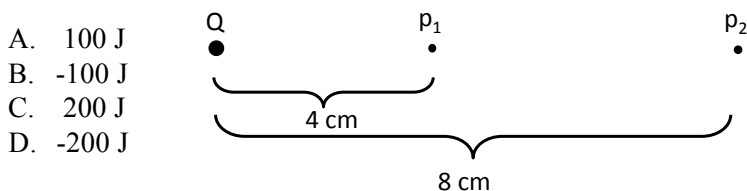
4.  $Q$ ,  $q$ , and  $V$  kept constant. Varying  $r$  and  $U$ : *Speech*: A third of the distance gives three times the  $U$  value. *Drawing*: Draws different distances from the charge in the centre of the screen. Draws a point charge and moving it around illustrating what is being said.

An interesting aside: the Khan Academy video also builds on students' previous knowledge about energy, and in particular the energy unit Joule (J). This is achieved by comparing the constituents of the Joule (the unit of electric potential energy) with those of the Joule per Coulomb (the unit of electric potential). In the transcript extracts presented earlier, the teacher also attempted to draw on an energy unit – the electron volt – to motivate the multiplication of the charge of the electron by a potential difference to get energy. However, the students did not appear to take up this association.

#### *Analysis for the second year data-group*

For the “intervention” comparison, the analysis of the second data-group of students, I drew on what I learnt from the first data-group analysis to make extensive field notes during the second data-group's tutorial session. This session began with the “intervention.” The “intervention” included showing the video to the students and stopping it in appropriate places to ask two clicker questions. These questions aimed to engage the students in discussions around the discernments that the “intervention” wanted to make possible. The questions given were:

1. The relationship between the electric potential  $V$  and the distance  $r$  to the charge  $Q$  creating the potential is described as:
  - A. The electric potential is proportional to the distance  $r$ .
  - B. The electric potential is inversely proportional to the distance  $r$ .
  - C. The electric potential is independent of the distance  $r$ .
2. A positive point charge  $Q$  is positioned according to the figure. The electric potential difference between the points  $p_1$  and  $p_2$  is 100 J/C. If a particle with the charge  $2C$  is moved from  $p_1$  to  $p_2$ , what is the difference in electric potential energy of the system constituted by the two charges?



- A. 100 J
- B. -100 J
- C. 200 J
- D. -200 J

### *The comparison analysis*

The final analysis of the video transcripts showed how none of the six groups of students in the first data-group were able to make the distinction between electric potential and electric potential energy needed to solve the tutorial problem correctly *without extensive help from the teacher*. According to the teacher, who regularly teaches the electromagnetism course that both year data-groups of students were attending, this outcome was very typical for the given problem.

The analysis of my field notes for the second year data-group of students showed that all three of the groups in the tutorial were able to make the distinction between electric potential and electric potential energy that was needed *without any help from the teacher*.

I need to point out that the “intervention” only dealt with the distinction between electric potential and electric potential energy and, in ways similar to the first year data-group of students, the second year data-group students still experienced many other challenges. For example, some students thought that  $r$  in the formula for electric potential was the distance from the sphere surface to the electron, and some students attempted to make an analogy with the potential energy in a gravitational field, such as that near the surface of the earth. Regarding making the needed conceptual distinction between electric potential energy and electric potential, one of the groups initially did not take a potential difference into account when attempting to solve the problem. There was also some *initial* confusion regarding whether or not both charges involved in the tutorial problem should be involved in the calculations.

In stark contrast to first year data-group of students studied, it must be emphasised that *all* the students in the second year data-group were able to constitute a correct conceptual distinction amongst themselves. In addition, the teacher observed that these students solved the problem more quickly and more effectively than students normally do.

#### 4.6.1 Answer to Research Question 6

*As an exploratory case study using a physics tutorial where the assigned problem has the distinctions between the concepts electric potential and electric potential energy in focus, what kind of intervention can be created to illustrate how the answer to Research Question 5 could be successfully implemented?*

The analysis shows that the Khan Academy video clip, used together with selected clicker questions, represents the kind of successful “intervention” that can be created to illustrate how the three essential factors that physics

teachers need to incorporate into their teaching practice to optimize learning outcomes could be successfully implemented.

### *Discussion and Implications*

The result that the “intervention group” of students were *all* able to make the needed distinction between electric potential and electric potential energy *without any help from the teacher* represents a considerable educational gain.

The “intervention” that was carried out supports the idea that in order to effectively help the students experience the learning objectives in a disciplinary way, tasks need to be designed that provide students with opportunities to experience contrasts (variation) within and across disciplinary-relevant aspects.

In Paper VI I have used the analysis to propose that students’ learning challenges can be seen to lie on a continuum from long-term conceptual hurdles that take time and effort to address, to quite short-term issues. I have characterized more short term learning challenges as a transient learning challenge. When physics teachers are able to recognize such transient learning challenges, the introduction of the kind of “intervention” that I have described can be seen as a way to very quickly and effectively address the learning challenge.

In conclusion, the whole process described in this exploratory case study presents a successful illustration of implementing the theoretical recommendations from Research Question 5. The exploratory case study also emphasizes the importance of providing students with opportunities to produce different kinds of semiotic resources in their interactive engagement.

## 5 Contributions to PER

In this chapter I summarise the implications for the teaching and learning of physics and the methodological and theoretical contributions that I see my thesis work making to the broader field of Physics Education Research. Some of the listed contributions are in more than section.

### 5.1 Implications for the teaching and learning of physics

Regarding disciplinary affordance and patterns of disciplinary-relevant aspects, the work in my thesis indicates that:

- different semiotic resources have different possibilities to provide access to different aspects of disciplinary knowledge. I have termed such access the disciplinary affordances of the semiotic resources;
- experienced teachers may have developed tacit knowledge about the disciplinary affordances of semiotic resources;
- enhancing teachers' awareness of the disciplinary affordances of the semiotic resources that they use can help them create better opportunities for student learning;
- physics content (objects of learning) can be described in terms of a pattern of disciplinary-relevant aspects, and students need a specific range of semiotic resources in order to deal appropriately with these disciplinary-relevant aspects;
- semiotic resources that provide explicit access to disciplinary-relevant aspects appear to better facilitate physics learning than those that provide implicit access – which aspects are disciplinary-relevant depend on the learning object;
- patterns of disciplinary-relevant aspects provide the basis for teachers to select appropriate semiotic resources; and,
- students might base their choice of semiotic resource on the frequencies of use of the different semiotic resources.



Regarding persistent and non-persistent semiotic resources, the work in my thesis indicates that:

- persistent semiotic resources can function as hubs in the students' discussions, and students therefore need opportunities to, and should be encouraged to, produce persistent semiotic resources in their interactive engagement. This implies that the students would need, for example, whiteboards to write and draw on;
- persistent semiotic resources can help teachers to find out what the students find challenging, and therefore teachers should be observant for which persistent semiotic resources the students produce; and,

Regarding rationalized semiotic resources, in my thesis I have:

- illustrated the learning challenges that rationalized semiotic resources present to students;
- proposed a way to modify circuit diagrams that allows students to more easily and explicitly access disciplinary knowledge – in particular about the connections to a common circuit grounding;
- argued that semiotic resources need to be unpacked (making them more explicit) in order for students to gain access to disciplinary-relevant aspects.

Regarding the creation of patterns of variation, the work in my thesis indicates that:

- disciplinary-relevant aspects once identified can provide clues to teachers about what needs to be varied in order to enhance the possibilities for learning.
- the explication of instances of “implicit variation” (in terms of being presented in the semiotic resource but not varied) is a way to enhance the possibilities for learning.
- student learning benefits from tasks designed to provide students with opportunities to experience variation within and across disciplinary-relevant aspects.
- the students can create the needed variation themselves in their interactive engagement around appropriate tasks.
- three factors are needed in order to enhance the possibilities for student learning: (1) identifying disciplinary-relevant aspects, (2) selecting appropriate semiotic resources, and (3) creating patterns of variation around the disciplinary-relevant aspects.

## 5.2 Methodological contributions

The methodological contributions to the field of PER are:

- an exemplification of how multimodal transcription of interactive engagement in physics can be achieved and presented in an analytically meaningful way;
- a development of ways to constitute and present both dynamic analysis and synoptic analysis of multimodal interactive engagement between students;
- showing that when dynamic and synoptic analyses are carried out “simultaneously,” they have the distinct potential to pinpoint moments in interactive engagement that are critical from a physics learning point of view;
- the way that dynamic and synoptic analyses together can be used in order to say something about the disciplinary affordances of the semiotic resources that are produced;
- disciplinary-relevant aspects as an analytical unit for the analysis of meaning-making in physics;
- an analytical approach to be used where disciplinary knowledge can be captured in terms of patterns of disciplinary-relevant aspects;

## 5.3 Theoretical contributions

The theoretical contributions to the field of PER are:

- creating a construct that I call disciplinary affordance in order to denote the access to disciplinary knowledge that a given semiotic resource provides;
- that an important aspect of achieving scientific literacy should be about becoming proficient in selecting which (persistent) semiotic resources have the appropriate disciplinary affordances for a given situation;
- the demonstration of how the constructs and concepts from Systemic Functional Linguistics (SFL) are educationally valuable for discussing many of the aspects that pertain to scientific text that could present learning challenges for students, including dynamic and synoptic perspectives on text; realisation; rank and rankshift; nominalisation and technicalisation; meaning potential; and, unpacking, for which I have suggested the term reverse rankshift;

- that students' initial choice of which semiotic resource to use will be a function of its frequency of use in educational settings;
- that many of the semiotic resources that are typically used in much of the teaching of physics do not provide students with access to many important aspects of physics knowledge. Students need to come to appreciate the disciplinary affordances of physics semiotic resources;
- that the distinction between persistent and non-persistent semiotic resources in relation to their roles in disciplinary meaning-making is important teaching knowledge for setting up interactive engagement learning scenarios;
- revealing the similarities between a social semiotic perspective on meaning making and the Variation Theory of Learning;
- that the conventions of how semiotic resources are used affect their disciplinary affordances; and
- that the choice of semiotic resource is important for attaining successful learning outcomes.

## 6 Concluding remarks

My research work as a PhD student has taken me on a journey that concluded with my writing of this thesis. But it is not the end; I feel that I have opened up new research possibilities both for myself and for others. So, in this final chapter I will reflect back on what I have done in order to propose ways to continue the journey. I do this against what I saw as some of the most interesting aspects to emerge from my PhD work.

During my PhD work I came to really appreciate that it is in the *processes* of meaning-making and exchange of meaning in learning situations that learning and the development of repertoires of meanings take place. In other words, this is how one becomes a ‘disciplinary insider’ – in the case of my research work, a physicist. Here, the semiotic resources that are used in physics to share ways of knowing with students and with other physicists play critical roles. Not only do semiotic resources make activities such as problem solving, doing experiments, and reporting research results possible, but they also play important roles in creating the kind of critical contrasts that facilitate the noticing of disciplinary-relevant aspects. At the same time, semiotic resources facilitate the coordination of sets of disciplinary-relevant aspects. From a social semiotic perspective it is the relationships between the parts and the whole that determine the relevance and meaning of the different parts. To optimize physics learning outcomes, following the research that makes up this thesis, I recommend that physics students should always be provided with opportunities to actively participate in processes of meaning-making. In order to create such learning opportunities I propose that it is particularly important for teachers to give consideration to the following when they design their lessons:

- Which disciplinary-relevant aspects will their students need to discern?
- Which semiotic resources will best help their students to discern these disciplinary-relevant aspects?
- Will the students in their class be able to appreciate the disciplinary affordances of the semiotic resources that they [the teacher] plan to use?

My research work indicates that a bringing together of semiotic resource insights such as those listed above and an application of the Variation Theory of Learning will help provide the basis for meaningful physics

classroom transformation. I propose that future research builds on the following themes:

- What is the educational relationship between:  
students' appreciation of the disciplinary affordances of different semiotic resources, the frequencies of use of different semiotic resources, and students' choice of a particular semiotic resource in a given physics context;  
the number of semiotic resources that are used to create variation in disciplinary-relevant aspects and students' learning outcomes; and,  
students' use of persistent and non-persistent semiotic resources as they engage with different learning objectives?
- How can teachers develop an analytic gaze to spot students' learning challenges through the persistent semiotic resources that the students use?

Finally, interactive engagement among students can generate possibilities for the students to experience variation that they create themselves. Such possibilities need to be further investigated, for example through a close analysis of both the different semiotic resources that the students use, and how these semiotic resources enable the creation of variation within and across the disciplinary-relevant aspects.

## 7 Sammanfattning på svenska

### 7.1 Kontexten för föreliggande avhandling: ett bidrag till forskningen i fysikens didaktik

Forskning i fysikdidaktik på universitetsnivå har bedrivits i USA sedan 50-talet. Under 80-talet publicerades flera studier där de svårigheter studenterna mötte i sina fysikstudier undersöktes systematiskt. När en särskild svårighet identifierats vidtogs likaså systematiska åtgärder för att komma tillrätta med dessa svårigheter. Denna forskning har lett till en rad forskningsbaserade undervisningsmetoder. En gemensam faktor hos dessa metoder är att de baseras på studenters aktiva interaktion med varandra och med läraren. En annan gemensam faktor är att dessa metoder också i första hand verkar för att utöka studenters begreppsmässiga kunskaper.

En förutsättning för interaktion i fysikundervisningen är både lärares och studenters användning av en rad olika *semiotiska resurser*<sup>62</sup>. Som exempel på semiotiska resurser kan nämnas talat och skrivet språk, matematiska ekvationer, grafer, diagram, bilder och gester. En viktig aspekt av lärande i fysik är därför studenters behärskande av de semiotiska resurser som är typiska för fysiken.

I min avhandling har jag fokuserat på studenters användande av semiotiska resurser i undervisningsmiljöer som präglas av interaktivt deltagande. I synnerhet har detta skett genom analys av data från studenters arbete med olika fysikuppgifter: att förklara ett fysikaliskt fenomen (refraktion), att koppla ihop en elektrisk krets (en RC-krets) i en laboratoriekontext, samt betydelsen av att kunna skilja mellan elektrisk potential och elektrisk potentiell energi i problemlösningssammanhang inom elektrostatik.

Avhandlingen har ett teoretiskt fokus som har tagit sin utgångspunkt i ett socialsemiotiskt perspektiv. Emellertid har likheter med variationsteorin framkommit i analysen av data, vilket har gjort att aspekter från båda dessa teoretiska perspektiv har använts och kompletterat varandra.

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<sup>62</sup> Resurser för meningsskapande, ofta synonymt med tecken.

## 7.2 Semiotiska resurser: meningsskapande verktyg

En utgångspunkt i det socialsemiotiska perspektivet är att betydelsen av olika semiotiska resurser beror på de sociala kontexter där de används och att de utvecklas över tid beroende på de meningsskapande individernas intressen. Det socialsemiotiska perspektivet fokuserar inte enbart på talat eller skrivet språk utan analyserar alltmer också andra semiotiska resurser såsom exempelvis bilder och matematik, vilket ibland karakteriseras ibland som multimodalitet.

## 7.3 Disciplinspecifik meningspotential hos semiotiska resurser

De olika betydelser som kan uttryckas med en viss semiotisk resurs kallas i socialsemiotiken för dess meningspotential. Jag har valt att kalla de olika betydelser som kan uttryckas med en enskild semiotisk resurs i *en vetenskaplig disciplin* för den semiotiska resursens *disciplinspecifika meningspotential* (disciplinary affordance). Inom en disciplin kan meningspotentialen upplevas som inneboende i varje semiotisk resurs, på ett liknande sätt som organismer kan uppleva att föremål i deras miljö erbjuder olika användningsmöjligheter – såsom att en sten kan kastas eller sitta på, etc.

## 7.4 Att välja lämpliga semiotiska resurser

En fysikers arbete inkluderar att välja lämpliga semiotiska resurser (medvetet eller omedvetet), till exempel, när något ska mätas, beräknas eller kommuniceras. Med utgångspunkt från fysikerns behov och intressen väljs den semiotiska resurs som antas ha mest ändamålsenlig disciplinspecifik meningspotential. Hos studenter är förmågan att välja en lämplig semiotisk resurs ofta mer begränsad än hos erfarna fysiker. Detta beror delvis på studenternas begränsade erfarenhet av de semiotiska resursernas disciplinspecifika meningspotential. Två viktiga aspekter av fysikundervisning som kan ses som konsekvenser av denna observation blir då att hjälpa studenter att utöka den uppsättning av semiotiska resurser som de behärskar ”flytande”, samt att hjälpa studenter att utöka sina kunskaper om den disciplinspecifika meningspotentialen hos varje semiotisk resurs, vilka båda kan öka möjligheten för studenter att välja lämpliga semiotiska resurser för ett visst ändamål.

## 7.5 Begreppsliga och kvantitativa aspekter med disciplinspecifik relevans

Inom socialsemiotiken beskrivs traditionellt en semiotisk resurs som att den har en viss betydelse. I min forskning har jag analyserat betydelser som var materialiserade både genom språk och genom andra semiotiska resurser. Min analys av en diskussion som fördes inom en grupp av studenter som försökte förklara uppkomsten av fenomenet refraction av ljus visar vilka de viktigaste betydelseaspekterna som behandlades i studenternas diskussion var.

Min analys visar tre tydliga kontrastpar: luft och vatten (det material som ljuset färdas i), tunnare respektive tjockare (materialets densitet) och snabbare respektive långsammare (ljusets hastighet i de olika materialen). Studenterna använde sig av olika semiotiska resurser i sin förklaring av fenomenet för att uttrycka dessa kontrasterande betydelser. Vid ett tillfälle bytte de semiotisk resurs (från ett stråldiagram till ett vågfrontdiagram) vilket möjliggjorde för dem att visa betydelsen av ljusets hastighet för en helhetlig förklaring av fenomenet refraction. Detta kan ses som ett exempel på att de olika semiotiska resurserna har olika disciplinspecifika meningspotentialer.

Min analys är därför ett exempel där viktiga aspekter av fysikaliska fenomen kan beskrivas genom att olika kontrastpar som är kvalitativt unika relateras till varandra i särskilda kombinationer eller mönster. Kontrasterna kan vara diskreta (såsom luft och vatten) eller kontinuerliga (såsom variation i hastighet). Jag har valt att kalla sådana kontrastpar som är relevanta för ett särskilt fysikaliskt fenomen eller begrepp *aspekter med disciplinspecifik relevans* (disciplinary-relevant aspects) vilka, som exemplen ovan visar, kan vara av både begreppslik och kvantitativ karaktär. Benämningen disciplinspecifik relevans som jag har valt för dessa aspekter kommer av att de är relevanta för en viss vetenskaplig disciplin och för ett visst ändamål inom disciplinen.

## 7.6 En likhet med variationsteorin

I detta skeende av min forskning såg jag tydliga likheter mellan min beskrivning av disciplinspecifika aspekter och vad som i *variationsteorin* kallas kritiska aspekter, eller *dimensioner av variation* (Marton, 2005, p. 111). Inom variationsteorin ses lärande som att studenter upptäcker nya aspekter av fenomen som de inte upptäckt tidigare. Lärande möjliggörs i detta perspektiv av att variation skapas inom en aspekt av en större helhet, och mellan olika aspekter av denna helhet. I fallet med refraction som en helhet är variation inom aspekter just vad mina kontrastpar visar, liksom att



det finns kvalitativa kontraster mellan de olika disciplinspecifika aspekterna. Detta samband mellan å ena sidan min analys av de semiotiska resurser som studenterna använde i sin diskussion och å andra sidan variationsteorin skapar nya möjligheter att se på sambandet mellan en socialsemiotisk analys av semiotiska resurser och lärande.

## 7.7 Två sätt att hjälpa studenter erfara disciplinspecifik meningspotential hos semiotiska resurser och aspekter med disciplinspecifik relevans

Jag ser två viktiga uppgifter för lärare med avseende på den del av lärande som kan beskrivas med hjälp av mitt teoretiska ramverk. Den första är att hjälpa studenter erfara den disciplinspecifika meningspotentialen hos semiotiska resurser. Den andra är att hjälpa studenter erfara nya aspekter med disciplinspecifik relevans. I min forskning har jag beskrivit två utmaningar som lärare står inför när de vill utföra dessa uppgifter. Det första är den ”förtätade” karaktären av semiotiska resurser. Det andra är svårigheten att åstadkomma den nödvändiga kontrasten i aspekter med disciplinspecifik relevans.

### 7.7.1 Den komprimerade/förtätade karaktären hos semiotiska resurser

De semiotiska resurser som används i undervisningssammanhang i fysik idag har utvecklats genom historien till att bli effektiva verktyg för fysiker för olika ändamål. Denna utveckling har emellertid skett till priset av att icke-fysiker ofta inte kan utläsa de semiotiska resursernas betydelse direkt – de semiotiska resurserna har komprimerats/förtätats. Denna utveckling inom språket är särskilt tydlig i naturvetenskapligt språkbruk och har beskrivits inom lingvistik. Ett exempel på en sådan komprimering/förtätning är att det är vanligt att namnge komplexa processer med substantiv, som annars skulle behöva beskrivas genom hela satser. Inom systemisk-funktionell lingvistik (som utgör en del av socialsemiotiken) beskrivs ”uppackningen” av text därför som ett ofta nödvändigt steg för att studenter ska komma att förstå dess betydelse. På motsvarande sätt ser jag uppackning av andra semiotiska resurser än språk som ett viktigt (kanske nödvändigt) led i lärares strävan att hjälpa studenter erfara den disciplinspecifika meningspotentialen hos de semiotiska resurser som är typiska för ett visst ämnesområde.

