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Exploring Physics Education Using a Social Semiotic Perspective

The Critical Role of Semiotic Resources

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To my family

1 List of Papers and supporting work

1.1 Papers

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

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

II 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.

III 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.

IV Fredlund, T., Airey, J., Linder, C. (Forthcoming) Att välja lämpliga resurser. En undersökning av studenters scientific literacy. In Östman, L. & Säljö, R. (Eds.) *Scientific literacy – teori och praktik.* Stockholm: Gleerups.

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1.2 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) *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., 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. 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.

2 Contents

Abbreviations

PER	Physics Education Research
SFL	Systemic Functional Linguistics
CA	Conversation Analysis
SF-MDA	Systemic Functional Multimodal Discourse Analysis
MER	Multiple External Representations

1 Introduction

1.1 Introduction

In Physics Education Research, PER, three of the most influential contributions towards enhancing student learning have been Peer Instruction developed at Harvard University (Mazur, 1997), the Tutorials developed at Washington University (McDermott & Shaffer, 2002) and the Active Learning material developed at Rutgers University (Van Heuvelen & Etkina, 2006). All of these approaches are grounded in the notion of interactive engagement (cf. Dewey, 1997, first published in 1916; Hake, 1998) and provide research-informed opportunities for students to develop and practice their skills in the interpretation and use of different representations, for example, spoken and written language, sketches, diagrams and mathematical formalism such as equations and graphs. (In this thesis I characterise such representations in terms of 'semiotic resources', see Section 2.3.2.) The application of these three approaches is integrated in the learning and working practices of physics. However, deep analysis of the semiotic resources that are used in physics teaching and learning contexts has been rare. Even more rare has been work that examines the relationship between these semiotic resources and disciplinary knowledge, for example through achieving "fluency" in the "disciplinary discourse"[1] (Airey & Linder, 2009) associated with particular parts of the curriculum (cf. "objects of learning", Marton & Tsui, 2004).

The aim of my PhD work is to *explore the roles that semiotic resources play in the representing and sharing of disciplinary knowledge in physics*. To do this I began by exploring undergraduate students' interpretation and use of semiotic resources when formulating an interactive explanation for the refraction of light and it is this part of the research journey that this Licentiate thesis reports on. The theoretical framework that I have used is a social-semiotic based meaning-making perspective. By meaning-making I mean those practices and praxes that include the production and interpretation of physics 'text'. This is in line with a contemporary use of the term 'text' – meaning any material result of a meaning-making process (cf. New London Group, 1996; Norris & Phillips, 2003). In this way, for my thesis, physics text is not limited to written language, but is made up of all

[1] I discuss "disciplinary discourse" more fully in Section 2.2.3.

the semiotic resources (representations) that get used to share knowledge, ways of knowing and working practices in physics. Also, in line with other relevant literature I will characterise text that contains several kinds of semiotic resources as 'multimodal text'. In summary, the analysis of multimodal text and its constituent semiotic resources in physics learning settings is a fundamental part of my thesis work.

My theoretical framework is built upon a contemporary form of social semiotics (see, for example, Halliday, 1978; Hodge & Kress, 1988; Kress, 2010; Lemke, 1990; O'Toole, 1994). This is a rather new theoretical framework for research in the area of physics education, which offers several advantages. Based upon anthropology (see, for example, Halliday & Martin, 1993, who refer extensively to the work of the British anthropologist Malinowski; for example, Malinowski, 1935) and linguistic research, social semiotics has the potential to produce detailed accounts of the different functions that text fills in both the social and the content aspects of the teaching and learning of physics, as well as how these functions are achieved by the production and use of semiotic resources. This framework also enables a focusing on the *individual* as a *meaning-making agent*, while simultaneously focusing on the social and physical context and how this context is produced and construed by different individual(s).

In my thesis I also draw on two perspectives on learning that work well with the social-semiotic based meaning-making perspective that I am using. The first characterises learning in terms of becoming "fluent in a critical constellation of the different semiotic resources" (Airey & Linder, 2009, p. 28), and the second sees learning as "a change in someone's capability for experiencing something in certain ways" (Marton & Booth, 1997, p. 208). These two characterisations of learning underpin the work that I have done for the thesis.