Ett exempel på studenters svårigheter att tolka en komprimerad/förtätad semiotisk resurs är när studenter ska koppla ihop elektriska kretsar baserat på elektriska kretsdiagram, i vilka många olika aspekter med disciplinspecifik relevans har utelämnats (se delkapitel 4.3.1). Inom områden

som ingenjörsvetenskap, teknik och fysik är dessa aspekter ofta underförstådda. När jag presenterat studenters problem med ett visst elektriskt kretsdiagram för fysiker har det emellertid visat sig att fysikerna själva ofta skulle lösa problemet, som kan ses vara orsakat av konventioner för elektriska kretsdiagram, genom en ”trial-and-error”-ansats.

Jag hävdar att uppackandet av semiotiska resurser är ett viktigt led för att studenter ska upptäcka både deras disciplinspecifika meningspotential och nya aspekter med disciplinspecifik relevans som av ett otränat öga inte direkt kan utläsas från en viss semiotisk resurs.

### 7.7.2 Att skapa variation kring aspekter med disciplinspecifik relevans

Enligt variationsteorin är variation inom aspekter av helheter en nödvändighet för lärande. Det är inte oproblematiskt att med hjälp av de semiotiska resurser som är typiska inom ett visst naturvetenskapligt område skapa den nödvändiga variationen kring aspekter med disciplinspecifik relevans. En bidragande orsak till detta är behovet av uppackning av semiotiska resurser – inte alla aspekter med disciplinspecifik relevans är direkt synliga (eller hörbara) i de semiotiska resurser som används inom exempelvis fysiken. Även om sådana aspekter skulle vara synliga i en semiotisk resurs kan de ofta ändå inte ses av ett otränat öga. Hur variationen av aspekter med disciplinspecifik relevans ska gå till är ofta inte självklart ens med aspekterna synliga i de semiotiska resurserna.

Ett första steg i riktning mot att skapa den nödvändiga variationen är naturligtvis att identifiera de aktuella aspekterna med disciplinspecifik relevans. Här kan vad som har blivit känt som *learning study*, där lärare tillsammans jobbar med ett visst ämnesområde för att ta reda på vad studenterna behöver erfa, vara ett alternativ. Jag hävdar att den multimodala analys som jag presenterar i denna avhandling innebär ett nytt sätt att ta sig an denna problematik. En noggrann analys av de semiotiska resurser som används i fysiktexter kan bidra till att identifiera aspekter med disciplinspecifik relevans.

Nästa steg mot att skapa den nödvändiga variationen skulle vara att reflektera över vilka semiotiska resurser som bäst synliggör aspekterna med disciplinspecifik relevans så att de kan varieras och därmed bli lättare för studenter att upptäcka. Detta steg skulle sedan operationaliseras genom att försöka åstadkomma den nödvändiga variationen med dessa semiotiska resurser.

Det finns exempel från forskning i fysikdidaktik som indirekt har använt en liknande metod – utan en teoretisk grund. Ett exempel är utvecklingen av en övning som är ämnad att hjälpa studenter uppleva innebörden av termen ”plan elektromagnetisk våg.” I detta fall visar resultat från undersökningar

att en enda semiotisk resurs såsom ett ord, ”plan våg”, eller en ekvation,  $E_y(x, t) = E_{max} \cos(kx - \omega t)$ , ofta inte är tillräcklig för att studenter ska uppleva betydelsen av den semiotiska resursen. Den övning som beskrivs i litteraturen, och som framgångsrikt har använts för att hjälpa studenter få en mer helhetlig förståelse av plana vågor, har använt en graf föreställande en elektromagnetisk våg i ett koordinatsystem. I koordinatsystemet har studenterna sedan fått rita ut det elektriska fältet i olika punkter ordnade i ett plan som är vinkelrätt mot vågens utbredelseriktning. Denna variation har haft positiv inverkan på studenternas lärande.

Ett exempel som jag har undersökt till viss del är hur studenter lär sig att skilja på begreppen/storheterna elektrisk potentiell energi och elektrisk potential, vilket är av betydelse bland annat i problemlösningssammanhang. Här måste studenter skilja mellan, och uppleva relevansen av, att ha ett begrepp (elektrisk potential) som beror bara på *en* laddning och olika punkter i rummet, samt ett annat begrepp (elektrisk potentiell energi) som beror på den första storheten i en given punkt samt en *annan* laddning som befinner sig i den punkten. Detta bygger på att studenter erfar skillnaden mellan de två begreppen/storheterna, och det är ett sådant sätt att erfara som lärare behöver försöka åstadkomma med hjälp av de semiotiska resurserna.

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## 9 References

- Aamoth, D. (2010). Good question: will the floppy disk 'save' icon ever die? Retrieved 09-27, 2012, from <http://techland.time.com/2010/04/30/good-question-will-the-floppy-disk-save-icon-ever-die/>
- Ainsworth, S. (1999). The functions of multiple representations. *Computers & Education*, 33, 131-152.
- Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and Instruction*, 16(3), 183-198.
- Airey, J. (2009). *Science, language and literacy. Case studies of learning in Swedish university physics*. (PhD thesis), Uppsala University, Uppsala. Retrieved from <http://publications.uu.se/theses/abstract.xsql?dbid=9547>
- Airey, J. (2013). Disciplinary literacy. In E. Lundqvist, R. Säljö & L. Östman (Eds.), *Scientific literacy : teori och praktik* (pp. 41-58). Malmö: Gleerups.
- Airey, J., & Linder, C. (2009). A disciplinary discourse perspective on university science learning: Achieving fluency in a critical constellation of modes. *J. Res. Sci. Teach.*, 46, 27-49.
- Ambrose, B. S. (1999). *Investigation of student understanding of the wave-like properties of light and matter*. (PhD thesis), University of Washington, Washington.
- Ambrose, B. S., Heron, P. R. L., Vokos, S., & McDermott, L. C. (1999). Student understanding of light as an electromagnetic wave: Relating the formalism to physical phenomena. *Am. J. Phys.*, 67, 891-898.
- Andersson, S. (2011). Rangordningsövningar i naturvetenskap: en inspirationsrapport om en studentaktiv undervisningsmetod. Uppsala: Uppsala university.
- Baldry, A., & Thibault, P. J. (2006). *Multimodal Transcription and Text Analysis*. London: Equinox Publishing.
- Bateson, G. (1972). *Steps to an ecology of mind : collected essays in anthropology, psychiatry, evolution, and epistemology*. New York: Ballantine Books.
- Beichner, R. J. (2009). An introduction to physics education research. In C. Henderson & K. A. Harper (Eds.), *Reviews in PER Vol. 2*. College Park, MD: American Association of Physics Teachers.

- Bernhard, J. (2010). Insightful learning in the laboratory: some experiences from 10 years of designing and using conceptual labs. *European Journal of Engineering Education*, 35(3), 271-287.
- Bétrancourt, M., Ainsworth, S., de Vries, E., Boucheix, J.-M., & Lowe, R. K. (2012). *Graphicacy: do readers of science textbooks need it?* Paper presented at the EARLI SIG 2 Meeting 2012, Grenoble, France.
- Bezemer, J., & Kress, G. (2008). Writing in multimodal texts : a social semiotic account of designs for learning. *Written Communication*, 25, 166-195.
- Bezemer, J., & Mavers, D. (2011). Multimodal transcription as academic practice : a social semiotic perspective. *International Journal of Social Research Methodology*, 14(3), 191-206.
- Bezemer, J., Murtagh, G., Cope, A., Kress, G., & Kneebone, R. (2011). "Scissors, please": The practical accomplishment of surgical work in the operating theater. *Symbolic Interaction*, 34(3), 398-414.
- Bickford, J. H. (2008). *Introduction to the design and behavior of bolted joints* (4th ed.). Boca Raton: CRC Press.
- Bing, T. J., & Redish, E. F. (2009). Analyzing problem solving using math in physics: Epistemological framing via warrants. *Phys. Rev. ST Phys. Educ. Res.*, 5, 020108
- Bing, T. J., & Redish, E. F. (2012). Epistemic complexity and the journeyman-expert transition. *Phys. Rev. ST Phys. Educ. Res.*, 8, 010105.
- Bliss, J., Säljö, R., & Light, P. (Eds.). (1999). *Learning Sites : Social and Technological Resources for Learning*. Oxford: Elsevier Science Ltd.
- Bloom, J. W., & Volk, T. (2007). The Use of Metapatterns for Research into Complex Systems of Teaching, Learning, and Schooling : Part II: Applications. *Complicity: An International Journal of Complexity and Education*, 4(1), 45-68.
- Booth, S. (1997). On phenomenography, learning and teaching. *Higher Education Research & Development*, 16(2), 135-158. doi: 10.1080/0729436970160203
- Booth, S., & Hultén, M. (2003). Opening dimensions of variation: An empirical study of learning in a Web-based discussion. *Instructional Science*, 31, 65-86.
- Bowcher, W. L. (2007). Field and multimodal texts. In R. Hasan, C. M. I. M. Matthiessen & J. Webster (Eds.), *Continuing Discourse on Language : A Functional Perspective Volume 2* (pp. 619-646). London: Equinox Publishing.
- Bowden, J., & Marton, F. (1998). *The university of learning : beyond quality and competence in higher education*. London: Kogan Page.
- Brookes, D. T. (2006). *The role of language in learning physics*. (PhD thesis), The State University of New Jersey, New Brunswick, NJ.

- Brookes, D. T., & Etkina, E. (2007). Using conceptual metaphor and functional grammar to explore how language used in physics affects student learning. *Phys. Rev. ST Phys. Educ. Res.*, 3(010105).
- Brookes, D. T., & Etkina, E. (2009). "Force," ontology, and language. *Phys. Rev. ST - Phys. Educ. Res.*, 5, 010110.
- Chandler, D. (2007). *Semiotics : The Basics* (2nd ed.). New York: Routledge.
- Chen, Z., & Gladding, G. (2014). How to make a good animation: A grounded cognition model of how visual representation design affects the construction of abstract physics knowledge. *Phys. Rev. ST - Phys. Educ. Res.*, 10(010111).
- Christensen, W. M., & Thompson, J. R. (2012). Investigating graphical representations of slope and derivative without a physics context. *Phys. Rev. ST - Phys. Educ. Res.*, 8(023101).
- Cloran, C. (1999). Context, material situation and text. In M. Ghadessy (Ed.), *Text and context in functional linguistics* (pp. 177-217). Amsterdam: John Benjamins.
- Close, E. W., Conn, J., & Close, H. G. (2013, July 17-18). *Learning assistants' development of physics (teacher) identity*. Paper presented at the PERC 2013, Portland.
- Cole, D. R., & Pullen, D. L. (Eds.). (2010). *Multiliteracies in Motion*. New York: Routledge.
- Cope, C. (2000). *Educationally critical aspects of the experience of learning about the concept of an information system*. (PhD thesis), La Trobe University, Bundoora, Victoria.
- Corominas-Murtra, B., Fortuny, J., & Solé, R. V. (2011). Emergence of Zipf's law in the evolution of communication. *Phys. Rev. E*, 83(036115).
- Crouch, C. H., & Mazur, E. (2001). Peer Instruction: Ten years of experience and results. *Am. J. Phys.*, 69(9), 970-977.
- De Cock, M. (2012). Representation use and strategy choice in physics problem solving. *Phys. Rev. ST - Phys. Educ. Res.*, 8(020117).
- Dewey, J. (1997). *Democracy and education: an introduction to the philosophy of education*
- diSessa, A. A. (1983). Phenomenology and the evolution of intuitions. In D. Gentner & A. L. Stevens (Eds.), *Mental Models*. Hillsdale, NJ: Lawrence Erlbaum Press.
- Docktor, J. L., & Mestre, J. P. (2014). Synthesis of discipline-based education research in physics. *Phys. Rev. ST Phys. Educ. Res.*, 10(020119).
- Domert, D., Airey, J., Linder, C., & Lippman Kung, R. (2007). An exploration of university students' epistemological mindsets towards the understanding of physics equations. *Nordina*, 1, 15-28.
- Duval, R. (1999). *Representation, Vision and Visualization: Cognitive Functions in Mathematical Thinking. Basic Issues for Learning*.

- Paper presented at the 21st Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education, Cuernavaca, Morelos, Mexico, October 23-26, 1999.
- Duval, R. (2006). A cognitive analysis of problems of comprehension in a learning of mathematics. *Educational studies in mathematics*, 61, 103-131.
- Duval, R. (2008). *A crucial issue in mathematics education: The ability to change representation register*. Paper presented at the the 10th international congress on mathematical education, Denmark: IMFUFA, Department of Science, Systems and Models, Roskilde University.
- Einstein, A. (1952). The foundation of the general theory of relativity (W. Perrett & G. B. Jeffery, Trans.). In H. A. Lorentz, A. Einstein, H. Minkowski & H. Weyl (Eds.), *The principle of relativity* (pp. 111-164). New York: Dover Publications.
- Engeström, Y. (1987). *Learning by expanding : an activity-theoretical approach to developmental research*. Helsinki: Orienta-konsultit.
- Engeström, Y. (1999). Activity theory and individual and social transformation. In Y. Engeström, R. Miettinen & R.-L. Punamäki (Eds.), *Perspectives on activity theory* (pp. 19-38). Cambridge: Cambridge University Press.
- Entwistle, N., Nisbet, J., & Bromage, A. (2004). *Teaching-learning environments and student learning in electronic engineering*. Paper presented at the Third workshop of the European Network on Powerful Learning Environments, Brugge. <http://www.etl.tla.ed.ac.uk/docs/Brugge2004.pdf>
- Etkina, E., Gentile, M., & Van Heuvelen, A. (2013). *College physics* (1st ed.). Boston, MA: Addison-Wesley.
- Feynman, R. P. (1949). The theory of positrons. *Phys. Rev.*, 76(6), 749-759.
- Feynman, R. P., & Leighton, R. (1992). *Surely you're joking Mr. Feynman*. London: Vintage.
- Feynman, R. P., Leighton, R. P., & Sands, M. (1963). *The Feynman Lectures on Physics : Volume I* (Vol. I). Reading: Addison-Wesley.
- Forsman, J., Moll, R., & Linder, C. (2014). Extending the theoretical framing for physics education research: an illustrative application of complexity science. *Phys. Rev. ST Phys. Educ. Res.*, 10(020122).
- Fortuny, J., & Corominas-Murtra, B. (2013). On the origin of ambiguity in efficient communication. *J Log Lang Inf*, 22, 249-267.
- Frank, B. W., & Scherr, R. E. (2012). Interactional processes for stabilizing conceptual coherences in physics. *Phys. Rev. ST Phys. Educ. Res.*, 8(020101), 1-9.
- Fraser, D., & Linder, C. (2009). Teaching in higher education through the use of variation: examples from distillation, physics and process



- dynamics. *European Journal of Engineering Education*, 34(4), 369-381.
- Fraser, J. M., Timan, A. L., Miller, K., Dowd, J. E., Tucker, L., & Mazur, E. (2014). Teaching and physics education research: bridging the gap. *Rep. Prog. Phys.*, 77(3), 1-17.
- Fredlund, T., & Linder, C. (2010a). *Choosing the proper representation(s) in physics*. Paper presented at the the EARLI SIG 2 Conference, Tübingen.
- Fredlund, T., & Linder, C. (2010b). *Naturvetarnas 'språk': Användandet av figurer, artefakter, ekvationer och ord i studentdiskussioner om fysikaliska fenomen*. Poster presented at the NU2010 conference. October 13-15. Stockholm.
- Garfinkel, H. (1967). *Studies in ethnomethodology*. Englewood Cliffs, N.J: Prentice-Hall.
- Gee, J. P. (2005). *An Introduction to Discourse Analysis, Theory and Method* (2nd ed.). New York: Routledge.
- Geertz, C. (1973). *The interpretation of cultures*. New York: Basic Books.
- Gentner, D., & Stevens, A. L. (Eds.). (1983). *Mental Models*. London: Lawrence Erlbaum Associates.
- Georgiou, H., Maton, K., & Sharma, M. (2014). Recovering knowledge for science education research: exploring the "Icarus effect" in student work. *Canadian Journal of Science, Mathematics and Technology Education*, 14(3), 252-268.
- Gibson, E. J., & Pick, A. D. (2000). *An ecological approach to perceptual learning and development*. Oxford: Oxford University Press.
- Gibson, J. J. (1979). *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin.
- Gibson, J. J., & Gibson, E. J. (1955). Perceptual learning: differentiation or enrichment. *Psychological Review*, 62(1), 32-41.
- Gilbert, J. K., & Treagust, D. F. (Eds.). (2009). *Multiple representations in chemical education*. Dordrecht: Springer.
- Goodwin, C. (1994). Professional vision. *American anthropologist*, 96(3), 606-633.
- Gurwitsch, A. (1964). *The Field of Consciousness* (Vol. 2). Pittsburgh: Duquesne University Press.
- Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *Am. J. Phys.*, 66(1), 64-74.
- Halliday, M. A. K. (1966). The concept of rank: a reply. *Journal of Linguistics*, 2(1), 110-118.
- Halliday, M. A. K. (1978). *Language as Social Semiotic*. London: Edward Arnold.
- Halliday, M. A. K. (1979). Modes of meaning and modes of expression: types of grammatical structure, and their determination by different semantic functions. In D. J. Allerton, E. Carney & D. Holdcroft

- (Eds.), *Function and context in linguistic analysis*. Cambridge: Cambridge University Press.
- Halliday, M. A. K. (1991). Towards probabilistic interpretations. In E. Ventola (Ed.), *Functional and systemic linguistics: approaches and uses* (pp. 39-61). Berlin: Walter de Gruyter.
- Halliday, M. A. K. (1993a). Language and the order of nature. In M. A. K. Halliday & J. R. Martin (Eds.), *Writing science : literacy and discursive power* (pp. 117-136). London: The Falmer Press.
- Halliday, M. A. K. (1993b). On the language of physical science. In M. A. K. Halliday & J. R. Martin (Eds.), *Writing science : literacy and discursive power* (pp. 59-75). London: The Falmer Press.
- Halliday, M. A. K. (1996). Literacy and linguistics: a functional perspective. In R. Hasan & G. Williams (Eds.), *Literacy in society* (pp. 339-376). New York: Addison Wesley Longman.
- Halliday, M. A. K. (1998a). Things and relations : Regrammaticising experience as technical knowledge. In J. R. Martin & R. Veel (Eds.), *Reading science : critical and functional perspectives on discourses of science* (pp. 185-236). London: Routledge.
- Halliday, M. A. K. (1998b). Things and relations : Regrammaticising experience as technical knowledge. In J. R. Martin & R. Veel (Eds.), *Reading Science : Critical and functional perspectives on discourses of science* (pp. 185-236). London: Routledge.
- Halliday, M. A. K. (1999). The Notion of "Context" in Language Education. In M. Ghadessy (Ed.), *Text and context in functional linguistics*. Philadelphia: Benjamin.
- Halliday, M. A. K. (2002). Linguistic function and literary style: an enquiry into the language of William Golding's *The Inheritors*. In J. Webster (Ed.), *Linguistic studies of text and discourse* (Vol. 2, pp. 88-125). London: Continuum.
- Halliday, M. A. K. (2004a). The grammatical construction of scientific knowledge: the framing of the English clause. In J. J. Webster (Ed.), *The language of science* (Vol. 5, pp. 102-134). London: Continuum.
- Halliday, M. A. K. (2004b). Language and knowledge: the 'unpacking' of text (1998). In J. J. Webster (Ed.), *The language of science* (Vol. 5, pp. 24-48). London: Continuum.
- Halliday, M. A. K. (2004c). Language and the reshaping of human experience *Collected works of M.A.K. Halliday, Volume 5: The language of science* (Vol. 5, pp. 7-23). London: Continuum International Publishing.
- Halliday, M. A. K. (2004d). Language and the reshaping of human experience (1995). In J. J. Webster (Ed.), *The language of science* (Vol. 5, pp. 7-23). London: Continuum.
- Halliday, M. A. K. (2004e). *The Language of Science* (Vol. 5). London: Continuum.
- Halliday, M. A. K. (2007). *Language and Education*. London: Continuum.

- Halliday, M. A. K., & Martin, J. R. (1993). *Writing Science : Literacy and Discursive Power*. UK: Falmer Press.
- Halliday, M. A. K., & Matthiessen, C. (2014). *Halliday's introduction to functional grammar* (Fourth ed.). New York: Routledge.
- Halliday, M. A. K., & Matthiessen, C. M. I. M. (1999). *Construing Experience through Meaning*. New York: Cassell.
- Halliday, M. A. K., & Matthiessen, C. M. I. M. (2004). *An Introduction to Functional Grammar*. London: Hodder Education.
- Hammer, D., Elby, A., Scherr, R. E., & Redish, E. F. (2005). Resources, Framing and Transfer. In J. P. Mestre (Ed.), *Transfer of Learning from a Modern Multidisciplinary Perspective*. Greenwich: Information Age Publishing.
- Hanauer, D. I. (2006). *Scientific Discourse: Multiliteracy in the Classroom*
- Harrison, A. G. (1994). Is there a scientific explanation for refraction of light? A review of textbook analogies. *Australian Science Teachers Journal*, 40(2), 30-35.
- Harrison, A. G., & Treagust, D. F. (1993). Teaching with Analogies: A Case Study in Grade-10 Optics. *Journal of Research in Science Teaching*, 30(10), 1291-1307.
- Hasan, R. (1984). Coherence and Cohesive Harmony. In J. Flood (Ed.), *Understanding Reading Comprehension*. Newark: International Reading Association.
- Hasan, R. (1995). The Conception of Context in Text. In P. H. Fries (Ed.), *Discourse in Society: Systemic Functional Perspectives* (pp. 183-283). Norwood: Ablex Publishing.
- Hasan, R. (1999). Speaking with reference to context. In M. Ghadessy (Ed.), *Text and context in functional linguistics* (pp. 219-328). Amsterdam: John Benjamins.
- Hasan, R. (2010). The meaning of 'not' is not in 'not'. In A. Mahboob & N. Knight (Eds.), *Applicable linguistics* (pp. 267-306). London: Continuum.
- Hasan, R., Cloran, C., Williams, G., & Lukin, A. (2007). Semantic networks: the description of linguistic meaning in SFL. In R. Hasan, C. Matthiessen & J. J. Webster (Eds.), *Continuing discourse on language : a functional perspective* (Vol. 2, pp. 697-738). London: Equinox.
- Hattie, J. (2012). *Visible learning : a synthesis of over 800 meta-analyses relating to achievement*. London: Routledge.
- Hawkins, J. M., Thompson, J. R., Wittmann, M. C., Sayre, E. C., & Frank, B. W. (2010). *Students' responses to different representations of a vector addition question*. Paper presented at the PERC 2010 proceedings.
- Heath, C., Hindmarch, J., & Luff, P. (2010). *Video in Qualitative Research*. London: SAGE Publications.

- Heckler, A. F., & Scaife, T. M. (2015). Adding and subtracting vectors: the problem with the arrow representation. *Phys. Rev. ST - Phys. Educ. Res.*, 11(010101).
- Heller, P., & Hollabaugh, M. (1992). Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups. *Am. J. Phys.*, 60(7), 637-644.
- Heller, P., Keith, R., & Anderson, S. (1992). Teaching problem solving through cooperative grouping, Part 1: Group versus individual problem solving. *Am. J. Phys.*, 60(7), 627-636.
- Helm, H., & Gilbert, J. (1985). Thought experiments and physics education—part 1. *Phys. Educ.*, 20(3), 124-131.
- Henderson, C., & Dancy, M. H. (2007). Barriers to the use of research-based instructional strategies: the influence of both individual and situational characteristics. *Phys. Rev. ST - Phys. Educ. Res.*, 3(020102).
- Hodge, R., & Kress, G. (1988). *Social Semiotics*. New York: Cornell University Press.
- Hsu, L., Brewster, E., Foster, T. M., & Harper, K. A. (2004). Resource Letter RPS-1: Research in problem solving. *Am. J. Phys.*, 72(9), 1147-1156.
- Hüttebräuker, N. (2010). *Empirische Untersuchung zum Verständnis ikonischer Repräsentationen am Beispiel der optischen Brechung*. Master thesis. Der Fakultät für Physik und Astronomie der Ruhr-Universität Bochum. Bochum.
- Huygens, C. (1678, 1912). *Treatise on light : in which are explained the causes of that which occurs in reflexion, & in refraction and particularly in the strange refraction of iceland crystal* (S. P. Thompson, Trans.). London: Macmillan & Co.
- Ingerman, Å., Berge, M., & Booth, S. (2009). Physics group work in a phenomenographic perspective – learning dynamics as the experience of variation and relevance. *European Journal of Engineering Education*, 34(4), 349-358.
- Ingerman, Å., Linder, C., & Marshall, D. (2009). The learners' experience of variation : Following students' threads of learning physics in computer simulation sessions. *Instructional Science*, 37(3), 273-292.
- Jaipal, K. (2010). Meaning Making Through Multiple Modalities in a Biology Classroom: A Multimodal Semiotics Discourse Analysis. *Science Education*, 94(1), 48-72.
- Jewitt, C. (2005). Multimodality, "Reading", and "writing" for the 21st century. *Discourse: studies in the cultural politics of education*, 26(3), 315-331.
- Jewitt, C. (2006). *Technology, Literacy and Learning*. London: Routledge.
- Jewitt, C. (Ed.). (2009). *The Routledge Handbook of Multimodal Analysis*. New York: Routledge.

- Jewitt, C., & Kress, G. (Eds.). (2003). *Multimodal Literacy*. New York: Peter Lang Publishing.
- Jones, D. C., Malysheva, M., Richards, A., Planinšić, G., & Etkina, E. (2013, July 17-18). *Resource activation patterns in expert problem solving*. Paper presented at the PERC 2013, Portland.
- Kappagoda, A. (2009). The use of Systemic Functional Linguistics in automated text mining. Australia: Command, Control, Communications and Intelligence Division, Defence Science and Technology Organisation, Commonwealth of Australia.
- Khan Academy. (2014). Electric potential at a point in space. Retrieved 2014-12-16, 2014, from <http://www.khanacademy.org/test-prep/mcat/physical-processes/electrostatics-1/v/electric-potential-at-a-point-in-space>
- Knight, R. D. (2002). *Five easy lessons : strategies for successful physics teaching*. San Fransisco: Addison Wesley.
- Kohl, P. B., & Finkelstein, N. D. (2005). Student representational competence and self-assessment when solving physics problems. *Phys. Rev. ST Phys. Educ. Res.*, 1, 010104.
- Kohl, P. B., & Finkelstein, N. D. (2006a). Effect of instructional environment on physics students' representational skills. *Phys. Rev. ST Phys. Educ. Res.*, 2, 010102.
- Kohl, P. B., & Finkelstein, N. D. (2006b). Effects of representation on students solving physics problems: A fine-grained characterization. *Phys. Rev. ST Phys. Educ. Res.*, 2, 010106.
- Kohl, P. B., & Finkelstein, N. D. (2008). Patterns of multiple representation use by experts and novices during physics problem solving. *Phys. Rev. ST Phys. Educ. Res.*, 4, 010111.
- Kohl, P. B., Rosengrant, D., & Finkelstein, N. D. (2007). Strongly and weakly directed approaches to teaching multiple representation use in physics. *Phys. Rev. ST Phys. Educ. Res.*, 3, 010108.
- Kress, G. (2003). *Literacy in the New Media Age*. London: Routledge.
- Kress, G. (2010). *Multimodality : A Social Semiotic Approach to Contemporary Communication*. London: Routledge.
- Kress, G., Jewitt, C., Ogborn, J., & Tsatsarelis, C. (2001). *Multimodal teaching and learning*. London: Continuum.
- Kress, G., & Van Leeuwen, T. (2001). *Multimodal Discourse : The Modes and Media of Contemporary Communication*. London: Arnold.
- Kress, G., & Van Leeuwen, T. (2006). *Reading Images : The Grammar of Visual Design* (2nd ed.). New York: Routledge.
- Kristeva, J. (1980). *Desire in language : a semiotic approach to literature and art*. New York: Columbia University Press.
- Kryjevskaiia, M., Stetzer, M. R., & Heron, P. R. L. (2012). Student understanding of wave behavior at a boundary: The relationships

- among wavelength, propagation speed, and frequency. *Am. J. Phys.*, 80(4), 339-347.
- Kuo, E. (2013). *More than just "plug-and-chug": exploring how physics students make sense with equations*. (PhD thesis PhD thesis), University of Maryland, College Park.
- Kvale, S., & Brinkmann, S. (2009). *Den kvalitative forskningsintervjuen* (2nd ed.). Lund: Studentlitteratur AB.
- Lemke, J. L. (1983). Thematic Analysis, Systems, Structures, and Strategies. *Semiotic Inquiry*, 3(2), 159-187.
- Lemke, J. L. (1990). *Talking Science*. Norwood, New Jersey: Ablex Publishing.
- Lemke, J. L. (1992). Intertextuality and educational research. *Linguistics and Education*, 4, 257-267.
- Lemke, J. L. (1995a). Intertextuality and Text Semantics. In P. H. Fries & M. Gregory (Eds.), *Discourse in Society: Systemic Functional Perspectives* (pp. 85-114). Norwood: Ablex Publishing.
- Lemke, J. L. (1995b). Intertextuality and text semantics. In P. H. Fries & M. Gregory (Eds.), *Discourse in society: systemic functional perspectives : Meaning and choice in language: studies for Michael Halliday* (pp. 85-114). Westport: Ablex Publishing.
- Lemke, J. L. (1995c). *Textual Politics : Discourse and Social Dynamics*. Oxon: Taylor & Francis.
- Lemke, J. L. (1998). Multiplying meaning : visual and verbal semiotics in scientific text. In J. R. Martin & R. Veel (Eds.), *Reading Science : Critical and functional perspectives on discourses of science* (pp. 87-114). London: Routledge.
- Lemke, J. L. (1999). Typological and topological meaning in diagnostic discourse. *Discourse processes*, 27(2), 173-185.
- Lemke, J. L. (2000a). Material sign processes and emergent ecosocial organization. In P. Bøgh Andersen, C. Emmeche, N. O. Finneman & P. Voetmann Christiansen (Eds.), *Downward causation : minds, bodies and matter* (pp. 181-213). Århus: Aarhus University Press.
- Lemke, J. L. (2000b). Opening up closure: semiotics across scales. *Annals of the New York Academy of Sciences*, 901, 100-111. doi: 10.1111/j.1749-6632.2000.tb06269.x
- Lemke, J. L. (2003). Mathematics in the middle: measure, picture, gesture, sign and word. In M. Anderson, A. Saenz-Ludlow, S. Zellweger & V. Cifarelli (Eds.), *Educational perspectives on mathematics as semiosis: from thinking to interpreting to knowing* (pp. 215-234). Ottawa: Legas.
- Lemke, J. L. (2004). The literacies of science. In E. W. Saul (Ed.), *Crossing borders in literacy and science instruction : perspectives on theory and practice*. (pp. 33-47). Newark: International reading association.
- Lemke, J. L. (2012). Jay Lemke Online. Retrieved 2012-08-20, from <http://www.jaylemke.com/short-biography/>

- Leont'ev, A. N. (1978). *Activity, consciousness, and personality*. Englewood Cliffs, N.J.: Prentice-Hall.
- Leutner, D., Leopold, C., & Sumfleth, E. (2009). Cognitive load and science text comprehension: effects of drawing and mentally imagining text content. *Comput. Hum. Behav.*, 25(2), 284-289.
- Lim, F. V. (2004). Problematising 'semiotic resource'. In E. Ventola, C. Charles & M. Kaltenbacher (Eds.), *Perspectives on multimodality* (pp. 51-63). Amsterdam: John Benjamins.
- Lim, F. V. (2011). *A Systemic Functional Multimodal Discourse Analysis Approach to Pedagogic Discourse*. (PhD thesis), National University of Singapore, Singapore.
- Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic Inquiry*. London: Sage.
- Linder, A., Airey, J., Mayaba, N., & Webb, P. (2014). Fostering disciplinary literacy? South African physics lecturers' educational responses to their students' lack of representational competence. *African Journal of Research in Mathematics, Science and Technology Education (AJRMSTE)*, 18(3), 242-252.
- Linder, C. (2007). *Theory in motion. The phenomenographic approach*. Plenary talk given at the Foundations and Frontiers in Physics Education Research Conference, August. Bar Harbor, Maine.
- Linder, C. (2013). Disciplinary discourse, representation, and appresentation in the teaching and learning of science. *European Journal of Science and Mathematics Education*, 1(2), 43-49.
- Linder, C., Fraser, D., & Pang, M. F. (2006). Using a variation approach to enhance physics learning in a college classroom. *The Physics Teacher*, 44, 589-592. doi: 10.1119/1.2396777
- Lindström, C. (2010). *Link Maps and Map Meetings: A theoretical and experimental case for stronger scaffolding in first year university physics education*. (PhD thesis), The University of Sydney, Sydney.
- Lindström, C., & Sharma, M. D. (2009). Link maps and map meetings: Scaffolding student learning. *Phys. Rev. ST Phys. Educ. Res.*, 5, 010102.
- Lindström, C., & Sharma, M. D. (2011). Teaching physics novices at university: A case for stronger scaffolding. *Phys. Rev. ST Phys. Educ. Res.*, 7(010109), 1-14.
- Lindwall, O., & Lymer, G. (2008). The dark matter of lab work: illuminating the negotiation of disciplined perception in mechanics. *The Journal of the Learning Sciences*, 17, 180-224.
- Liu, Y., & Owyong, Y. S. M. (2011). Metaphor, multiplicative meaning and the semiotic construction of scientific knowledge. *Language Sciences*.
- Lo, M. L. (2012). *Variation theory and the improvement of teaching and learning* (Vol. 323). Gothenburg: Göteborgs Universitet.

- Lo, M. L., & Marton, F. (2011). Towards a science of the art of teaching : Using variation theory as a guiding principle of pedagogical design. *International Journal for Lesson and Learning Studies*, 1(1), 7-22.
- Lynch, M., & Woolgar, S. (Eds.). (1990). *Representation in Scientific Practice* (First appeared as a special issue of Human Studies, vol. 11, nos. 2-3 (April/July 1988) ed.). Boston: MIT Press.
- Mahoney, M. S. (1994). *The mathematical career of Pierre de Fermat, 1601-1665*. Princeton: Princeton University Press.
- Maloney, D. P. (1987). Ranking tasks; a new type of test item. *Journal of College Science Teaching*, 16(6), 510.
- Manogue, C. A., Browne, K., Dray, T., & Edwards, B. (2006). Why is Ampère's law so hard? A look at middle-division physics. *Am. J. Phys.*, 74(4), 344-350.
- Martin, J. R. (1992). *English Text : System and Structure*. Amsterdam: John Benjamins Publishing Co.
- Martin, J. R. (2001). Cohesion and Texture. In D. Schiffrin, D. Tannen & H. E. Hamilton (Eds.), *The Handbook of Discourse Analysis* (pp. 35-53). Oxford: Blackwell Publishers.
- Martin, J. R. (2006). Genre, ideology and intertextuality: a systemic functional perspective. *Linguistics and the Human Sciences*, 2(2), 275-298.
- Martin, J. R. (2011). Multimodal semiotics: theoretical challenges. In S. Dreyfus, S. Hood & M. Stenglin (Eds.), *Semiotic margins : meaning in multimodalities* (pp. 243-270). London: Continuum.
- Martin, J. R. (2013). Embedded literacy: Knowledge as meaning. *Linguistics and Education*, 24, 23-37.
- Martin, J. R., & Rose, D. (2007). *Working with Discourse : Meaning Beyond the Clause* (2nd ed.). London: Continuum.
- Martin, J. R., & Veel, M. (Eds.). (1998). *Reading Science. Critical and Functional Perspectives on Discourses of Science*. London: Routledge.
- Martinec, R. (1998). Cohesion in action. *Semiotica*, 120(1/2), 161-180.
- Marton, F. (2005). Om praxisnära grundforskning. In I. Carlgren, I. Josefsson, C. Liberg, J. Anward, A.-C. Evaldsson, F. Marton, T. Nordenstam, I. Orre & G. Weiner (Eds.), *Forskning av denna världen II : om teorins roll i praxisnära forskning* (pp. 105-121). Stockholm: Vetenskapsrådet.
- Marton, F. (2015). *Necessary conditions of learning*. New York: Routledge.
- Marton, F., & Booth, S. (1997). *Learning and Awareness*. Mahwah, New Jersey: Lawrence Erlbaum Associates.
- Marton, F., & Pang, M. F. (2006). On some necessary conditions of learning. *Journal of the Learning Sciences*, 15(2), 193-220.
- Marton, F., & Pang, M. F. (2013). Meanings are acquired from experiencing differences against a background of sameness, rather than from experiencing sameness against a background of difference: putting a



- conjecture to the test by embedding it in a pedagogical tool. *Frontline Learning Research*, 1, 24-41.
- Marton, F., Runesson, U., & Tsui, A. B. M. (2004). The space of learning. In F. Marton & A. B. M. Tsui (Eds.), *Classroom discourse and the space of learning* (pp. 3-40). London: Lawrence Erlbaum Associates.
- Marton, F., & Tsui, A. B. M. (2004). *Classroom Discourse and the Space of Learning*. Mahwah: Lawrence Erlbaum Associates.
- Maruo, M., Inagawa, H., Toratani, Y., Kondo, T., & Matsushita, M. (2014). Three-dimensional laser-scanning confocal reflecting microscope for multicolor single-molecule imaging at 1.5 K. *Chemical physics letters*, 591, 233-236.
- Maton, K. (2008). *Grammars of sociology*. Paper presented at the the Fifth International Basil Bernstein Symposium, Cardiff University, Cardiff. [http://scholar.googleusercontent.com/scholar?q=cache:bqq-liCJzGIJ:scholar.google.com/+%22Fifth+International+Basil+Bernstein+Symposium%22+Proceedings&hl=sv&as\\_sdt=0,5](http://scholar.googleusercontent.com/scholar?q=cache:bqq-liCJzGIJ:scholar.google.com/+%22Fifth+International+Basil+Bernstein+Symposium%22+Proceedings&hl=sv&as_sdt=0,5)
- Maton, K. (2013). Making semantic waves: A key to cumulative knowledge-building. *Linguistics and Education*, 24, 8-22.
- Matthiessen, C. M. I. M. (2009a). Ideas and new directions. In M. A. K. Halliday & J. J. Webster (Eds.), *Continuum Companion to Systemic Functional Linguistics* (pp. 12-58). London: Continuum International Publishing Group.
- Matthiessen, C. M. I. M. (2009b). Meaning in the making: meaning potential emerging from acts of meaning. In N. C. Ellis & D. Larsen-Freeman (Eds.), *Language as a complex adaptive system* (pp. 206-229). The USA: University of Michigan.
- Matthiessen, C. M. I. M., Teruya, K., & Lam, M. (2010). *Key terms in systemic functional linguistics*. London: Continuum.
- Maxwell, J. A. (2005). *Qualitative research design : an interactive approach*. Thousand Oaks, CA: Sage Publications.
- Maxwell, J. C. (1871). Remarks on the mathematical classification of physical quantities. *Proceedings of the London Math. Soc.*, 224-233. [http://www.clerkmaxwellfoundation.org/MathematicalClassificationofPhysicalQuantities\\_Maxwell.pdf](http://www.clerkmaxwellfoundation.org/MathematicalClassificationofPhysicalQuantities_Maxwell.pdf)
- Mazur, E. (2009). Farewell, lecture? *Science*, 323, 50-51.
- McDermott, L. C. (1990). A view from physics. In M. Gardner, J. G. Greeno, F. Reif, A. H. Schoenfeld, A. A. diSessa & E. Stage (Eds.), *Toward a scientific practice of science education* (pp. 3-30). Hillsdale: Lawrence Erlbaum Associates.
- McDermott, L. C., & Redish, E. F. (1999). Resource letter PER-1 : Physics Education Research. *Am. J. Phys.*, 67, 755-767.
- McDermott, L. C., & Shaffer, P. S. (1992). Research as a guide for curriculum development: An example from introductory electricity.

- Part I: Investigation of student understanding. *Am. J. Phys.*, 60(11), 994-1003.
- McDermott, L. C., & Shaffer, P. S. (2002). *Tutorials in Introductory Physics* (1 ed.). Upper Saddle River, N.J.: Prentice-Hall.
- McGregor, W. (1991). The concept of rank in systemic linguistics. In E. Ventola (Ed.), *Functional and systemic linguistics : approaches and uses* (pp. 121-138). Berlin: Mouton de Gruyter.
- Meltzer, D. E. (2005). Relation between students' problem-solving performance and representational format. *Am. J. Phys.*, 73(5), 463-478.
- Meltzer, D. E. (2007). Analysis of shifts in students' reasoning regarding electric field and potential concepts. *AIP Conference Proceedings*, 883, 177-180.
- Meltzer, D. E., & Thornton, R. K. (2012). Resource Letter ALIP-1: Active-Learning Instruction in Physics. *Am. J. Phys.*, 80(6), 478-496.
- Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis : an expanded sourcebook* (2nd ed.). Thousand Oaks, CA: SAGE Publications.
- Muntigl, P. (2004). Modelling multiple semiotic systems : the case of gesture and speech. In E. Ventola, C. Charles & M. Kaltenbacher (Eds.), *Perspectives on multimodality* (pp. 31-50). Amsterdam: John Benjamins.
- New London Group. (1996). A pedagogy of multiliteracies: Designing social futures. *Harvard Educational Review*, 66(1), 60-93.
- Newton, I. (1730). *Opticks or treatise of the reflections, refractions, inflections & colours of light*. Based on the fourth edition: London (1730); New York: Dover (1952, 1979).
- Nordling, C., & Österman, J. (2006). *Physics handbook : for science and engineering*. Lund: Studentlitteratur.
- Norman, D. A. (1988). *The psychology of everyday things*. New York: Basic Books.
- Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education*, 87(2), 224-240.
- Northedge, A. (2002). Organizing Excursions Into Specialist Discourse Communities: A Sociocultural Account of University Teaching. In G. Wells & G. Claxton (Eds.), *Learning for Life in the 21st Century* (pp. 252-264). Oxford: Blackwell Publishing.
- Novak, G. M. (2011) Just-in-Time Teaching. *New directions for teaching and learning*. 128, 63-73
- Novak, J. D., & Cañas, A. J. (2008). The Theory Underlying Concept Maps and How to Construct and Use Them, Technical Report IHMC Cmap Tools 2006-01 Rev 01-2008. *Florida Institute for Human and Machine Cognition*.