1.2 My research journey and how this plays out for the thesis

Through a dynamic and iterative process between literature studies, my engagement with the data that I collected for this thesis, and a number of *generative* research questions, I have formulated and refined my PhD research question, which in this thesis, I call my overarching research question. I use the term *generative* to characterize the role that these research questions played in the convergent formulation of my overarching question, which has become:

In what way can social semiotic theory be instrumental in the characterisation of disciplinary knowledge as it is realised in interactive engagement in an undergraduate physics setting?

What I report on in this Licentiate thesis is part of the answer to this question; the more complete answer will be addressed in my final PhD thesis.

The generative research questions are reported on in the papers that are attached to my thesis, labelled and referred to as Papers I-IV. Hence, only a summary of the answers to these is provided in the main body of this thesis. This is done in Chapter 5. The rest of the thesis deals mainly with how far I have progressed with the answering of my overarching research question at the time of writing this Licentiate thesis. In this way my research journey so far has unfolded around my answering the generative research questions. I bring all of the data analysis experience together in my Analysis Chapter (Chapter 4) as a partially constituted answer to my overarching research question that reflects the essence of the theoretical and analytical contributions that my work so far has produced. Although, as such, my Analysis Chapter represents the core outcome that I am reporting on in my thesis, the generative research questions iteratively underpin its constitution. So my Discussion Chapter (6) will not only bring to the fore important observations relating to the Analysis Chapter, but it will also deal with the generative research questions and as such brings these together into a discussion about implications for the teaching and learning of physics.

2 Theoretical framework

2.1 Introduction

In this chapter I review the literature that is relevant for this thesis and describe the theoretical framework. Here I discuss what Maxwell (2005) calls a "conceptual framework": "the system of concepts, assumptions, expectations, beliefs, and theories that supports and informs" a given piece of research (p. 33; see also Miles & Huberman, 1994; and Robson, 2002). In other words, the literature review in this chapter provides a background for the discussion of the central tenets of the papers that make up the thesis and the theoretical framework provides the methodological setting for these papers.

In order to situate the thesis in Physics Education Research, PER, I begin by reviewing research in PER that relates to 'interactive engagement', representations in the teaching and learning of university physics, and refraction (the particular physical phenomenon that I investigate in this thesis). After that follows an outline of my theoretical framework under the heading of *social semiotics*, and an introduction of the notion of scientific literacy. Finally, the theoretical framework is summarised.

2.2 Physics Education Research

2.2.1 Introduction

The domain of Physics Education Research, PER, is primarily situated in 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[2]. Internationally, most PER has been carried out at physics departments. The most established research groups are in the USA, where approximately 100 PER "programs" are active at the time of writing this thesis (Physics Education Research Central, n.d.). In 2000,

[2] See http://prst-per.aps.org.

Uppsala University became the first university in Scandinavia to have a formalised PER group situated in a department of physics.

A contemporary trend in PER has been one of increasingly using a number of different theoretical frameworks to explore issues in the teaching and learning of university physics. Most of the seminal frameworks used have derived from different forms of constructivism (cf. Redish, 2003) and from the notions of P-prims – phenomenological primitives (cf. diSessa, 1983) and framing (cf. Hammer, Elby, Scherr, & Redish, 2005). These frameworks 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 education research (for an early seminal example, see Wood, Bruner, & Ross, 1976), and has recently played an important part in PER (for example, Lindström, 2010; Lindström & Sharma, 2009, 2011; Podolefsky, 2008). Another example is how constructs such as "artefacts" and "zone of proximal development" from different socio-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). In this thesis, I draw on a well-established theoretical framework that is relatively new to the PER community: *social semiotics* (cf. Kress, 2010; Lemke, 1990).

Over the past 15 years a number of overviews of work done in PER have been carried out, the most comprehensive of these being McDermott and Redish (1999), Knight (2002), Redish (2003), Thacker (2003), Hsu, Brewe, Foster, and Harper (2004), Thompson and Ambrose (2005), and Beichner (2009). What follows is a review of the PER work that is related to my own research.