- <http://cmap.ihmc.us/Publications/ResearchPapers/TheoryUnderlyingConceptMaps.pdf>
- Nwosu, V. (2012). *A study of postgraduate students in an astrophysics bridging year : identifying contradictions in a complex system*. (PhD), University of Cape Town, Cape Town.
- O'Halloran, K. L. (2005). *Mathematical discourse : language, symbolism and visual images*. London: Continuum.
- O'Halloran, K. L. (2008a). *Mathematical discourse : language, symbolism and visual images*. London: Continuum International Publishing.
- O'Halloran, K. L. (2008b). Systemic functional - multimodal discourse analysis (SF-MDA) : constructing ideational meaning using language and visual imagery. *Visual Communication*, 7(4), 443-475.
- O'Toole, M. (1994). *The language of displayed art*. London: Pinter Publishers.
- O'Toole, M. (1995). A systemic-functional semiotics of art. In P. H. Fries & M. Gregory (Eds.), *Discourse in society: systemic functional perspectives* (pp. 159-179). Norwood, NJ: Ablex Publishing Corporation.
- Oliviero, A., & Woodward, B. (2014). *Cabling : Part 2 : Fiber-optic cabling and components*. Indianapolis: Wiley.
- Painter, C. (1999). *Learning through language in early childhood*. London: Continuum.
- Pang, M. F., & Marton, F. (2013). Interaction between the learners' initial grasp of the object of learning and the learning resource afforded. *Instructional Science*, 41, 1065-1082.
- Peirce, C. S. (1998). What is a sign? In Peirce Edition Project (Ed.), *The essential Peirce : selected philosophical writings* (Vol. 2 (1893-1913), pp. 4-10). Bloomington: Indiana University Press.
- Peirce Edition Project, (Ed.). (1998). *The Essential Peirce : Selected Philosophical Writings*. Bloomington: Indiana University Press.
- Pepper, R. E., Chasteen, S. V., Pollock, S. J., & Perkins, K. K. (2012). Observations on student difficulties with mathematics in upper-division electricity and magnetism. *Phys. Rev. ST Phys. Educ. Res.*, 8(010111).
- Physics Education Research Central. (n.d.). <http://www.per-central.org/programs>. Retrieved, 2015
- Planinic, M. (2006). Assessment of difficulties of some conceptual areas from electricity and magnetism using the Conceptual Survey of Electricity and Magnetism. *Am. J. Phys.*, 74(12), 1143-1148. doi: 10.1119/1.2366733
- Podolefsky, N. S. (2008). *Analogical scaffolding: making meaning in physics through representation and analogy*. (PhD thesis), University of Colorado, Colorado.

- Podolefsky, N. S., & Finkelstein, N. D. (2006). Use of analogy in learning physics: The role of representations. *Phys. Rev. ST Phys. Educ. Res.*, 2, 020101.
- Podolefsky, N. S., & Finkelstein, N. D. (2007a). Analogical scaffolding and the learning of abstract ideas in physics: An example from electromagnetic waves. *Phys. Rev. ST Phys. Educ. Res.*, 3, 010109.
- Podolefsky, N. S., & Finkelstein, N. D. (2007b). Analogical scaffolding and the learning of abstract ideas in physics: Empirical studies. *Phys. Rev. ST Phys. Educ. Res.*, 3, 020104.
- Podolefsky, N. S., & Finkelstein, N. D. (2007c). Salience of representations and analogies in physics *PERC Proceedings 2007*: AIP Press.
- Polanyi, M. (1967). *The tacit dimension*. London: Routledge.
- Pong, W. Y. (2000). *Widening the space of variation – inter-contextual and intra-contextual shifts in pupils' understanding of two economic concepts*. (PhD thesis), University of Hong Kong, Hong Kong.
- Prather, E. E., Rudolph, A. L., Brissenden, G., & Schlingman, W. M. (2009). A national study assessing the teaching and learning of introductory astronomy. Part I. The effect of interactive instruction. *American Journal of Physics*, 77(4), 320-330.
- Redish, E. F. (2003). *Teaching Physics : with the Physics Suite*. Hoboken: John Wiley & Sons.
- Rehn, D. A., Moore, E. B., Podolefsky, N. S., & Finkelstein, N. D. (2013). Tools for high-tech tool use: A framework and heuristics for using interactive simulations. *Journal of teaching and learning with technology*, 2(1), 13-55.
- Reif, F., & Allen, S. (1992). Cognition for Interpreting Scientific Concepts: A Study of Acceleration. *Cognition and Instruction*, 9(1), 1-44.
- Roberts, D. A. (2007a). Linné Scientific Literacy Symposium: Opening Remarks. In C. Linder, L. Östman & P.-O. Wickman (Eds.), *Promoting Scientific Literacy: Science Education Research in Transaction*. (pp. 9-17). Uppsala: Uppsala University.
- Roberts, D. A. (2007b). Scientific Literacy/Science Literacy. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of Research on Science Education* (pp. 729-780). London: Lawrence Erlbaum Associates.
- Robson, C. (2002). *Real World Research* (2nd ed.). Oxford: Blackwell Publishing.
- Rose, P., & Basturkmen, H. (2013). Exploring children's use of referencing in narrative writing in Guyana. *New Zealand Studies in Applied Linguistics*, 19(1), 35-48.
- Rosengrant, D., Etkina, E., & Van Heuvelen, A. (2007). An overview of recent research on multiple representations. *AIP Conference Proceedings*, 883, 149-152.
- Rosengrant, D., Van Heuvelen, A., & Etkina, E. (2009). Do students use and understand free-body diagrams? *Phys. Rev. ST Phys. Educ. Res.*, 5(010108), 1-13.

- Roth, W.-M., & Bowen, G. M. (1999). Complexities of graphical representations during ecology lectures: an analysis rooted in semiotics and hermeneutic phenomenology. *Learning and Instruction*, 9(3), 235-255.
- Roth, W.-M., & McGinn, M. K. (1998). Inscriptions: toward a theory of representing as social practice. *Review of Educational Research*, 68(1), 35-59.
- Royce, T. D. (2002). Multimodality in the TESOL classroom: exploring visual-verbal synergy. *TESOL Quarterly*, 36(2), 191-205.
- Royce, T. D. (2007). Intersemiotic complementarity: a framework for multimodal discourse analysis. In T. D. Royce & W. L. Bowcher (Eds.), *New directions in the analysis of multimodal discourse* (pp. 63-109). Mahwah, NJ: Lawrence Erlbaum Associates.
- Rundgren, C.-J. (2008). *Visual Thinking, Visual Speech - a Semiotic Perspective on Meaning-Making in Molecular Life Science*. (PhD thesis), Linköping University, Norrköping.
- Sacks, H. (1992). *Lectures on conversation*. Oxford: Blackwell Publishers.
- Säljö, R., & Bergqvist, K. (1997). Seeing the light. In L. Resnick, R. Säljö, C. Pontecorvo & B. Burge (Eds.), *Discourse, tools and reasoning. Essays on situated cognition* (pp. 385-405). New York: Springer-Verlag.
- Saussure, F. d. (1959). *Course in general linguistics* (W. Baskin, Trans. C. Bally & A. Sechehaye Eds.). New York: Philosophical library.
- Sayre, E. C., & Heckler, A. F. (2009). Peaks and decays of student knowledge in an introductory E&M course. *Phys. Rev. ST - Phys. Educ. Res.*, 5(013101).
- Schegloff, E. A. (n.d.). Emanuel A. Schegloff's homepage. Retrieved September 28, 2012, from <http://www.sscnet.ucla.edu/soc/faculty/schegloff/>
- Schell, J., Lukoff, B., & Mazur, E. (2013). Catalyzing learner engagement using cutting-edge classroom response systems in higher education. In C. Wankel & P. Blessinger (Eds.), *Increasing student engagement and retention using classroom technologies: classroom response systems and mediated discourse technologies* (pp. 233-262): Emerald.
- Scherr, R. E. (2008). Gesture analysis for physics education researchers. *Phys. Rev. ST Phys. Educ. Res.*, 4(010101), 1-9.
- Schönborn, K. J., & Bögeholz, S. (2009). Knowledge transfer in biology and translation across external representations: experts' views and challenges for learning. *International Journal of Science and Mathematics Education*, 7(5), 931-955.
- Schönborn, K. J., & Bögeholz, S. (2013). Experts' views on translation across multiple external representations in acquiring biological knowledge about ecology, genetics, and evolution. In D. F. Treagust

- & C.-Y. Tsui (Eds.), *Multiple representations in biological education* (pp. 111-128). New York: Springer.
- Schumacher, B., & Westmoreland, M. (2010). *Quantum processes, systems, & information*. Cambridge: Cambridge University Press.
- Schutz, A. (1962). *Collected Papers I : The Problem of Social Reality*. The Hague: Martinus Nijhoff.
- Sengören, S. K. (2010). How do Turkish high school graduates use the wave theory of light to explain optics phenomena? *Phys. Educ.*, 45(3), 253-263.
- Serway, R. A., Moses, C. J., & Moyer, C. A. (1997). *Modern Physics* (2nd ed.). Orlando, Florida: Saunders College Publishing.
- Shaffer, P. S., & McDermott, L. C. (1992). Research as a guide for curriculum development: An example from introductory electricity. Part II: Design of instructional strategies. *Am. J. Phys.*, 60(11), 1003-1013.
- Sharrock, W. (2004). What Garfinkel makes of Schutz: The past, present and future of an alternate, asymmetric and incommensurable approach to sociology. *Theory & Science*, 5(1).
- Singh, A., & Butler, P. H. (1990). Refraction: conceptions and knowledge structure. *International Journal of Science Education*, 12(4), 429-442.
- Singh, C. (2014). What can we learn from PER: Physics Education Research? *The Physics Teacher*, 52(9), 568-569.
- Smith, M. K., Wood, W. B., Adams, W. K., Wieman, C., Knight, J. K., Guild, N., & Su, T. T. (2009). Why Peer Discussion Improves Student Performance on In-Class Concept Questions. *Science*, 323, 122-124.
- Stake, R. E., & Trumbull, D. J. (1982). Naturalistic Generalizations. *Review Journal of Philosophy and Social Science*, 7(1), 1-12.
- Stetzer, M. R., van Kampen, P., Shaffer, P. S., & McDermott, L. C. (2013). New insights into student understanding of complete circuits and the conservation of current. *Am. J. Phys.*, 81(134), 134-143.
- Streeck, J., Goodwin, C., & LeBaron, C. (Eds.). (2011). *Embodied interaction : Language and body in the material world*. Cambridge: Cambridge University Press.
- Tang, K. S. (2011). *Hybridizing cultural understandings of the natural world to foster critical science literacy*. (PhD thesis), The University of Michigan, Michigan.
- Tang, K. S. (2013). Instantiation of multimodal semiotic systems in science classroom discourse. *Language Sciences*, 37, 22-35.
- Tang, K. S., Delgado, C., & Birr Moje, E. (2014). An integrative framework for the analysis of multiple and multimodal representations for meaning-making in science education. *Science Education*, 98(2), 305-326.

- Tang, K. S., Tan, S. C., & Yeo, J. (2011). Students' multimodal construction of the work-energy concept. *International Journal of Science Education*, 33(13), 1775-1804.
- Tao, P.-K. (2001). Developing understanding through confronting varying views: the case of solving qualitative physics problems. *Int. J. Sci. Educ.*, 23(12), 1201-1218.
- Tasker, R., & Dalton, R. (2006). Research into practice: Visualisation of the molecular world using animations. *Chemistry Education Research and Practice*, 7(2), 141-159.
- Thacker, B. A. (2003). Recent advances in classroom physics. *Rep. Prog. Phys.*, 66, 1833-1864.
- Thibault, P. J. (1991). *Social semiotics as praxis : text, social meaning making, and Nabokov's Ada*. Minneapolis: University of Minnesota Press.
- Thibault, P. J. (2004). *Brain, mind and the signifying body : an ecosocial semiotic theory*. London: Continuum.
- Thompson, J., & Ambrose, B. (2005). A literary canon in physics education research. *Forum on Education of The American Physical Society*. <http://units.aps.org/units/fed/newsletters/fall2005/canon.html>
- Tobias, S. (1986). Peer Perspectives: On the Teaching of Science. *Change*, 18(2), 36-41.
- Tolman, E. C., & Brunswik, E. (1935). The organism and the causal texture of the environment. *Psychological Review*, 42(1), 43-77.
- Tseng, C. (2008). Coherence and cohesive harmony in filmic text. In L. Unsworth (Ed.), *Multimodal semiotics : functional analysis in contexts of education* (pp. 89-104). London: Continuum.
- Unsworth, L. (Ed.). (2008). *New Literacies and the English Curriculum : Multimodal Perspectives*. London: Continuum International Publishing Group.
- Van Heuvelen, A. (1991a). Learning to think like a physicist: A review of research-based instructional strategies. *Am. J. Phys.*, 59(10), 891-897. doi: <http://dx.doi.org/10.1119/1.16667>
- Van Heuvelen, A. (1991b). Overview, Case Study Physics. *Am. J. Phys.*, 59(10), 898-906.
- Van Heuvelen, A., & Etkina, E. (2006). *The Physics Active Learning Guide*. San Francisco: Addison-Wesley.
- Van Heuvelen, A., & Zou, X. (2001). Multiple representations of work-energy processes. *Am. J. Phys.*, 69(2), 184-194.
- Van Krieken, R., Habibis, D., Smith, P., Hutchins, B., Martin, G., & Maton, K. (2014). *Sociology* (5th ed.). Frenchs Forest: Pearson.
- van Leeuwen, T. (1999). *Speech, music, sound*. London: Macmillan Press.
- Van Leeuwen, T. (2005). *Introducing Social Semiotics*. New York: Routledge.
- Van Leeuwen, T. (2011). Rythm and multimodal semiosis. In S. Dreyfus, S. Hood & M. Stenglin (Eds.), *Semiotic margins : Meaning in*

- multimodalities* (pp. 168-176). London: Continuum International Publishing Group.
- Veel, R. (1998). The greening of school science : Ecogenesis in secondary classrooms. In J. R. Martin & R. Veel (Eds.), *Reading science : Critical and functional perspectives on discourses of science* (pp. 115-151). London: Routledge.
- Von Korff, J., & Rebello, N. S. (2012). Teaching integration with layers and representations: a case study. *Phys. Rev. ST Phys. Educ. Res.*, 8(010125).
- Vygotsky, L. S. (1978). *Mind in society: the development of higher psychological processes*. Cambridge, Mass.: Harvard University Press.
- Vygotsky, L. S. (1986). *Thought and Language*. Cambridge, Mass.: MIT Press.
- Wertsch, J. V. (1985). *Vygotsky and the social formation of mind*. Cambridge, Mass.: Harvard University Press.
- Wickman, P.-O., & Östman, L. (2002). Learning as a discourse change : A sociocultural mechanism. *Science Education*, 86(5), 601-623.
- Wittgenstein, L. (1979). *On certainty* (D. Paul & G. E. M. Anscombe, Trans.). Oxford: Blackwell.
- Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *J. Child Psychol. Psychiat.*, 17, 89-100.
- Wood, K. (2013). A design for teacher education based on a systematic framework of variation to link teaching with learners' ways of experiencing the object of learning. *International Journal for Lesson and Learning Studies*, 2(1), 56-71.
- Woolgar, S. (1988). Time and documents in researcher interaction: some ways of making out what is happening in experimental science. *Human Studies*, 11(2/3), 171-200.
- Young, H. D., & Freedman, R. A. (2004). *University Physics with Modern Physics* (11th ed.). San Francisco: Pearson.



# Appendix A Transcripts

Transcript

11.23-14.15

Translation

30.25-38.11

R:Researcher

V:Vera

11.20-

M:Mike

N:Nick

M Aha

M Den här ringen, ligger den på botten?

M OK

V En bra bild

M Ja, men asså det där tänker jag att det där får man ju lite så här

kan man inte om man tar ett sån ah

M Jag tänker att man har ju man har ju erfarenhet av brytning liksom typ om man tittar på

glas så här om man tittar på kanten på glaset så kan man se botten fast man inte borde = se botten och så där

V Det skulle va bra å ha en stor vattenbehållare typ = sån där som Cedric hade med cola-flaskorna

M = A

M Ja eller det räcker väl med ett glas med vatten liksom, kanske

V Det är ju roligare om man har en stor

M Det [skratt] är roligare om man har en stor.

N Det kanske är lättare att visa liksom så hära titta på dom? stora? små? sakerna?= stora?

M = A

M Men liksom ja vad är det man vill förklara att vattnet

att att ljuset bryts i vattnet

N Att ljuset bryts har väl dom nästan nån slags så hära

V Jag tror in... det är inte alls säkert =1 att folk har

M =1 Nä

N Nä, näj men att man har dom har sett såna er...? =

M = En erfarenhet liksom

N Man har nån erfarenhet av det som man kanske inte har kopplat ihop på ett öh systematiskt sätt men

M Nä

M Men, = eh, ja

V Ja, men om du, det är inte så att man kanske har sett det men det är inte säkert att man har tänkt på det men då kan det vara sjysst att se det igen att se liksom att =ja just det här

brukar jag ju faktiskt se=. =Fast nu har han ju också sett det han har ju sett det när han ,= när han gjorde det här

N =Mm =Mm

M =Men

N =Mm

M Ja, ja prec... på nåt sätt har han ju sett det när när han testade det liksom. Han hade ju en pinne å sticka ner som man kan se liksom som riktlinje så här om man står här, och sen, här har vi vattenytan

V Är den anatomiskt korrekt den där bilden

M Ja, (skratt) det är anatomiskt korrekt ser du inte det och så ringen här

och så kan man ju se, pinnen kan man ju se som siktlinsen och så kan man se eller eller alltså pinnen kan man se som raka linjen och så kan man se öh, vad heter det, ja

N [Ohörbart]

M Jag menar att liksom han har ju på nåt sätt upplevt att raka avståndet är inte det han ser liksom = tänker jag

N = Nä

M Men jag vet inte man kanske borde typ så här eller jag vet inte tänka på att man inte ska förklara det så att ja så att han tänker att jag tittar här så bryts ljuset där och så =typ ser jag ringen fel

V = Det är ju inte riktigt det som...

M Å, jag vet inte, nå det är inte =det han undrar över (?)

V =Frågan är väl hur bra | hur bra känsla han har för ljus-(=)strålar och så, det är inte säkert att

M =A

N Mm

M = Nä men precis

V = Man kanske borde börja prata om liksom linser och =ljus är vågor och sånt där först det beror på = hur liksom djupt du vill att

han = ska förstå

M =A

M =f...

N =fast

M A

N A, fast man, ljusstrålar som bryts, jamen  
varför bryts ljusets strålar, ja det blir  
=[ohörbart]?

M =Men, kan man kan man inte så här kan  
man ja kan man inte liksom så här ja men  
ljuset bryts i i en vattenyta  
och det kan man se för att om det blir  
vågor på vattnet så så krusar ju sig liksom  
tänk dej att det skulle va  
vågor över den här ringen, då ser det ju ut  
som att ringen flyttar på sig å typ ändrar  
form och så här

N Mm

V Men då skulle det va sjysst å ha att att kunna =kolla på den å göra lite  
experiment å liksom titta på det under tiden

M =Aa, att kunna visa det liksom

N Mm, men okej nu då kan vi peka på men  
ljusstrålar bryts, vad betyder bryts i det här  
sammanhanget jomen att de  
böjs av

V De = ändrar riktning

M =Aa

N När dom när dom kommer till ytan

V och när är det dom bryts när de kommer in i vad då ett annat ett annat  
medium nånting som inte har =samma egenskaper som

N =Aa

M =Ett annat material liksom luft och  
vatten är olika saker liksom

N =Det det är skillnaden mellan luft och  
vatten

M Men man kan ju man kan ju börja med att säga så här ja men så här hur ser  
vi jomen det är ju ljusstrålar som faktiskt  
reflekteras på den där ringen och kommer till dina ögon = det är så du kan se  
den = och sen så händer det nånting med dom där  
ljusstrålarna på vägen

V =Ja

N =Ja

N Mm

M Och vanligtvis så tänker vi att dom går rakt så här men det kan hända saker  
i typ i gränsskikt det kanske är där man ska börja typ

V Ja för det är det som är hans antagande att =ljusstrålarna går =rakt  
=egentligen eller =kanske =inte explicit men ändå som att

M =Ja, =ja, =ja

N =Mm, =mm

M Men på nåt sätt känns det som att man måste börja med att vädja till att  
okej men en ljusstrålare reflekteras där sen går  
det rakt till dina ögon liksom

N Mm

M Det är så synen fungerar liksom

N Mm

M Och sen så ba okej men om vi sätter nåt  
här emellan så händer det nånting med  
ljusstrålen liksom

N Och grejen var att [hör inte] gå från den  
punkten

M Aa

V Ja och också det här det som jag tycker är svårt med dom här förklaringarna  
det är att det är som att det bara är en stråle

M Aa

V alltså att att det kommer det kommer komma hur många ljusstrålar som  
helst = =här och just den här ljusstrålen som du tror =,  
den kommer inte träffa ditt öga liksom

M =Aa

N =Mm, men det är

M Nä

N Det är en annan ljusstråle som träffar  
ditt öga

M Ja

N Det kan vi =väl...