2.2.2 Interactive engagement – actively engaging students in learning

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). Interactive engagement refers to the active engagement in interaction between students, or between students and teachers. The educational importance of interactive engagement is not a new idea, and was in fact pointed out, for example, by Dewey (1997, p. 31; 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." 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 (Prather, Rudolph, Brissenden, & Schlingman, 2009). Instead, Prather et al. suggest that "it is the proper implementation of interactive learning strategies that is key to achieving higher gains in student learning" (p. 329). The role that representations play in interactive engagement has received relatively little attention in PER. This makes the use of representations in interactive engagement a highly relevant area of research.

2.2.3 Representations in the teaching and learning of physics[3]

In PER, work with student understanding of representations[4] has been an integral part of the general aim of enhancing learning outcomes (for example, see McDermott & Shaffer, 1992). However, relatively little work has been done with a direct focus on representations in the sense of them being communicative semiotic resources for sharing knowledge in physics teaching and learning environments. The more focused early PER investigations dealing with university physics students' use of (multiple) representations began to emerge following the early work of Van Heuvelen (1991a, 1991b). This work has led to the development of new physics curricula, that emphasise students' active participation and use of qualitative representations (for example, see Van Heuvelen & Etkina, 2006). And Van Heuvelen's research colleagues have continued the work in this area (for example, see Rosengrant, Etkina, & Van Heuvelen, 2007; Rosengrant, Van Heuvelen, & Etkina, 2009). An interesting development from their work focuses on the role of language[5] in physics education (Brookes, 2006; Brookes & Etkina, 2007), which includes students' difficulties in

[3] 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), and mathematics (Duval, 2008).
[4] In this PER section I am using the term representations instead of semiotic resources, following its use so far in PER literature.
[5] This includes a systemic functional linguistic (SFL) perspective, which will be explained further in Section 2.3.3.

appropriately interpreting the analogies and metaphors that are used in physics.

The relationship between (multiple) 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 on 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 they reported that novice problem solvers spend more time exploring representations than expert problem solvers do, 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 by, for example, Scherr (2008). Scherr concluded that gestures could help researchers to, for example, 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).

Using examples from physics, a "disciplinary discourse" perspective for viewing the learning of science has been proposed by Airey and Linder (2009; disciplinary discourse is described as "the complex of representations, tools and activities of a discipline", p. 29). They metaphorically suggest that students need to become "fluent" in a "critical constellation" (p. 41) of semiotic resources. They exemplify such semiotic resources as "spoken and written language, mathematics, gesture, images (including pictures, graphs and diagrams), tools (such as experimental apparatus and measurement equipment), and activities (such as ways of working – both practice and praxis, analytical routines, actions, etc.)" (p. 27).

2.2.4 PER work on refraction

The physical phenomenon that is dealt with in this thesis is 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 Appendix C). A visual effect of this 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. The straight handle partially immersed in water appears to bend at the water-air boundary as a result of the refraction of light (Fredlund & Linder, 2010).

Investigations into which semiotic resources 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 semiotic resources 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 were used in less than half of the reviewed textbooks. Common analogies that were 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 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).

It has also been shown that introductory university physics students may have difficulties with representing light appropriately and usefully as waves (Sengören, 2010). For a further explanation of refraction, see Appendix C.

In the next section I present an overview of the social semiotic work that relates to my analysis of multimodal text and its constituent semiotic resources in physics learning settings.

2.3 Social semiotics

2.3.1 Introduction

Social semiotics is a perspective on meaning-making that takes semiotic resources to be the materialisation or realisation (Kress, 2010, p. 57), actualisation (O'Toole, 1994) or instantiation[6] (Halliday & Matthiessen, 2004) of meanings. 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. Traditionally they were called 'signs'" (Van Leeuwen, 2005, p. 3)[7]. From a social semiotic perspective, all communication is realised through "the making of signs" (cf. Kress, 2010, p. 62). Thus 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.

The essence of social semiotics is that meanings do not occur in isolation, but they are always produced in relation to a particular context. For example, a raised right thumb can be the realisation of a wish to hitch a ride if made in an everyday context by a person standing on the side of a highway. Moving to a physics context, the change in meaning is dramatic. Here it is more likely to mean the orientation of a magnetic field around a conductor, or the direction of an angular velocity vector.

Broadly speaking, the accounts of social semiotics in the literature differ widely in terms of the details that are focused on and/or omitted. Many of these aspects are, however, neither directly related nor relevant to the situating or discussion of my research work. Hence, I will now proceed to present only the most pertinent aspects of social semiotics that are needed to provide a sufficiently comprehensive introduction to the framing of this thesis research.