V =Så vilke ljusstråle kommer det vara som  
träffar ditt öga, ja men det är den här  
ljusstrålen

N Kan vi hitta nån sån här laser(=)grej

V =och då ser det liksom ut som

N som gör många ljusstrålar också det finns  
(=) det kommer jag ihåg min lärare på  
gymnasiet hade

V =[suckliknande ljud, hhä]

M Jaha

N Han hade nån sån här som han satt på tavlan (=) och sen så hade han med  
magnet med linser som satt på magneter (=) som han satt på tavlan  
jätte fint så här

M =ja, =ja

M Precis

V Vi kanske inte kan tänka oss att vi har  
dom här resurserna =riktigt

R =Fast, ni är ju i labbet, så att ni kan gö...  
ni får utnyttja vilka grejer ni vill som ni  
finner här

N Ähä

M Här finns det vatten =och här finns det  
en

V =Vi behöver en en stor glasbehållare

M UUhh

M Fyller du på

[Vattenoljud, deltagarna ur bilden]

V Mer vatten är bättre eller hur

M Ja, lagom mycket vatten är bäst. Kanske halvvägs upp kanske.  
V Precis  
V Man borde ha nåt bra det ska va en ring  
V Den där är för stor  
M Ja, men man kan titta på det här s..., a fast i och för sig, nu ligger de[hör inte] vatten[hör inte] typ strecket härunder.  
N Jag hittade jättemycket laserpennor, oop  
M Co(=)olt  
V =Stoppa dom inte i vattnet  
N Nä. Nu har vi ju en glasyta(?) där också.  
Ja, vi kanske skulle ha, ha nå så hära halvgenomskinligt i vattnet  
N =så att man ser strålen  
V =Vi behöver en lång pinne också  
N typ mjölk  
M Mjölk  
N Jag kanske har lite i min flaska  
M,N [skratt]  
V Varför borde vi ha något halvgenomskinligt i vattnet  
N Jo =för att se  
M Jomen så att man ser strålen  
V Kan vi verkligen få  
N Ja man ser, det är ju som rök liksom, när du är på disco vet du [Vera], [skratt] då har man ju laserstrålar och så =har man rök römaskin  
V Den är lite för stor den här grejen. Behöver nånting mindre.= Den är liksom för stor så att jag pekar på den även om jag inte pekar på den  
N =Men, men nu  
M Aha, du menar man ska ha en liten  
V en liten pluttpryl  
N Men nu ska vi alltså, e..., ege..., egentligen så borde vi ju inte bara visa, vi borde ju låta den här kompisen experimentera själv  
V Ja, det kan vi väl göra  
N Vi kanske ska skriva en labinstruktion  
V Nej  
M Det är väl bättre att ge en muntlig  
N Här har vi lite mjölk om vi vill ha [skratt]  
M Här har vi småspik  
V Ja, småspik är bra  
N Har ni grejer att lägga i (?)  
N Okej, vi upprepar, vi upprepar experimentet  
V Mmm, det funkar inge bra, ser du att jag pekar på den  
M Men, men, men, men man måste typ titta ur en tillräckligt oblique angle liksom  
V Men försök  
M Pekar med "pinnen" snett ner i vattnet  
N Inte från sidan

N Den är alldeles rak härifrån  
M Aa, nu ser den sned ut liksom  
N Här ser den sned ut  
M Här ser den verkligen sned ut

N Det är roligt när man, det här är kul,  
  
om man tittar så här från sidan,(=1) sen så  
går man dit,(=2) då är den avskuren så här

M =1 aa, =2 aa  
N Att det är, eeh,

M Vill du ha skruven åt andra hållet eller  
vad =då  
N =Nej, att den, att den är diskontinuerlig

M Mm

V Funkar det  
M Ja, om du =står så här  
V =Får man titta från sidan

M Nej, om du står här

V Aa

M Då ser man att den inte är rak

N Om man tittar från sidan  
V Men va'nte det han sa att när han  
nuddade  
N Nej = aa  
V = Vad var det han sa'

N Att att han inte kunde peka på den där  
han trodde att han skulle göra, om man om  
man är om man står

här och tittar och ska peka peta på den  
med pinnen här

N Böjer sig ned tittar snett från  
sidan

M =1 Böjer sig ned tittar lite mer rakt från sidan,

N =1 Tittar rakt från sidan

M =2 Reser sig upp

N =2 Tittar rakt från sidan, och rör sig sedan ut mer snett från sidan

N Visar med händerna och pekfingrarna som en rotationsrörelse, sedan li  
snett uppåt och nedåt med höger hand

M Tittar på N

M Tittar på skålen

M Böjer sig ned och tittar rakt  
från sidan

N Reser sig upp

N Visar med händerna, rör den ena handen snett upp från den andra mer  
pekfingret mot den andra  
M Reser sig upp

V Kommer in i bilden

M Tittar hela tiden ner i vattnet

V Böjer sig ned och tittar rakt  
från sidan,

V = Reser sig

M = Pekar snabbt mot vattnet

V =1 Går mot M och tittar på  
vattnet, ställer sig och tittar  
bredvid M

N =1 Går mot tavlan,

N =1 Kommer tillbaka och  
ställer sig och tittar på vattnet

M Drar sakta upp "pinnen"  
(diskborsten) ur vattnet,  
N Läser i instruktionen som  
ligger på bordet bredvid skålen

M Skakar till "pinnen"

N Pekar på diskborsten och på  
Ms hand

N Sen så så när man stoppar ner pinnen i vattnet  
så så blir det fel.  
V Okej, ja, man ser ju att den böjer sej så då ändrar man ju vart man tror att man ska peka  
M = Ja  
M Sticker ner "pinne" i vattnet igen  
N Backar mer åt höger  
M drar upp "pinne" och skakar av den (bekymrade ögonbryn)  
V = Man ser ju att den böjer sig  
M Men precis, han  
N Pinnen bryts  
V Tittar på en sked som ligger bredvid "skålen".  
M vad var det han upplevde egentligen?  
V Tar skeden, men lägger tillbaka den och tar upp ett papper med instruktionen på  
N Går närmare V och tittar på papperet, tittar ner i vattnet,  
N Går mot tavlan, går iväg  
V När han stod på en brygga och försökte plocka upp en ring från botten en bit ut i en sjö med en pinne så upptäckte han att det inte gick att peka rakt emot den plats där ringen såg ut att ligga om han skulle träffa den  
M Skakar "pinne" som klingar mot skålen  
V Läger ner papperet, tittar på M,  
V Tar upp skeden och sticker ner den i vattnet  
N Går runt och tittar  
M ser man ju att den bryter sig liksom  
M Pekar mot vattnet med "pinne"  
M Sticker ner "pinne" i vattnet, tittar ner i vattnet  
M och då korrigerar man ju för det, = och så pekar man på den ändå (lite så här?)  
V Drar upp skeden och skakar av den, lägger ner den, tittar ner i vattnet  
V = och  
V Ja, men det är ju, och man kan ju tänka sig att att man inte ser pinnen så bra ifall det är en sjö för att vattnet är typ mörkt  
N Eller så kan man jamen  
V Fast man såg ju ringen på botten  
N Sätter sig mellan och bakom M och V och tittar  
M Drar upp och sticker ner "pinne" ett par gånger, drar upp den och håller den uppe  
N Han kanske observerade att jamen pinnen hamnade inte där jag trodde först men sen så kan väl han reagera på det men alltså (att det inte stämde ändå?)  
V tittar på M och sedan =1 ner i skålen igen  
M =1 Sticker ner pinnen igen, =2 drar upp den  
V =2 tittar på M, ler, och sedan på pinnen igen

N ...eller...

Man kan ju det är ju  
det är ju en skillnad i  
vad heter det

M = Sticker ner pinnen rakt uppifrån i vattnet

V = Sätter sig mitt bakom skålen, tittar på vattnet, lutar sig bakåt

M Vickar på pinnen sedan rakt upp igen, drar upp pinnen helt, sedan rakt ner igen

V Sätter sig ned på huk, =tittar rakt från sidan på  
vattnet

hur det uppför sig om  
(man inte nån göra det  
göra det i luft?)

V Och, ja

N Den här kompis  
observerade väl den  
skillnaden kanske

M Drar upp pinnen, sedan ner igen, upp igen

V Kan du inte ta den  
snett,

M Sätter i pinnen snett ner, drar upp den, sedan ner  
igen

V så, om man det är  
häftigt om man kollar  
på det från sidan, för  
då är det som att den  
är

okontinuerlig, pinnen.

V Visar med handen hur pinnen går ner i vattnet och sedan har ett hack, tittar upp på M

M Böjer sig ner och tittar på skålen rakt från sidan,  
bredvid V, in i vattnet

N Hur då(?)

V Det ser ut som att  
det är ett hack, att det  
går så här och så hack  
så fortsätter den inte  
längre

V pekar med fingret upp och ner i samma riktning som pinnen, sedan horisontellt åt sidan  
(motsatt pinnens lutning, dvs bort från henne) sedan snett ner efter pinnen igen

M Aha, så menar du,  
aha, men det, man ser  
reflektionen i

M Böjer sig ner ytterligare, sedan upp igen

N Nej men om du

N Bockar sig ner, tittar mot vattnet, sedan upp igen

V Nej jag menar liksom  
att den är  
okontinuerlig

N Om du tittar så att  
du inte s... om du  
tittar precis på vid  
vattenytan så att du  
inte ser reflektionen

V Tittar mot N, sedan mot vattnet igen

M A, lite grann

N Om, men om, om du  
tittar ändå mer  
från/på(?) sidan så  
=[hör inte]

M Reser sig upp, tittar på vattnet, på N sedan på  
vattnet igen,

V Men det är ändå  
som att han kan han  
kan hålla på och  
testa det här och kolla  
från olika håll och  
experimentera liksom  
och se att det händer

V Tittar på M



nånting när den går  
ner i vattnet

M Drar upp pinnen

N Mm

M Sticker ner pinnen igen

V Tittar på vattnet

R Så, om jag lägger  
mig i litegrann, så är,  
frågan då som man  
ställer det är ju hur ska  
ni kunna förklara det  
här för honom

R Fångar deras uppmärksamhet

M Ja

V Mm, vi är på väg

R Från ett fysik..., a  
just det, a, då ska jag  
inte jag lägga mig i,  
=jag bara tänkte så att  
ni...

N =[skratt]

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R Jag tror inte problemet egentligen kanske är att han inte lyckas få upp  
ringen eftersom det här var ju nånting som han...

V Nej

M Nä

V Nej men alltså poängen var ju att han skulle kunna göra det här igen  
=och fundera på det och se det liksom

R =A, just det

R ja, yes, ursäkta

N Tänker mig att man inte kan såhär förklara [ohörbart] okej nu har vi sagt  
sagt det här och sen säger vi så här att strålarna  
vattenstrålar... ljus... ljusstrålar, ljusstrålar,  
ljus är som strålar, fast det är  
koncentrerade ljusstrålar

V Man kan tänka på ljus som strålar

N Ja, kanske man ska säga

M Men man kan ju jämföra typ med spegling liksom. Man kan ju du kan ju  
spegla sig i vattenytan, det kan bryta sig när det går igenom också  
typ.

N Va

V Varför det

M Men asså det händer ju nånting det händer ju nånting med ljuset när det  
kommer till en yta. Det kan speglas där till exempel.

V Aa

M Och då är det ju liksom så här okej men om vattnet kan påverkas så det  
spegla... eller om ljuset kan påverkas så det speglas  
kanske det kan påverkas så det kan brytas  
liksom också

N Mm

V Men ska vi, då börjar vi med typ vad vad  
ljus är liksom

M Aa, hur man =ser det liksom

V =Sen, sen hur man ser, och sen, och, men  
hur kommer kommer det här in då

M Ja men man kan ju titta så här jamen titta på den här den är ju rak nu liksom men om du stoppar ner den i vattnet och ska peka på den där

V Ja, hur man ser och sen

M Så ser du att den kommer va...

V Okej, men det är strålar och i vattnet så bryts dom. Kolla vad som händer.

M Ja

V Och sen så det hära.

M Mm

V Hur blir det då för dig?

M Aa

V I det här

M Ja typ så.

N Mm, och sen så kan vi titta mer. Vi måste ha med laser också

M [Skratt]

V Nej, det måste vi inte, det är så svårt att få det att se ut som nånting

M Ja, men man ser ju inte att dom...

N Men om man har i mjölk

V Men...

M Men hämta mjölk då

N Men det står där

M Men håll i det då

V Håll i mjölken, men då,

N Vi bara,

V vi kan hålla i nytt vatten sen

N Vi bara måste prova, för att det är så

V Det är inte tillräckligt mycket mjölk

M Nej

N Jo, jag tror det

N ([Svårt att höra:] på lasern lite, eller, vi får ha så lite?)

V [Suckliknande ljud]

N Vad läskigt det ser ut

V Vi skulle ha dimma också här uppe

M Aa, det syns inte så jättebra

N Men kan man, aa, nä

M Men om du lyser ner i vattnet, så att [ohörbart]

N [Skratt]

M Nu börjar vi bara experimentera själva [skratt]

N A, men

V Jag tror att det är svårt för vi kan ju fortfarande inte se hur strålen går innan den går i vattnet

M Nä, =Men nu kan man faktiskt se strålen typ härunder

N Nä, [ohörbart]

N Ja

M Ja

[En lärare kommer in genom dörren för att hämta något]

V Jarå, va coolt, ja, har vi, har vi bestämt hur vi ska göra

M Ja typ

N Hur ska vi =göra

M =Vet inte om vi hade en kompis här skulle man ju typ ha en diskussion med den

R Men ni kan ha mig som kompis, nu är jag eran kompis

N Aha

M Okej, men liksom så man har nånting å liksom, vad är det du inte förstår

R Jomen alltså jag fattar ju inte varför varför man inte kan peka rätt på den så här bara [klickljud med tungan].  
och träffa den

M Men, =eh

R =det verkar ju helt naturligt

M Ja

R För den är ju så, om man sticker ner den så här va så ser den helt böjd ut

N Mm, pinn, pinnen

M Eh,

R Ja

V Men nu har ju du sett oss = nu har ju du sett oss testa det = med pinnen här

R = [ohörbart]

V =Vill du (?)

R =Det är ju fusk, ja men eftersom jag att trodde, fast jag menar

R Kolla här, nu hade inte jag en sån här pinne jag hade ju en träpinne då men ändå dom den den var rakare = innan jag stoppade ner den i vattnet

V =ja

R Fast nu, det var ju inte så här grunt dårå där jag pekade

V Nej

M Aa

R Nej, utan det var ju djupare, så då s...,  
men man ser ju ändå tydligt

V Du kan se samma fenomen nu också

R böjd liksom

M Aa

R Jag fattar inte det liksom hur den kan se böjd ut när den är rak

V så vad betyder det att du ser pinnen och att du ser bollen på botten

R Att, att den ligger på botten

V Hjälp mej

M Ja

N Ja

V =Sluta

M =Men, men, men

V [dfilkgj?] härifrån

N Hur fungerar det när man när du ser nånting

R Man tittar och så ser man den

[Dörren öppnas]

M Ja, man kan ju, man tänker ju gärna så här att man tittar på nånting och så ser man det, men eh,

till exempel om du tittar på reflektionen i vattenytan här, eh då kan du se lampan där, ser du det

R A, just det

M Aa

V Men finns lampan här nånstans under vattnet

R eh, nej, men den speglas ju där

M =utan det, a

M Den speglas där, det är ljuset från den där som kommer och så speglas det där och så kommer det till dina ögon

R Mm

M Och precis på samma sätt så ser du den där bollen alltså.

R A, just det

M Ljuset som som träffar den där bollen speglas och [sdlkjf] på den där bollen.

R Ja, det studsar på den

V Så att om vi släckte lampan och det inte fanns nå = ljus här så skulle du inte kunna se bollen

R =([Svårt att höra:] då blir det mörkt)

R Har ni läst barnböcker, kråkan städar i mammas mamma mu's lagård genom att släcka lyset

M [Skratt]

V Ja just det

R Jättesnabb...

M Ja

R ...på och städa.

M Det var smart, men ja precis

R Ja okej så =ljuset studsar på den

M =det, det

M Det är ljusstrålen som går =från den där till

R =men varför går den inte rakt då

M Precis varför går den inte rakt. Men då kan du titta om vi tittar på den här reflektionen igen eh

R Mm

M så ser du ju att det är nånting som händer med ljuset när det träffar vattenytan det reflekteras det studsar på vattenytan

R Aa

M Öh, Men det kanske kan hända något  
mer på vattenytan, när ljuset kommer här  
underifrån  
R Att det kan gå rakt igenom i stället  
M Aa, fast det kanske kan böja sig  
R A, till exempel det verkar ju så  
M Om om du tittar på den här så ser det ju  
ut som att den är böjd, eh  
R Men  
M Om, är den böjd liksom, böjer man den  
sej  
R Fast den är ju rak under vattnet också  
M Aa, den  
V Det är som att det händer nåt precis där i  
vattenytan  
R a, a fast, ja i och för sig, att den böjs  
precis där  
M Aa, =så man  
R =Sen blir den rak igen (?)  
M Mm, Ska vi titta om han kan  
V Ja  
M tänka på den här  
R [Jag fattar inte riktigt?]  
M Nej [Skratt] Det är klart du kan fatta nåt.  
Men om man tänker sej att det här är  
pinnen liksom som du håller i  
R Mm  
M Om du tittar på den här  
V Du kanske vill rita =själv  
M =ja  
R Nej, tack, rita ni  
[Dörren öppnas]  
R Du får rita en större plupp  
M Ja  
V Nej, men då  
R A, mm  
M sådär, nej, om om vi säger att det här är en ljusstråle som kommer från den  
här ringen, eh nej ja inte en ljusstråle, det här är =pinnen du håller i,  
R =ja  
M Om det här är pinnen du håller i då går  
den ju rakt om du tittar på den här från  
sidan liksom  
R Mm  
M Då ser man ju att den går rakt  
R Den är verkligen fortfarande rak  
M Aa,  
V Men(?)  
M Men så att den här pinnen är ju rak liksom om om vi skulle tänka oss att  
det inte var nåt vatten här skulle du ju peka rakt på den  
R Mm  
M När du pekar på den  
R Ja

M Men men ljusstrålen då ja men om vi om  
vi antar så här att den att den böjs när den  
träffar vattenytan

R Mm

M så antingen så måste den ju åka på nåt  
sätt

sånt här och då böjs den där och sen går den till dina ögon eller så åker den  
på nåt sätt så här eh och böjs den liksom upp till dina ögon

V Så att den va den strålen som skulle få  
dig och se pinnen som helt rak den stråle  
som skulle gå här

N Mm

V När dom kommer den kommer åkandes här och kommer hit då böjer den  
av och den kommer aldrig träffa dina ögon

R Men det är det där som jag inte fattar  
varför det blir

M Varför det blir så, varför den böjer sig  
liksom =eller

R =Ja varför böjer den sig liksom

M Ja

V Varför ljusstrålen böjer sig

M Det eh har väl och göra med typ vattnets  
elektriska egenskaper

N Aa

R Men men pinnen är ju inte elektrisk

M Nä men ljuset är det faktiskt

R Jaha

N ([Svårt att höra:] Hä)

M =Eh [dörren öppnas]

R =[Bara (svårt att höra)] man inte känner  
det

M Nä

R Mhm

M Det ja alltså typ fysiken idag tänker ju att  
ljuset är elektriskt det är elektrisk strålning

V Och att det är vågor

M Ja elektriska vågor i i luften

N [Suckar]

R [Ja-]ha

M Men dom eh dom här vågorna dom  
beter sig olika i vattnet och i luften för att  
vattnet och luften är har olika  
egenskaper du kan ju till exempel leda  
elektrisk ström genom =vattnet

R =Mm

M Men inte genom luften

R Just det

N Lä... Lättare

R =[Ohörbart] också

M =Ja

N Ja

V Mm om du skulle sammanfatta hur du  
tänker på det här nu hur

R Ja jag vet inte jag fattar ju uh okej så att anledningen till att pinnen ser ut och och bara böja sig precis i vattenytan det är att ljuset böjer sig precis i vattenytan

M Aa

R Sen går det rakt igen

M Precis

R Och det är för att ljuset är en elektrisk våg

M Aa precis =man kan

R =[dölfkgldk lite mer (hör inte)] aa det är väl okej men

M Man kan till och med göra så här om du tänker sig att det här är ss ljusstrålen som går ut ifrå ifrån pinnen och träffar ditt öga

R Mhm

M så har du ljusstrålar så här eh

N Mm

M Å Då

N Där man tänker bilde[n]

M Då där du ss där du kommer tänka i ditt huvud för du är ju van att tänka att strålar är raka så kommer du tänka att okej men den här pluppen den ligger här borta

R Mm

M Och sen så börjar pinnen här och så säger den här okej men sen så är pinnen här liksom då kommer du få en bild av pinnen som ser ut så där liksom.

R Mm

M Förlängningen av den linjen istället för den liksom

N [Ohörbart]

M Ja, så då får du liksom en sån här pinne som går [Gör ljud: dik dik] liksom och om du om vi tittar på den här delen liksom

R Mm

M Känns det vettigt att det skulle kunna va så

R Aaaa just det för den ser ju ut att ligga längre bort

M Precis

R Aa

N Man kan ju säga det är ju dom här sak det är det man använder att ljus att ljuset så hära bryts av när man gör såna hära kikare och linser och sånt dära =[och (ohörbart)]

V Förstoringsglas

M Aa

N Glasögon

M Aa

V Kan du tänka dig hur det skulle fungera när man ska använda det här för och göra ett förstoringsglas

R Man kan göra ett för försnedningsglas kanske om man

M Aa

R Man får väl anta att att ljuset för att vatten och glas funkar på samma sätt alltså

M Aa

R [sldkfldsk] Right känner ni att ni har förklarat det för mig nu så att jag har  
nån sorts förståelse för vad det här betyder

M Jaa jag tycker det u under liksom

V ja jag skulle nog om om det var min kompis så skulle jag nog vilja prata om  
att om att att att ljust är strålar att ljust är alltså det är ju inte

det be det behöver inte vi behöver inte tänka på det här sättet det här är inte  
sanningen det här är ett sätt att förklara det på

R =Mm

V =Det vi vet är det vi ser liksom

M Mm

V Men det känns inte som att som att det  
är det du är ute efter som kompis =just nu

R =Nä

M Det och det är =svårt

R =Fast, fast, fast jag har liksom bara  
funderat på

M Ja

R Ja tycker ni att den ser ut och ligga lika djupt då där borta alltså man måste  
ju ha en längre pinne man tror ju att man behöver en längre pinne  
om den ligger här

N Ja

M Ja

V He he

M Precis ja

V Ja jag tycker att det är svårt att göra såna  
dära konstruktioner av bilder under vattnet  
grejer det är

M Ja

V Jag skulle jag skulle inte våga göra det jag  
tycker att det är svårt

N Nej jag missa

R Okej vet ni vad att det finns en uppgift  
två också om ni vill fortsätta orkar ni nåt  
mer

M Ja visst

V Ja

R Då går vi vidare med uppgift nummer två

N [Ohörbart]

R Ni har ni ni ska strax slippa det här

R Okej

V Kolla [plutten] har lagt sig på på botten  
den har lagt sig på den här ss aa

R Och nu aa det nu nu är det nu är det ett dilemma här för er för nu är det en  
kurskamrat som har haft ett litet studieuppehåll och han berättar  
för er i i förtroende att han inte kunde  
förtse var han skulle peka nånstans för  
och träffa en ring som låg på botten

V Han också

R Ja, [dslkjf] eller om det var en hon jag vet inte, samma problem alltså han  
skulle pek plocka upp en ring från botten en bit ut i en sjö med en  
pinne och han kunde inte förtse vart han skulle peka och hur skulle du som



en mer erfaren eller som åtminstone har det här i med fräschare minne

förklara honom eller få honom hjälpa honom att få en någorlunda helhetlig  
förståelse av fysiken i situationen och nu får vi väl anta att han möjligen  
redan kan det som den förra personen kunde men att han inte fatta varför  
han ska att han inte kunde förutse att han ska peka på den ena eller andra  
sidan av den här saken

V Alltså han förstod att den skulle

R Det bryts okej han vet att det bryts  
=ljuset bryts

V =Men han kunde inte förutse hur det  
bryts

R Nej

V Jag kan inte heller förutse hur det bryts

jag brukar försöka

N Man kan slå upp det och titta på  
formlerna

M Ja, jag brukar tänka så här att om det är tjockare så bryts det liksom så här  
om det om det här är tunnare om det här är tjockare då bryts det liksom  
inåt

I use to think [that] if this is thinner an  
this is thicker, it bends [] inVards.

N Mm

M Medans

N Det är en minnesregel

M Ja

N Mest

V Men är du är du fortfarande kompisen

R Nå nu kan jag va jag kan vara

V Det skulle vara bra om du kan vara  
kompisen

R Jag kan va eran kompis

V Jag skulle vilja prata med kompisen

R Direkt

M Ja

V Ja vad är det du inte förstår

R Men jag fattar inte så här om jag pekar på pekar på den men men jag är  
rädd att jag till exempel ska grumla vattnet fast nu är jag ju fysikstudent  
så därför så tycker jag bara det är kul att  
kunna förutsäga var jag ska peka

M Aa

R Eftersom jag vet att det bryts så nu ska  
jag peka på den där vad är det för nånting  
en boll =fast

V =En boll

R egentligen så var det en ring då nu ska jag peka på den så nu vill jag kunna  
förutsäga ska jag sikta där eller ska jag sikta här nu ska vi se jag  
chansar på att jag ska sikta där det var fel jag skulle ha siktat här ja så jag  
fattar inte hur ska jag kunna jag jag kan ju inte lära mig sånt här  
utantill hur ska jag komma ihåg att jag ska peka åt det här hållet liksom [dfk]  
när jag ser den uppifrån luften så här det fattar jag inte hur ska man  
kunna komma ihåg jag kan inte lära mig  
och komma ihåg

M Ja

V Det känns inte som att det är så stor

poäng med att du lär dig och bara komma

ihåg hur du ska peka

R Nej utan det

V Vad vad är det du är ute efter liksom

R Nämen va varför bryts det varför bryts det åt det där hållet och inte åt det här hållet för

V Okej

M Mm alltså ja jag brukar tänka när det är vatten att  
eller  
jag har liksom en minnesregel för hur det funkade om man om det beroende på hur tjockt

det här materialet är liksom du kommer ihåg att vi pratade om brytningsindex

R Ja just det

M Om att det är ett mått på

M liksom hur =(a jag vet inte)

R=A men hur hjälper det ja i och för sig då måste jag lära mig utantill då att

M Ja men du måste alltså man måste ju veta typ att den här har eh den här att att glas eller att att

30.20-

På 'det där': pekar hitom (på sin egen sida om) bollen på botten av bytten med vatten, på 'det här': pekar bortom bollen på botten av bytten med vatten.

N Sitter längst till vänster, tittar på vattnet

V Sitter i mitten tittar på vattnet

R = Drar upp pinnen ur vattnet, lägger den på kanten av skålen

M = Står bakom, handen mot munnen (som funderande)

V Tittar upp på M

N Tittar på M

R Tittar först på vattnet sedan på M

M Tittar hela tiden på vattnet Rör lite vid näsan, slår sedan ut med handen åt sidan med en (uppgiven) gest, skakar på huvudet,

N Tittar på vattnet

M Lyfter höger hand ett par gånger, tar upp vänster hand ur fickan sedan höger och vänster hand varannan gång upp och ned med handflatorna uppåt

(två gånger med varje hand, sedan ner)

N Tittar åt sidan

M Upp och ned ytterligare en gång med varje hand, tittar mot

R

R tittar fortfarande på M, nickar, vrider huvudet mot vattnet och nickar

M Tittar på vattnet, två gånger med vänster hand upp och ner och en gång med höger där emellan

V Vrider huvudet mot vattnet, tittar igen på M sedan

M Lyfter upp båda händerna samtidigt en liten bit med handflatorna uppåt

N Tittar upp mot vattnet eller

M, rättar till glasögonen

R Kliar sig i huvudet

V tittar på R, sedan på vattnet

M Går fram till vattnet, gör ett litet lyft med höger hand (visar handflatan) och håller fram vänster hand mot nederkanten av skålen, pekar lite med hela handen i sidled och handflatan uppåt.

N Tittar på M

	<p>M Vinkar lite med ett par fingrar, klingar mot skålen, fortfarande med handen vid nederkanten av skålen. Tar ned handen, lyfter upp den med handflatan upp och sedan ner igen snabbt, lyfter upp båda händerna litegrann med handflatan upp</p>
N vatten	
M vatten [dörren öppnas] är liksom tjockare än luft liksom	<p>R Tittar på M</p> <p>M Lyfter båda händerna till midjehöjd med handflatan upp, gör en vridande gest med handflatorna vridande uppåt mot sig och sedan ut med händerna</p>
R Mm	<p>snabbt och sedan ned igen, sedan lyfter han händerna lite med handflatorna upp och roterande ut åt sidorna igen, tittar på R sedan mot dörren</p> <p>V = Tittar mot dörren,</p>
V Men brukar =vi inte kunna brukar vi inte kunna tänka på han Huychens eller Huygens	<p>R = Tittar på N eller V</p> <p>N = Tittar mot dörren</p> <p>V = tittar mot M</p> <p>M = Tittar på N eller V</p> <p>N = Tittar på M</p> <p>R Tittar mot dörren, sedan mot N och/eller V igen</p>
M =Hey... Huygens princip	<p>M =1 Sätter armarna i kors</p> <p>V =1 Följer M:s händer med blicken</p>
V Ja och tänka på det att vågen kommer in så här och så nånting och därför så bryts den mot eller från normalen	<p>V Håller upp armarna och händerna med handflatan snett neråt, höger hand snett ovanför vänster hand, händerna och underarmarna som i ett lutande plan snett nedåt vänster (från henne sett), rör händerna och armarna snett nedåt vänster (från henne sett) och full stopp, sedan nedåt lite till och tar ned händerna helt, sedan rör hon höger hand med handen helt utsträckt men roterad vertikalt upp och ned två gånger</p>
M Ja men det är trögare liksom =det är ju	<p>M Tittar på vattnet, ruskar på huvudet,</p>
V =ja	<p>V tittar snabbt på R sedan tillbaka till M</p>
M vatten är trögare det är ju tjockare än luft liksom	<p>M tittar på R, lyfter vänster och sedan höger hand upp och ned med kupade handflator uppåt</p>
V Är det det du är ute =efter vill du ha nåt slags	<p>V tittar på R, sänker axlarna (som att hon sjunker ihop)</p> <p>M Sträcker sig till bänken efter en krita bredvid skålen</p> <p>V (Följer Ms hand med blicken), tittar på skålen</p> <p>M Går till tavlan</p>
R =Mhm ja just det det är ju ja exakt	
V = eller om du bara vill kunna komma	<p>V Tittar på R, pekar på skålen,</p> <p>R Vrider huvudet, tittar på skålen, sedan tillbaka till V igen</p>

V ihåg då kan du ju bara lära dig att det	M =Ritar horisontellt streck på tavlan,börjar med tydligt ljud N Tittar mot tavlan V Rycker på ena axeln
V =1 bryts så här så kan du komma	R =1 Tittar på skålen igen N =1 Lutar sig tillrätta mot bänken, tittar på tavlan V pekar hastigt på skålen
V ihåg det till nästa gång R =1 Aa men det har jag förskräckligt svårt för	R tittar på V igen, sedan vrider han sig och tittar mot tavlan V Vrider sig och tittar på tavlan
R då verkar det bättre att ha nån sorts [fdlkgjd]	M Ritar ett vinkelrätt streckat streck uppifrån som korsar det horisontella strecket, bättrar på det streckade strecket nedanför det lägsta horisontella strecket,
1 M Men om om det här är en vinkelrät liksom eh linje till vattenytan och så så har du att bollen ligger här och så har du att	M Ritar en "rät-vinkel-hake" i "första kvadranten" och en i tredje, V Reser sig N Reser sig M =1 Pekar kort på den nedre horisontella linjen, drar ett till horisontellt streck under det nedersta horisontella strecket. V =1 Tar en krita vid tavlan M Ritar en rejäl prick på det understa horisontella strecket, kliar sig i huvudet, mättar med handen ovanför det översta horisontella strecket, rör
2 V Vi kanske kan ta en allmän det kanske inte behöver ha	handen i sned linje mellan pricken och "korset" mellan horisontella mittlinjen och vertikala linjen, upp, ner, upp, ner, suddar lite med handen, upp till "korset" igen,
3 N En boll	
4 V Bollen jag tänker att det blir jobbigare =då	M Drar ett streck snett ned till höger till pricken R Tittar mot dörren sedan tillbaka mot tavlan M Håller kvar handen ett tag, N Ler, tittar mot kameran sedan tillbaka mot tavlan V Tittar mot R, sedan på tavlan
5 M =Ja, ja nä men en nånting ligger här en nånting	M Följer linjen upp till "korset" igen, rör handen upp i sned linje åt vänster och sedan ner igen till korset, drar ett streck från korset och snett uppåt åt vänster. V Hostar,
M och så kommer ljuset här	M Ritar ett stiliserat öga från sidan som tittar ner åt höger V Tittar mot R, sedan mot tavlan M Står med handen redo i luften att fortsätta rita, för handen till munnen.
M och så tittar du här	
M här är ditt öga	

6 V Men är inte poängen att vi vill beskriva det som en vågfront som kommer in	V Rör handen (med kritan som en cigarett) uppifrån höger och ned åt vänster	But, isn't the point that we want to describe it as a wave front? ...coming in
7 M Ja fast jag jag jag brukar inte tänka på vågfronter jag brukar liksom bara tänka att men här är tunnare och det här är tjockare	M tar ner handen	Yes, but I... I usually don't think of it as wave fronts, I usually kind of just think that:
M så när ljuset	V sätter handen mot munnen	
a jag vet inte	M Håller kritan mellan tumme och pekfinger, pekar med de andra utsträckta fingrarna först ovanför horisontella mittenstrecket sedan under horisontella mittenstrecket, pekar sedan på korset, sätter kritan mot prickén, vinkar med handen upp (roterar handen så kritan pekar uppåt) och sedan ned, ruskar på huvudet, vinkar en gång till upp och ned med handen mot prickén	well, this is thinner and this is thicker. So when the light... I don't know
8 V =Men varför varför varför bryts det varför blir vinkeln	V Går mot tavlan, pekar på korset,	But, why, why, why does it bend, why is the angle
9 R =[Men du vet bara att det är så där]	R Pekar mot tavlan,	But you just know it's like that
V den här vinkeln	V sätter ut "vinklar" (vinkelbågar) mellan vertikala strecket och de lutande strecken, börjar med den undre högra vinkeln (se nedan för beteckningar)	this angle
10N Mindre än den andra och =1 inte tvärt om	N Sätter sig (avslutar sedan meningen åt V)	
	V Sätter ut beteckningar på vinklarna, theta 1 vid den undre högra vinkeln, theta 2 vid den övre vänstra vinkeln, (närmast det vertikala strecket),	smaller than the other and not the other way around
11R =1 Det är det jag aldrig kan =2 ja	Skriver med matematiska tecken theta 1 är mindre än theta 2.	That's what I never can, well...
12V =2 Varför är det varför är den här mindre och inte större	V Pekar på "mindre än"-tecknet, backar undan åt vänster, tittar på M	Why is it, why is this smaller and not bigger
13M Ja för att det här är tätare liksom	M Kliar sig i huvudet, vrider sig, pekar under det horisontella mittenstrecket med utsträckta fingrar, tittar på V, N Tittar på tavlan/M	Well, because this is denser, kind of
14V Varför varför blir det så för att den är tätare	V rycker på axlarna	Why, why does that happen because it is denser
15M Ja då m får man ju börja tänka på typ Huygens princip =1 eller	M tittar på tavlan igen, vinkar med höger hand upp och ned, tittar sedan på V	Well, then one has to start thinking of Huygen's principle, or...

16V =1 Ja jag har =2 för mig att vi att vi =3 har förklarat det så någon =gång	V Tittar på R, tittar på tavlan, tittar på M, R Tittar på V/N	Yes, I think We have explained it that way some time
17R =2 Vad innebär det då		What does that mean then
18N =3 [det är på] elektromagnetiska	V tittar på N	It's electromagnetic...
19M =4 Ja, ja eller typ bara [eller] elektromagnetiska vågor	R Tittar på M	Yes, or kind of just, or, electromagnetic waves
20N =4 [vågor vid aa]	V Tittar på tavlan R =1 Tittar på N N =1 Sitter och svänger fram och tillbaka på stolen V =1 Tittar på M, sedan tillbaka på tavlan	...waves at, yes
21R =1 Men testa lite	R Tittar på tavlan	But try a little bit
22V =1 Men på nåt sätt tänker vi på det som en vågfront	V Håller upp kritan i midjehöjd och vinkar litegrann med den M = Backar åt höger	But somehow we're thinking of it as a wave front
23M Aa	R = Flyttar sig lite åt höger	Yeah
24V Och då kommer liksom en en del av vågfronten träffa jag kan inte göra den förklaringen själv men att en del av vågfronten kommer liksom träffa vattnet	V Viftar till med kritan kring korset, visar ett vinkelrätt rakt streck (en vågfront) tvärs över det övre sneda strecket åt vänster, uppifrån höger nedåt vänster M = Suddar lite till höger på det övre horisontella strecket med handen V = Håller kvar kritan vid horisontella mittenstrecket, pekar litegrann kort till höger och vänster, pekar kort uppifrån och ned mot horisontella mittenstrecket	And then, kind of, a part of the wave front will hit, I can't do that explanation myself, but a part of the wave front will kind of hit the water
25M In före =och sen så går det snabbare	M Viftar till i en båge uppifrån höger nedåt vänster med sin högra hand	Before and then it goes faster
26V In före =och det går långsammare [i vattnet]	V Pekar nedanför horisontella mittenstrecket	Before and it goes slower in the water
27N =Ja		Yes
28M Ja just det det är tätare det betyder att det går långsammare där	M Vinkar lite med kritan, tittar på V, tittar på tavlan, pekar också under horisontella mittenstrecket N Tittar på R, sedan på tavlan V Tittar på M, tittar på tavlan, Pekar på horisontella mittenstrecket/vågfronten M Pekar på det nedre sneda strecket	Yes, that's right! It's denser which means it's going slower there
30V =1 Och då kommer det liksom inte		And then it won't kind of...
29R =1 Vad är det som går långsammare då =2 [jag fattar inte]	V = Tittar på R (med kritan upp i luften)	What is going slower then? I don't understand.
31M =2 Ljuset går långsammare	M = Tittar på R (med kritan upp i luften),	The <i>light</i> is going slower!