2.3.2 Semiotic resources

'Classical' or 'formal' semiotics is closely linked to the work done by Saussure and Peirce[8] in the 1800s and early 1900s. This work principally focused on signs in language – "the systematic study of the systems of signs

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[6] Note that Kress and van Leeuwen (2006) also talk about semiotic resources at more abstract levels, which I will not be doing in this thesis.
[7] For this reason I will at times use the term "sign" to mean semiotic resource.
[8] Social semiotics work most often references the work of Saussure, in comparison Peirce is only occasionally referred to (see, for example, Lemke, 2003; Martin & Rose, 2007).

themselves" (Lemke, 1990, p. 183). Social semiotics takes as its object of study not only this formal semiotics, but also meaning-making in its widest sense, particularly in social contexts. Social semiotics is concerned with the "act of meaning making" (cf. Thibault, 2004, p. 68). Semiotic resources are the material result of the productive, or generative, aspect of the meaning-making process (or semiosis) (Van Leeuwen, 2005, p. 3). It should be noted here that 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 resources; Kress (2010, p. 28) exemplifies modes with "*speech; still image; moving image; writing; gesture; music; 3D models; action;* [and] *colour.*"

Another example of the terminological ambiguity 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, Tan, & Yeo, 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 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" (see Section 2.4.8 below), which rather follows the former sense of "modality", that is, as a multiplicity of different kinds of semiotic resources (see Figure 2.2).

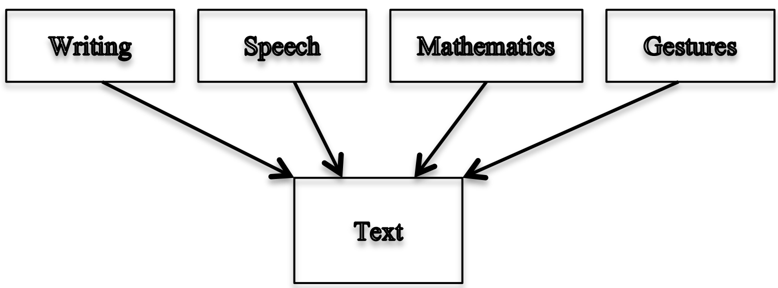

Figure 2.2. The relationship between semiotic resources (the top row) and (multimodal) text.

This discussion brings me to the point where I can sum up the terminology I will be using in this thesis. I will use "semiotic resources" synonymously with "signs." These semiotic resources make up (multimodal) texts, through the productive and interpretive aspects of the meaning-making process. In other words, written and spoken language, mathematical formalism, gestures, pictures, diagrams and so on, all constitute text.

The set of meanings that a semiotic resource can convey[9] is called its meaning potential. For example, gestures, which can produce signs such as a raised thumb in the example mentioned in Section 2.3.1, have different and distinct meaning potentials. Different aspects of these meaning potentials can be (and often should be) differently realised in different contexts. To illustrate this I reuse my earlier physics example: the sign made up of a right hand with curled fingers and an extended thumb can be used to make meaning of, amongst other things, the direction of a magnetic field around a conducting wire (or a quantity that is a vector product of other quantities). In everyday contexts the meaning potential of the raised thumb can range from indicating that a ride is wanted to indicating that all is 'going well'. In the production of a semiotic resource (such as raising the thumb and curling the fingers) or a coherent collection of semiotic resources – a (communicative) text – (in a particular context) the intent is to 'realise' some essential part of the meaning potential of that semiotic resource. It is important to note that the meaning potential of semiotic resources can change with time. Kress (2010) points out that it is in the production of semiotic resources, that there is a possibility of a change in the meaning potential of those semiotic resources (cf. Halliday, 1978).

Thus, semiotic resources (such as language) are not static in a long-term perspective, but reflexively developing. This is the view of language that is taken by Halliday (1978). Halliday (1991) thus describes language as a dynamic open system. In other words, language is a system that can be altered by changing its meaning potential. Language should therefore not be interpreted "as a set of rules but as a *resource*" (Halliday, 1978, p. 192).