32R jaha =3 [så är det]	R Tittar på tavlan,	
33M =3 så att om du har om du har vattenytan här och så har du en vågfront eh	V Tittar på tavlan M börjar rita ett nytt horisontellt streck ovanför till höger på tavlan, pekar mitt på denna, viftar till lite med pennan, V tittar på R	Aha So, if you have the surface of the water here and then you have a wave front eh
34R Jag trodde ljuset alltid hade ljusets hastighet		I thought light always had the speed of light
35M Ja	M ritar ett streck snett nedåt höger från mitten av det nya horisontella strecket. Ritar ett vinkelrätt streck nedifrån vänster uppåt höger tvärs över det sneda strecket, slutar när det kommer fram till det horisontella strecket, sänker handen. Lyfter höger hand ovanför den nya horisontella	Yes
36V Mm ja		Mm yes
M Fast inte om det kommer liksom det är ju som att det går in i sirap liksom	linjen och drar den = hastigt ned åt höger efter det sneda strecket. =Vrider huvudet och tittar på R V Tittar på R	But not if it comes, kind of, it's like it enters syrup, kind of
R [Skratt]		
M Det går långsammare i = sirap = liksom det fastnar liksom	M Slår ut/upp med händerna med handflatorna uppåt, håller fram händerna med handflatorna uppåt.	It is slower in syrup, kind of, it's stuck, kind of
R Okej		
N =[Det går] Anledningen till ljusets hastighet i vacuum är alltid samma fast när det är i material så när ljuset fortplantar sig i material så gör det ju egentligen det genom att det krockar med atomerna sen så blir det nya ljus	M = Tittar på N.Gör en kort rörelse uppåt med först den högra sedan den vänstra handen.  R = Vrider huvudet och tittar på N. V = Vrider huvudet och tittar på N. M =2 Vänder sig mot tavlan, ritar ytterligare två korta ("måttar" först innan han ritar det andra) vinkelräta streck ned åt vänster från den nya horisontella linjen korsande den sneda linjen ner åt höger från den nya horisontella linjen. N =2 Vrider sig och tittar på skålen, pekar mot den. M =2 Ritar ytterligare 3 tvärsreck som tidigare, under tiden som de närmaste nedanstående raderna. N =2 Tittar på R, tittar hastigt till handen, gör en häftig hack-/stegvis rörelse framåt med den pekande högra handen, fast med alla fingrar (utom tummen) utsträckta, V Vrider huvudet och tittar på R N Tittar på R och =gör en ny likadan rörelse med den högra utsträckta handen. V =Tittar på N:s hand/skålen.	The reason, the speed of light in vacuum is always the same, but in a material, so when light propagates in a material it is really hitting the atoms then there is new light
R Mm		Mm

N Det blir nytt ljus	N =Lägger ned handen på bordet. V =Tittar på R R =Nickar och vrider sig och tittar på V N Vrider huvudet och tittar på M. R Tittar på M	It is new light
V Så att själva ljushastigheten är ju konstant men den måste ju göra en massa andra saker på vägen	V Tittar på skålen, = tittar på R.  R = Tittar på V V =2 Lyfter upp handen gör en rörelse utåt nedåt och lyfter upp handen igen. Pekar/rör handen fram och tillbaka kort framåt (åt höger i bilden) två gånger sedan ner med handen igen. Ler, vänder sig mot M M =2 Har ritat färdigt strecken, tvekar med handen i luften, rör handen mot munnen sedan upp mot och pekar på korsningen mellan den nya horisontella linjen och den sneda ner åt höger med kritan. V Tar ett par steg närmare M (åt höger i bild). M Tar ned handen något och sätter den utsträckta handen i linje med tvärsstrecken med handflatan	So the speed of light is constant, but it has to do a lot of other things along the way
M Men		
M Om vi tänker oss att dom här vågorna kommer och så är det trögt att gå liksom för det är vatten här nere	snett upp åt vänster och rör den snett uppåt vänster efter det sneda strecket och sedan ned igen samma väg och tar ihop handen igen. För handen	
V Ja	utåt höger till skärningspunkten mellan det nedersta tvärstrecket och det nya horisontella strecket. Skriver något [vatten] strax nedanför på tavlan.	
M Öh då	V =Vrider huvudet flera gånger åt höger och tillbaka. N Tittar mot dörren och tillbaka. R Pekar mot tavlan	
R Ja just det för det är därifrån ljuset [nåt från] nånting kommer	M Pekar på skärningspunkten mellan den nya horisontella linjen och den som går snett därifrån nedåt höger med kritan, tar bort handen något och pekar sedan på samma punkt igen med kritan V Går fram mot tavlan, höjer höger hand med krita i handen, ritar en liten ring i nedre högra änden på det sneda strecket nedåt höger. M Har kritan i samma riktning som tvärsstrecken dvs nedifrån vänster och uppåt höger, =gör rörelse uppåt vänster från höger, först strax till vänster av det sneda strecket som går uppför från vänster och nedåt höger, sedan samma rörelse strax till höger om samma streck. V =Backar ett par steg åt vänster i bild M Sätter kritan till höger på det nya horisontella strecket gör en liten rörelse nedåt längs ett av tvärstrecken mot skärningspunkten längst till höger mellan det nedersta tvärsstrecket och det nya horisontella strecket. Sätter sedan kritan strax till höger om mitten på det nya horisontella strecket igen men flyttar sedan kritan till skärningspunkten mellan det nya horisontella strecket och strecket som går snett nedåt höger. Vrider huvudet	
V Det kommer härifrån		
M Dom här går liksom så här aahh långsamt så här trögt trögt trögt men det som har kommit upp i luften det går snabbare liksom		



	tittar på R V Tittar på R
R Mm	
M Så då får du att det blir brantare här liksom	M Tittar mot tavlan igen
	V Tittar på tavlan
R Varför det då	M Ritar ett streck snett uppåt höger från den tidigare positionen, något brantare än de andra snedstrecken. Ritar flera (fem) parallella sådana streck till höger om det första, vart och ett med början i skärningen mellan ett tvärstreck och det nya horisontella strecket. Tar ner handen och
M Öh	håller kritan parallellt med tvärstrecken och rör handen snett uppåt vänster. V Går framåt tavlan
M Jomen för att det = kom V = För att om man tänker det här strecket kommer den här lilla biten av strecket kommer det liksom och och börja gå lite fortare	M = Pekar längre till höger på det nya horisontella strecket, för handen till munnen.  V = Sätter vänster pekfinger till vänster om det sneda strecket som går från mitten av det nya horisontella strecket nedåt höger, på ett av tvärstrecken
M Ja	som går mot skärningen mellan tidigare nämnda streck, och pekar med kritan (höger hand) mot skärningspunkten med det nya horisontella strecket, ritar som en punkt där. Vänder sig mot R, och tar ett steg bakåt från tavlan. Håller båda armarna lite snett upp i luften, den ena högre upp än den andra, och rör händerna något uppåt och nedåt. Tar ner armarna.
V Och då om man tänker nästa bit av strecket den kommer liksom inte kommer börja gå lite fortare lite senare så det är som att den inte hinner ikapp	
	M Tittar på tavlan R Tittar på tavlan [/V] N Reser sig går mot tavlan
N Den den första biten alltså det är ju liksom att	V Tittar på N, backar ett steg M Flyttar handen mot mitten av nya horisontella strecket, tar bort handen igen
V Så tänker jag	N Tar en krita vid tavlan, Pekar med vänster hand långt ned på strecket som går nedifrån vänster och uppåt mot den nya horisontella linjen. Flyttar
N Om man tänker sig att de rör sig så hära så är det ju [dkj] den här biten som är här ute att den kommer ju fram till ytan före före den här biten	dit den högra handen (pekar med pekfinger) och flyttar vänstra handen uppåt åt vänster mot korsningen med nya horisontella strecket.  V Flyttar sig åt höger i bild för att se N Flyttar höger hand (pekar) upp till höger på den horisontella linjen (nära det första tvärstrecks korsning), för handen till vänster längs horisontella strecket till korsningen för nästa tvärstreck och följer sedan

R Mm	detta uppåt höger med pekfingeret. Tar upp en krita, ritar två prickar på olika höjd på det streck som är längst till vänster av de som är ritade snett uppåt från horisontella linjen. Pekar sedan på korsningen mellan strecket han ritat prickar på och horisontella strecket och på en motsvarande korsning två steg till höger med kritan. Rör sedan högra handen med
N Så att den hinner liksom	kritan vinkelrätt mot de sneda strecken snett uppåt vänster från det horisontella strecket två gånger, tittar på R, sedan en till rörelse med höger
R Ja just det	hand. Sätter sedan händerna parallellt med strecken ovanför det horisontella strecket och visar med höger hand en snabb rörelse från höger till
N =Röra sig mer i det här snabbare mediet	vänster ovanför horisontella strecket. Tar ner händerna, lägger ifrån sig kritan
R =[så blir det när det går fortare] ja just det	
N Och då liksom =[kfj] upp så	M Tar ner handen med kritan till midjehöjd, tittar på V, tittar på R, pekar med höger hand (utsträckt) åt kamerans håll, håller sedan upp båda
M =Man om man ja man kan tänka på det som en bil som kör i typ lera så här vi har en bil här som kör i lera eh fyra hjul och så är det lera	händerna parallellt snett uppåt. Vänder sig mot tavlan. Ritar fyra ovala former i hörnen på en (tänkt) rektangel, med riktning snett uppåt vänster.
V Det är sant det är ju bra	Pekar på de fyra figurerna med kritan, pekar sedan på översta högra ovalen med vänster pekfinger
M Och sen så kommer den ut på asfalt här	
R Mm	V Gör en hastig horisontell rörelse med höger hand mot kroppen och tillbaka ut (står vänd mot tavlan med ryggen mot kameran).
M Då kommer ju det =här	M Ritar ett horisontellt streck genom den övre högra ovalen, pekar på den med höger (långfinger?) Tittar på R,
V =Gör ett streck där asfalten är	
M Här är asfalten liksom	
R Mm	
M Det här hjulet kommer ju dra mycket mer	R Nickar
R Mm	M Gör en ryckig rörelse med vänster hand, tittar på tavlan, håller upp båda händerna parallellt med figuren på tavlan, vrider dem samtidigt åt vänster, tittar på R
M Det kommer gå snabbare så då kommer det svänga liksom bara för att det här hjulet drar mer liksom eh och sen när det hjulet kommer upp då kommer det dra mer än det hjulet för det kommer upp före då blir det sån här [sch] så ba att det det är trögare att åka här det betyder att om man kommer in på	M =Vrider dem flera gånger åt höger och vänster, tittar ömsom på tavlan och R
snedden då kommer man svänga liksom så funkar det för ljuset också det gå trögare här och sen så när det kommer här då ss då acc då liksom det här	V =Tittar på M/R, tittar på tavlan
snabbare	M Håller händerna parallellt med figuren, rör dem upp och ner, nu med händerna osynkroniserat upp och ner också, vrider igen, tar ner händerna, håller upp händerna igen parallellt med figuren, nu med vänsterhanden "något tappande neråt"
	V Går mot tavlan och tillbaka

	igen
	M Håller händerna parallellt
	med figuren igen, vrider lite på
	händerna
	N Tar krita vid tavlan
	R Följer nu strecket som går snett upp åt vänster upp mot det "nya horisontella strecket" (som nu är ett äldre horisontellt streck än det senaste),
	och vrider vid det horisontella
	strecket på händerna. ...och
	igen
	V Håller upp händerna som om
	hon höll i två glas
	N Börjar rita till vänster på tavlan, först ett horisontellt streck, sedan ett vertikalt som skär rakt igenom det första
	M För vänster hand till näsan
V Men det accelerar inte lika fort alltså [deras hjul är alltså kjhdsf] helt olika delar eller	N Ritar fler parallella horisontella streck under det första
	V Rör händerna synkroniserat lite ner åt höger och upp igen som om hon höll i glaset eller snöbollar
M Mm det =acc det ändrar ju hastighet	M Visar med de parallella händerna igen och vrider högst upp vid den horisontella linjen
	N Ritar fler parallella horisontella linjer ovanför det första
V =[dfkjg Ojämt så] Det är inte som vi tänker på det som att det har en utbredning nu	V För händerna ifrån varandra som för att ge M en kram, släpper ner händerna hastigt (som uppgivet) mot kroppen
M Ja	M tittar på V
V Men varför gör vi det	
M Hur då	
V Det är ju det som är så konstigt	
N det är för att det är vågor = egentligen	
V =För att vi säger ju att det är en stråle här och den har ju inte olika delar som accelereras olika fort här är det olika hjul liksom men ifall det här är en stråle den är ju liksom helt som bara en matematisk punkt	V tittar på tavlan, pekar på nedre högra änden på det sneda strecket sedan högst upp till vänster på samma streck vid korsningen med det horisontella
	strecket, ruskar på huvudet. Sätter handen på det horisontella strecket vid de fyra ovalerna, pekar sedan på nederdelen av det sneda strecket igen,
	och följer det snett upp åt vänster. Tar ett steg bakåt och håller samtidigt upp höger hand och med fingrarna utsträckta klämmer som på en stressboll tre gånger och tar sedan ner handen. Paus
N Det =det	
M =Ja fast förhållandet skulle fortfarande bli så skulle det inte det	M Pekar på den översta högra ovalen, tittar på tavlan, mättar som för att rita något först med kritan, pekar sedan hastigt med de utsträckta fingrarna
N Men	mättar med kritan igen, pekar sedan med vänster pekfinger och kritan i höger hand på de två översta ovalerna

M För att om om om om man tänker sig att  
eh det det är två personer som det är två  
bilar det här

V Aa

M Så kommer eeh

V Men nu tänker du på flera strålar jag  
tänker på en stråle

M Ja fast

N Men är inte grejen att egentligen

M Eh

N är det en våg som har en slags  
utsträckning

M Ja precis kanske

V Jag vet inte riktigt

N Att egentligen som eller på nåt sätt så är  
det ju en våg som går så här kan man tänka  
sig så då blir det ju liksom en skillnad här  
nåt sånt

R Jag tycker det där verkar ganska men det  
där är ju

M Ja alltså

R Jag skulle nog kunna tänka mig och vara  
ganska nöjd med den där förklaringen  
=faktiskt

M Aa

N Då kan man ju

R Men kan man säga veta nånting om hur  
mycket det där är då

M Aa

N Ser sig hela tiden omkring  
runt tavlan, tittar på M

M Pekar lite, Suddar bort  
ovalerna

V Håller upp armarna med böjda armbågar så att underarmarna pekar  
snett uppåt parallellt, rör höger arm upp och ned i armens riktning, för  
handen till näsan

M Tittar upp mot det tidigare  
ritade ögat

R Tittar på N

V Tittar på N

M Tittar på N

V Tittar på R?

N Tittar på dörren

V Tittar på M/tavlan

N Tittar på M

V =Backar och sätter sig, tittar  
på tavlan

N =Går till tavlan och tar en  
krita

N Ritar ett horisontellt streck  
på tavlan

M Läger ifrån sig sin krita

N Ritar en vågform nedifrån höger upp mot den nyligen ritade horisontell  
linjen. Fortsätter rita vågformen ovanför linjen, men lutar den mer ner  
mot den horisontella linjen. Drar sedan ett streck tillbaka "genom"  
vågformen mot skärningspunkten med den horisontella linjen, och  
fortsätter sedan  
med det raka strecket genom vågformen under det horisontella strecket.  
Läger ifrån sig kritan och backar undan åt vänster. [Man hör att kritan  
faller.]

R Pekar på tavlan

N Böjer sig ner och plockar upp något [en krita, hörs på ljudet] från golvet  
lägger på tavlan

M = Kliar sig i huvudet, tittar på  
R.

R = Tittar på V

V = Nickar

N Går tillbaka åt vänster från tavlan, tittar på skålen, tittar på tavlan,  
kliar sig i huvudet

M Tittar på tavlan, tittar på R

R Pekar kort på tavlan

N Tittar på R, tittar på tavlan

R som den som det skiljer i dom där	R Pekar kort på tavlan igen
M Man har ju nån man har ju nåt värde på brytningsindexet	M Tittar på tavlan, höjer handen mot tavlan med handflatan uppåt, och ner igen, A teacher Kommer ut ur dörren till höger om tavlan.
R Ja det där	R = Höjer handen igen och pekar på ett av tvärstrecken på en "tidigare bild", tittar på R, gör en kort gest med handen (sträcker snabbt ut alla fingrarna), tar sedan ner handen igen N = Tar en krita från tavlan
M Det är typ det och det ger ju hastigheten vad är det	M Vinkar mot tavlan igen, tittar på tavlan N Måttar mot korset mellan horisontella och vertikala strecket på bilden med ögat. Sätter kritan högst upp på vertikala strecket, sedan i mellanrummet
V Ja brytningsindex och hastigheten har =hänger typ ihop	mellan det sneda strecket nedåt höger och det horisontella strecket
M Typ hastigheten är lika med ljushastigheten genom brytningsindex eller nåt	R Tar en krita, tittar på tavlan, =skriver $v=c/n$ på ett rakt bråkstreck högst upp på tavlan, håller kvar handen bredvid ekvationen på tavlan N =Tittar på M M Tittar på V
V Eller nåt	
N Ja exakt eller nåt men njæj så blir det	N Nickar lite, pekar på det M har skrivit, nickar lite R Tittar på N V =Reser sig, går halvvägs mot tavlan M =Pekar på ekvationen N = Nickar
M Nej så []	
N Så är det så är det	
M =Så att	R Nickar, tittar på tavlan, tittar på N/V, M Tittar på R
V = Så [att] vad kommer brytningsindex	
M Brytningsindex säger hur mycket långsammare det går	R Tittar på M M Tittar på N V =Tittar på R M =Tittar på R N Tittar på M, tittar på tavlan R =Nickar M =Tar ner den pekande handen, lägger ifrån sig kritan, tittar på tavlan V =1 Tittar på tavlan, (nickar?), vickar till huvudet M =1 Tittar på V, "gnuggar" händerna R =1 Tittar på V N =1 "Måttar" mot korset igen
R Just det mm	
V Och sen finns det nåt samband mellan =brytningsindex och [flgkh] vinkeln	

R =Aa just det det kan jag aldrig lära mig  
 heller hur man ska komma ihåg det

V =Lyfter upp handen mot tavlan, gör först en rörelse med handen  
 uppfifrån vänster nedåt höger, visar sedan med handen/pekfingret (böjer  
 i handleden)  
 uppfifrån höger nedåt vänster,  
 och tar ner handen, tittar på R  
 R =Tittar på tavlan  
 N Börjar skriva något på tavlan

M Tittar på R  
 R Pekar uppåt i luften, tittar på  
 tavlan där N skriver  
 M Tittar på tavlan  
 V Tittar på tavlan

[Dörren öppnas]  
 N Skriver  $\sin\theta_1$ , fyller på så att det blir  $n_1\sin\theta_1$ , skriver något  
 (jag tror  $n_1$ ) under, fyller sedan på så att det blir  $n_1\sin\theta_1=n_2\sin\theta_2$

M Men varför blir det så då  
 M = Slår ut med händerna lite, handflatorna uppåt, och släpper ner  
 händerna igen  
 N = Skriver  $n_2$  under horisontella linjen, lägger ifrån sig kritan och backar  
 från tavlan

N Jaa det följer elektromagnetisk fältteori  
 V Backar från tavlan och lutar  
 sig mot bänken  
 N Tittar på M, tittar på tavlan

V [Skratt]  
 M Ja =precis  
 V =Man kan härleda det på olika sätt  
 M, V, N Rör sig, verkar glada

M Ja ja  
 R Det låter bra är ni nöjda med den här  
 förklaringen  
 V Jae ganska  
 M Läger ifrån sig kritan

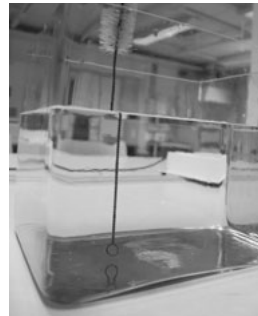
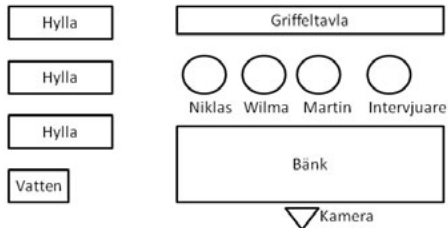
M Jag är också ganska nöjd  
 38:11:00

R Jag har en sista fråga om ni kan tänka er att svara på den om det var några  
 skillnader mellan era förklaringar beskriv gärna vilka och varför  
 M Va [ohörbart]

V Skillnaden är ju att i det andra fallet utgår vi ifrån att det vi försöker  
 förmedla i det första fallet redan finns där =alltså tänka på att det  
 är ljus och tanken på att ljuset kan brytas  
 behöver vi ju inte =prata om  
 M =Nä =nä och jag tänker också att en skillnad är så här vad vi använder  
 för redskap liksom det är som att om man är fysikstudent då då typ så  
 här då är man mer van vid att okej det här betyder att det är vinkelrätt liksom  
 då kan jag säga det och då förstår du det liksom eh och man är mer  
 van vid så här abstrakt...

## A CA style piece of transcript

Clip 1. Starting at 11.06.



1. Nick Den är alldeles rak härifrån= ((böjer sig  
It's completely straight from here= ((bends doVn))
2. ned))
3. Mike =A: (.) nu ser den <sned ut> (.) liksom  
=Yeah: (.) it looks <skewed> now (.) kind of
3. Nick Här ser den sned ut=  
Here it looks skewed=
4. Mike =Här ser den verkligen sned ut (2.0)  
=Here it really looks skewed (2.0)
5. Nick ((står upp igen)) (Vik...) (.) aa (10) ((M och N  
((stands up again)) (Wha...) (.) yeah (10) ((M and N  
6. böjer sig ned))  
bend down))
7. Nick Det är roligt(.) när man (0.2) det här är kul (.)  
It is fun (.) When you (0.2) this is fun (.)
8. (asså) (.) om man tittar så här <från sidan>=  
(that is)(.) if you look like this <from the side>=
9. Mike =aa= ((står upp igen))  
=yeah= ((stands up again))
10. Nick =sen så går man dit(.) ((flyttar sig i sidled))  
=then you go there (.) ((moves sideways))
11. Mike aa  
yeah
12. Nick då är den avskuren så här ((visar med händerna))  
then it is cut off like this ((shows with his  
hands))
13. (^t)  
(^t)
14. Nick Att det är (0.7) eh: (2.0)  
That it is (0.7) eh: (2.0)
15. Mike ((Böjer sig ned)) Vill du ha skruven åt <andra  
((Bends down)) do you want the screw the <other  
16. hållet> eller vad [då]  
way> or [what]
17. Nick [Nej] att den(.) att den är  
[No] that it (.) that it is
18. diskontinuerlig(.)  
discontinuous (.)

19. Mike Mm(.)  
Mm(.)

20. Vera ((kommer in i bilden från sidan)) Funkar det  
((comes into the frame from the side)) Does it work

Ending at 11.42.

---

Clip 2. Starting at 13.27.

21. Vera Kan du inte >ta den snett< ((Sitter på huk))  
Can't you >hold it slantingly< ((squats))

22. om man(.) >det är häftigt om man kollar på det<  
if you(.) >it's cool if you look at it<

23. från sidan(.) för då är det som att den är (0.5)  
from the side(.) because then it's like it is (0.5)

24. okontinuerlig=  
discontinuous=

25. Nick =m(0.2)  
=m(0.2)

26. Vera pinnen=  
the stick=

27. Mike ((Böjer sig ned och tittar))  
((Bends down and looks))

28. Nick =m(5.0)  
=m(5.0)

29. Mike >Hur då,< (1.8)  
How, (1.8)

30. Vera Det ser ut som att(.) det är ett hack (0.2) att det  
It looks like (.) there's a jump (0.2) that it

31. går så här: och så ^hack ((visar med  
goes like this: and then ^jump ((shows with his

32. handen)) så fortsätter den inte längre=  
hand)) it doesn't continue=

33. Mike =Aha(.) så menar du (1.0) aha(.) men det(.) <man  
=Aha(.) so you mean (1.0) aha(.) but it (.) <you

34. ser reflektionen i>(.)  
see the reflection in>(.)

35. Nick Nej men om du: (0.8)  
No but if you: (0.8)

36. Vera >Nej jag menar liksom att< den är okontinuerlig,  
>No I mean kind of that< it's discontinuous,

37. Nick Om du tittar så att du inte s- om du tittar  
If you look so that you don't s- if you look

38. precis på- vid vattenytan så att du inte ser  
exactly on- at the water surface so you don't see

39. reflektionen (1.0)  
the reflection (1.0)

40. Mike A: lite grann (0.3) [a]  
Yeah: a little (0.3) [yeah]

41. Nick [Om], (.) men om,(.) om du  
[If], (.) but if,(.) if you

42. tittar ändå mer (från) [sidan]-  
look even more (from) [the side]-

43. Vera [men,] ((byter ämne))



[but,] ((changes the subject))

Ending at 14,03

For a key to the notation, see Schegloff (n.d.):

Schegloff, E. A. (n.d.). Emanuel A. Schegloff's homepage Retrieved September 28, 2012,  
from <http://www.sscnet.ucla.edu/soc/faculty/schegloff/>



## Appendix B

### **Avtal avseende användningsbegränsning av forskningsmaterial**

Detta avtal är ett medgivande till materialanvändning från den som deltagit vid en bild och/eller ljudupptagning med avsikt att ge råmaterial till forskning, primärt vid Institutionen för fysik och materialvetenskap, *Avdelningen för fysikens didaktik vid Uppsala Universitet*.

#### **Allmänt användande av materialet**

Allmänt användande av materialet avser t.ex. analys av deltagarnas interaktion med såväl varandra som med maskin- och mjukvara. Det innebär att materialet ej sprids utanför de inblandade forskargrupperna.

☐ Jag medger

☐ Jag medger ej

att upptaget bild- och ljudmaterial där jag medverkar får användas i forskningssyfte och datorbehandlas, förutsatt att det hanteras i enighet med vedertagen svensk forskningsetik.

#### **Utdrag ur materialet för användning vid presentationer**

Det huvudsakliga syftet med att använda utdrag ur materialet är att kunna visa på specifika situationer där beteenden exponeras som bedöms vara relevanta i relation till forskningen.

☐ Jag medger

☐ Jag medger ej

att utdrag ur upptaget bild- och ljudmaterial där jag medverkar får användas vid presentationer anknyttande till forskning, förutsatt att mitt namn döljs.

#### **Utdrag ur materialet för användning vid elektronisk publicering**

Elektronisk publicering är en möjlighet att sprida kunskap om forskning vid Uppsala Universitet, primärt till andra forskare men även till allmänheten. Bilder och videoutdrag underlättar förståelsen för sampresenterat skriftligt material och är ett ypperligt sätt att visa intressanta exempel.

☐ Jag medger att utdrag ur upptaget *bild- och ljudmaterial* där jag medverkar får användas vid elektronisk publicering anknyttande till forskning, förutsatt att mitt namn döljs.

☐ Jag medger att *endast stillbildsutdrag* ur upptaget bildmaterial där jag medverkar får användas vid elektronisk publicering anknyttande till forskning, förutsatt att mitt namn döljs.

☐ *Inget* bild- och ljudmaterial där jag medverkar skall användas vid elektronisk publicering.

## Utdrag ur materialet för användning vid tryckning

Forskningsmaterial publiceras oftast i tryckt form och fotografier eller utvalda stillbilder ur videosekvenser kan förtydliga budskapet. Publicering sker mestadels i vetenskapliga tidskrifter och i samband med forskningsrelaterade konferenser.

☐ Jag medger

☐ Jag medger ej

att utdrag ur upptaget bildmaterial där jag medverkar får användas vid publicering i tryckt form, förutsatt att mitt namn döljs.

## Ångerrätt

Jag förbehåller mig rätten att vid senare datum ändra mina nuvarande medgivanden, varvid jag insänder en uppdaterad version av detta avtal till nedanstående kontaktperson. Det uppdaterade avtalet träder i kraft när det mottages av kontaktpersonen och gäller ej retroaktivt avseende publicering utför i enighet med tidigare avtal.

## Kontaktperson:

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751 21 UPPSALA

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## Underskrift:

Namn (textat)	Personnummer
Ort och datum	
Underskrift	

## Appendix C Ancillary papers

### Choosing the Proper Representation(s) in Physics

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**Abstract.** The representations used and produced by three undergraduate physics students discussing the physical concept of refraction were analyzed in terms of what roles the different representations were playing. Important contributions to the discussion were being made by speech, diagrams, mathematics and gestures. Although some redundancies between the representations were observed, they were to a great extent intertwined and reciprocally informing each other. The importance of practicing scientific communication is highlighted.

**Keywords:** Representations, physics, refraction, disciplinary discourse, discussion.

#### Introduction

Insight into the roles of representations in a disciplinary discourse (Airey & Linder, 2009) such as physics is an essential pedagogic appreciation. Our aim is to explore the roles that different representations play in the “agency of maker and remaker of messages” (Kress, 2010) in a physics discussion between undergraduate students. For this we draw on a social-semiotic perspective.

In the theoretical framework of social semiotics different representations have different affordances (Kress, Jewitt, Ogborn, & Tsatsarelis, 2001), meaning that different representations contribute in different proportions to a holistic, coherent picture of the topic at hand.

When communicating, the representation(s) that best ‘fits’ the intended message gets made (Kress *et al.*, 2001; Kress, 2010). In analyzing communication, paying attention not only to the spoken or written words, but also to other modes of representation, may reveal the roles of the representation(s). We are viewing the discussion in terms of the representations used and produced by the students.

#### Method

In the pilot case study to be presented here, a group of three advanced undergraduate physics students were being asked to produce two explanations regarding the physical phenomenon of refraction, which is the bending of light when entering another medium (see *Figure 1*). One of the explanations was intended for a peer student who had forgotten about the phenomenon, and both were later being enacted by the researcher. A part of the discussion analysis is given in detail in *Figure 2*.

The students were being informed that they could use any equipment available in their explanation, which took place in a student physics laboratory. The students’ discussion was video recorded and transcribed multimodally (Kress *et al.*, 2001; Norris, 2004), meaning not only verbally but also in terms of other modes of representation, such as images and gestures etc.

The analysis was being done in terms of what representations the students used/produced in their discussion, in order to answer the question: What are the roles that the different representations play in this discussion? The relationships between the representations were analyzed through the construction of an analytical tool: a “thematic pattern” (Lemke, 1993).

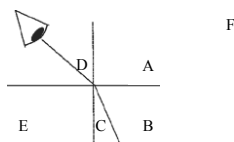
#### *Thematic patterns.*

A thematic pattern (cf. Lemke, 1993) is a diagram showing thematic items (e.g., concepts) and what the meaning relations between them are. In this analysis a thematic pattern was being constructed out of the multimodal transcript, and thus extended to include entries not only from speech but also from other representational modes (e.g. visual and gestural). In an attempt to illustrate how this extended

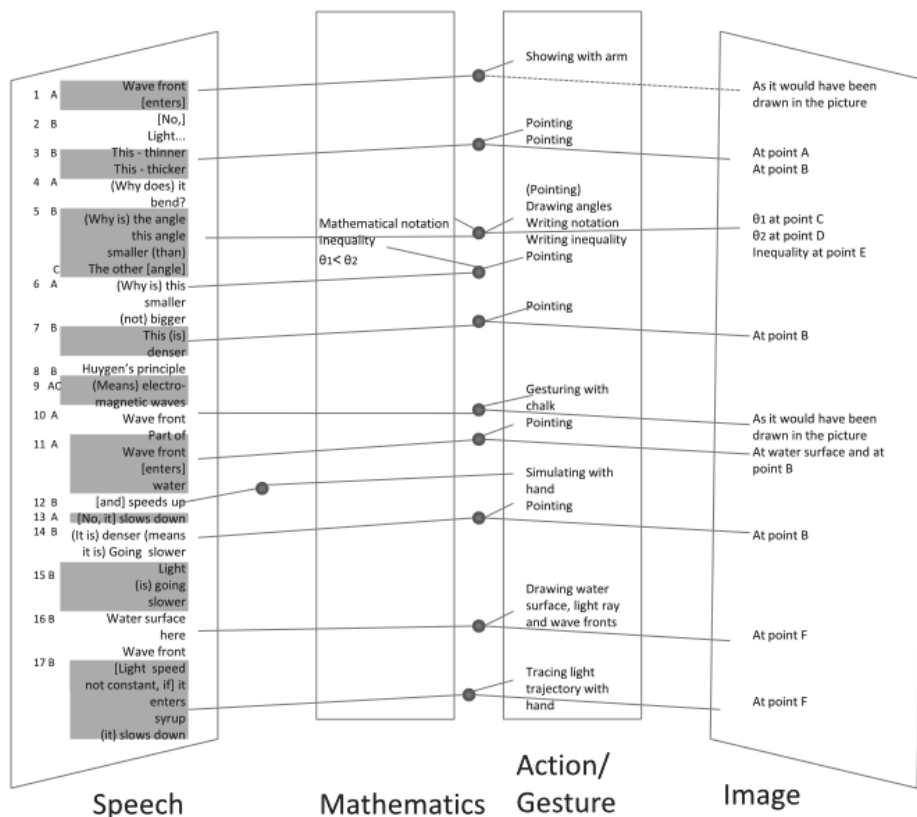
thematic pattern evolved dynamically we draw on the work by (Bloom, 2001) in showing the evolving discussion on a vertical timeline.

## Results

At the time when the presented analysis of the students' discussion begins they had just finished drawing a ray diagram (see *Figure 1*) on the blackboard. Then the discussion referred to in *Figure 2* took place.



*Figure 1.* Diagram already drawn on the blackboard, showing a ray of light coming from below water, entering air and reaching the eye. Capital letters are positions referred to in *Figure 2*.



*Figure 2.* The dynamic development of the discussion. Points A-F are positions in *Figure 1*.

## Discussion

*Wave Fronts.* The use of wave fronts<sup>1</sup> are suggested by student A. Despite being a canonical representation (i.e. used in most, or all, text books) the other students seem reluctant to use it until it has been properly motivated, and its explanatory power has been revealed. Important features of “wave fronts” may be appresented (Marton & Booth, 1997) (i.e. being experienced as a whole, despite many parts being invisible) to the person making the utterance, but may not be so for the listener.

*Speech, Mathematics, Action/Gesture and Image.* Eventually the spoken words ‘electromagnetic waves’ provide the key to the wave front as a viable means to explain refraction. Words often describe cause – consequence relationships; properties of things; and unfolding of events.

As a contrast to the motivation needed for the wave front diagram, the use of mathematics, such as  $\theta$  (which is used by convention rather than being motivated) to stand for an angle, is not contested. The mathematics appears to be mostly redundant in the discussion, and its power may be obvious only later. However its statements are persistent through time, in contrast to gesture and speech.

Gesture is mostly used to point in the image, to make meaning in cooperation with, and to position spatially, what is being said in words. Occasionally it is used to simulate movement, and sometimes also to illustrate things before they are sufficiently agreed upon as to be drawn on the blackboard.

The image is a persistent sign, displayed and/or interacted with on the black board, as is the mathematics. It is a hub around, and with, which the other representations work. Images deal especially well with spatial and directional relationships.

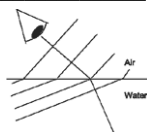
*Conclusion.* The different representations are specialized, and the maker of a representation chooses the most apt one for doing the intended communicative work. That is why, in physics, any of all available representations may be used to complete a message, and in constant co-operation with other representations, rather than alone. “Knowledge is made and given shape in *representation* [...]; the process of representation is identical to the shaping of knowledge. Makers of representations are shapers of knowledge. [...] That is, knowledge is always *produced*, rather than *acquired*.” (Kress, 2010, p. 27) How to make different representations and how to relate them to each other are thus important goals in physics teaching and learning. Increasing the opportunities of practicing, rather than consuming, this co-operation of representations is of outmost importance in physics education.

## References

- 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
- Bloom, J. W. (2001). Discourse, Cognition, and Chaotic Systems: An Examination of Students' Argument about Density *The Journal of the Learning Sciences*, 10(4), 447-492.
- Kress, G. (2010). *Multimodality : A social semiotic approach to contemporary communication*. London: Routledge.
- Kress, G., Jewitt, C., Ogborn, J., & Tsatsarelis, C. (2001). *Multimodal teaching and learning*. London: Continuum.
- Lemke, J. L. (1993). *Talking Science*. Norwood, New Jersey: Ablex Publishing Corporation.
- Marton, F., & Booth, S. (1997). *Learning and Awareness*. Mahwah, New Jersey: Lawrence Erlbaum Associates.

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<sup>1</sup> An example of a wave front diagram:







# Critical aspects of scientific phenomena – to the fore, in the background, or not present in scientific representations

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**Abstract.** In order to talk about how meaning can be construed from scientific representations we draw on the phenomenological term *appresentation*. *Appresentation* refers to those parts of an object that are not readily presented, but experienced as co-present with the presented object. We review a number of scientific representations that students have had reported difficulty with using in certain prescribed situations. Our analysis indicates that representations that are conventionally used in many scientific situations often do not lead students to appresenting the critical aspects of scientific phenomena. Critical aspects of scientific phenomena can range from being present and foregrounded (salient), through present but in the background, to not present at all in the representation at hand. Our discussion suggests that pedagogical implications of these conclusions include the need for teachers to be aware of that their taken-for-granted interpretation of common representations may not be the same as students' interpretations, especially in unfamiliar or less common situations.

**Keywords:** Representations; appresentation; awareness; science; physics; critical aspects.

## Introduction

Scientific communication is often not as transparent as many instructors may expect. For example, Sheila Tobias (1986) invited non-science professors to attend carefully prepared university level physics lectures given by teachers recently awarded prizes for their teaching. One of the attending professors who was interviewed, afterwards said: 'It seemed to me during these lectures that I lacked any framework of prior knowledge, experience or intuition that could have helped me order the information I was receiving. I had no way of telling what was important and what was not.'

Science students experience similar challenges in their classes. For example, Airey and Linder (2009, p. 37) quote a student who, having been exposed to a presumably well known representation depicting a transformer together with written text on the whiteboard, in a stimulated recall interview commented, '.... I don't know what this is. I didn't know what he [the teacher] was writing...' And: '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.'

In both examples above, the interviewees appeared to expect that what the instructor said and did would make them aware of something they would recognize from before and be able to refer to. In the former example some kind of knowledge structure, and in the latter some details of the laboratory equipment represented in a drawing. Marton & Booth (1997, p. 99) point out a 'highly critical aspect of awareness', which can be useful in order to talk about the experiences of the students in the examples above, namely '*appresentation*' (cf. Husserl, 1931, 1973; and Schutz, 1962).

*Appresentation.* *Appresentation* is that, which lies behind the visually experienced and is simultaneously 'co-present' in the experiencing of a presented object. For example, 'the strictly seen front of a physical thing always and necessarily appresents a rear aspect and prescribes for it a more or less determinate content' (Husserl, 1931, 1973, p. 109); The '*appresented* is co-being along with what exists' (Husserl, 1989, p. 352). Schutz (1962) calls this relationship '*appresentational pairing*', where

an appresenting member (e.g. the ‘front’) of a pair represents an appresented member (e.g. the ‘rear aspect’)<sup>1</sup>.

Following Airey and Linder (2009), we draw on this idea of appresentation to explore that which is often taken for granted in the intended meaning of representations when being used in educational situations. We present an analysis of examples of representations that are often used in physics. Some of the analysed representations, and the situations they represent, have previously been shown by research to be problematic for many students.

*Research questions.* Our research interest as presented above led us to formulate the following research question to guide our analysis:

- Does a particular representation present all the critical aspects that a learner needs to be aware of in order to explain the represented physical phenomenon, make predictions of the represented physical situations, or solve related physics problems?

## **Method**

The analysed representations were chosen on the basis of students appearing to have problems with working effectively with them. Some of these representations have previously been analysed by others (see references in the analysis section). In these cases we have interpreted the existing analyses through our theoretical lens in order to describe how the notion of appresentation can provide a useful and fruitful way to discuss the learning challenges that they present to the students. In one case, the analysis was made from our own video data. The analysis was accomplished by applying our knowledge as physics teachers in conjunction with using a multimodal discourse (Kress & van Leeuwen, 2001) lens to look for features of the presented representations that may potentially be paired with critical aspects of the phenomena – or for the problems – at hand. A similar analysis, using Lemke’s (1990) thematic patterns, was recently made, where such potential of representations was called ‘disciplinary affordances’ (Fredlund, Airey, & Linder, 2012, p. 658), these were defined as ‘the inherent potential of that representation to provide access to disciplinary knowledge’.

## **Analysis**

Examples of situations where representations were analysed include:

- 1) Getting a bulb to shine using a battery, a bulb and only one wire (McDermott & Shaffer, 1992; Redish, 2003; Shaffer & McDermott, 1992). Here the interior construction of a bulb has to be appresented; appresenting the bulb as a unit without its parts is not sufficient for constituting an appropriate understanding.
- 2) Seeing the refraction of light in terms of a changing the speed of light across two different optical media. The speed of light can potentially be perceived as proportional to the distance between wave fronts in a wave front diagram, yet there is nothing directly representing speed in a ray diagram (Fredlund, et al., 2012).
- 3) Appreciating that the normal force is not always as big as, and in opposite direction to, the force of gravity requires appresenting the earth, and the forces acting on the earth.
- 4) Being able to build advanced electric circuits in the laboratory means having to appresent those parts that by convention are not represented in circuit diagrams, but often taken for granted (Stetzer, 2011).

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<sup>1</sup>In many ways, Kress’s (2010, p. 70) analysis of the basis of representation is similar: a ‘relation of analogy’ (this *is like* that) which in turn leads to ‘a metaphor’ (this *is* that) exists between the signifier and the signified.

## Discussion

At a number of places in our analysis there are opportunities for appresentational pairing between features of a representation and the critical aspects of the physical phenomena at hand. Following Fredlund, Airey and Linder (2012) we suggest that these opportunities constitute the disciplinary affordances of the representation. At other places in our analysis, such a pairing between representational features and critical aspects of the phenomenon was either absent, or hardly noticeable. The critical aspects needed must then be inferred and appresented from the represented situation, thus potentially represented separately, juxtaposed with, or inserted into already existing representations, or represented in another format or semiotic system, which may in turn provide the needed 'disciplinary affordances.' Conversely, the appresented aspects need also be taken to be critical.

## Conclusions

Our results suggest that a directly visual or passive interpretation of representations is often not sufficient for making appropriate inferences in the different cases mentioned in our research question. Rather, students often require access to information either not presented or not foregrounded in the representations. This is information that students need to appresent on the basis of previous experience of situations that are similar to the situation at hand. Pedagogical implications of these conclusions include the need for instructors to be aware of the risk that their taken-for-granted interpretation of common representations may not be the same as their students' interpretations of the same representation—especially in unfamiliar or less common situations. Furthermore, the kind of analysis presented herein may provide instructors with a tool to identify those critical aspects of the studied phenomena that students may lack access to. Such identification may potentially change the ways in which certain representations are used in instruction, and how this use is motivated.

## References

- 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, 27-49.
- Fredlund, T., Airey, J., & Linder, C. (2012). Exploring the role of physics representations: an illustrative example from students sharing knowledge about refraction. *Eur. J. Phys.*, 33, 657-666.
- Husserl, E. (1931, 1973). *Cartesian Meditations : an Introduction to Phenomenology* (D. Cairns, Trans.). The Hague: Dordrecht : Kluwer.
- Husserl, E. (1989). *Collected works. Vol. 3, Ideas pertaining to a pure phenomenology and to a phenomenological philosophy, second book : studies in the phenomenology of constitution* (R. Rojcewicz & A. Schuwer, Trans.). The Hague: Nijhoff.
- Kress, G. (2010). *Multimodality : A Social Semiotic Approach to Contemporary Communication*. London: Routledge.
- Kress, G., & van Leeuwen, T. (2001). *Multimodal Discourse : The Modes and Media of Contemporary Communication*. London: Arnold.
- Lemke, J. L. (1990). *Talking Science*. Norwood, New Jersey: Ablex Publishing.
- Marton, F., & Booth, S. (1997). *Learning and Awareness*. Mahwah, New Jersey: Lawrence Erlbaum Associates.
- McDermott, L. C., & Shaffer, P. S. (1992). Research as a guide for curriculum development: An example from introductory electricity. Part I: Investigation of student understanding. *Am. J. Phys.*, 60(11), 994-1003.
- Redish, E. F. (2003). *Teaching Physics : with the Physics Suite*. Hoboken: John Wiley & Sons.
- Schutz, A. (1962). *Collected Papers I : The Problem of Social Reality*. The Hague: Martinus Nijhoff.
- Shaffer, P. S., & McDermott, L. C. (1992). Research as a guide for curriculum development: An example from introductory electricity. Part II: Design of instructional strategies. *Am. J. Phys.*, 60(11), 1003-1013.
- Stetzer, M. R. (2011). *Upper-division analog electronics: When is a lab course really a lab course?* Paper presented at the Foundations and Frontiers of Physics Education Research 2011, Bar Harbor, Maine.
- Tobias, S. (1986). Peer Perspectives: On the Teaching of Science. *Change*, 18(2), 36-41.

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