2.3.3 Systemic Functional Linguistics

By far the most well-researched semiotic resource (cf. semiotic system, Hasan, 1995, p. 186; or semiotic resource system, Lemke, 1995, p. 86) is language. A central aspect of Halliday's (for example, see 1978, 1979, 1991, 1996, 1998, 1999, 2004, 2007) work has been concerned with characterising language in terms of *Systemic Functional Linguistics*, commonly known as SFL[10]. Other important authors who have participated in developing SFL include Martin (see, for example, 1992), and Hasan (1984). It should be noted that, as in social semiotics (see Section 2.3.2), the terminology of SFL is still under development, and that different authors use somewhat different terminology. However, the term 'functional' is central in SFL, in that it refers to how language is always related to the social function it plays, and thus develops according to changes that are of a social nature. SFL depicts

[9] In Section 2.3.3.1 I introduce the terms realisation and expression, which may be more appropriate to use here (see, for example, Figure 2.3).
[10] SFL can thus be considered a subset of social semiotics.

language as a stratified system (see Figure 2.3 and Section 2.3.3.1) – a network system of (paradigmatic) choice within each stratum of language. A lower level of stratification in language (e.g., the sounds of spoken language in phonology/phonetics) *realises* the next higher level of the stratified system (e.g., the lexicogrammar – a joining of the spoken words and the grammar).

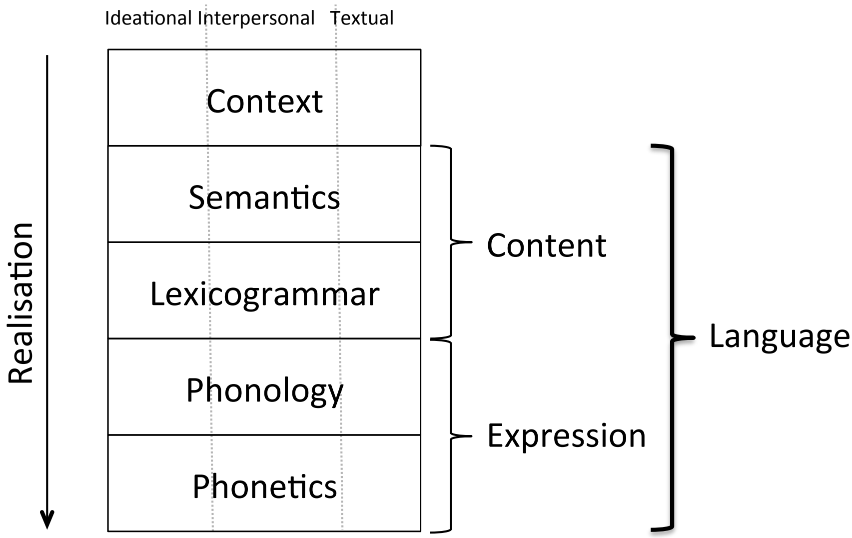

Figure 2.3. Stratification of (spoken) language. The content and expression planes of language, and realisation (cf. Halliday & Matthiessen, 2004). At the top of the figure the three metafunctions that are described in Section 2.3.5 can be seen.

In the following sections (2.3.3.1-2.3.6) a short description of SFL terminology is included.

2.3.3.1 Realisation, construal, and stratification of language

An important aspect of SFL is that language can be seen, theoretically, as being divided into different "strata" (Halliday, 1978). For example, as shown in Figure 2.3, spoken language thus consists of (from lower to higher strata) phonetics, phonology, lexicogrammar, and semantics[11]. Above this is the stratum of context[12]. A higher stratum is *realised* by a lower one. The content (semantics[13] and lexicogrammar,) together with the expression (phonology and phonetics) is what constitutes spoken language (Halliday & Matthiessen, 1999). In my work this orientation facilitated my interest in

[11] Martin (1992) calls this stratum "discourse semantics."
[12] Martin (1992) divides context into register and genre. Halliday (1978) divides context into the contexts of situation (cf. Martin's register) and culture (cf. Martin's genre). However, Halliday does not deny the possibility of more abstract strata above context.
[13] Semantic analysis is further described in Section 2.3.6.

exploring students' awareness of the content plane (cf. Figure 2.3) of physics – that is, the meanings made in physics as a discipline – and the relationship between the content and its realisation through the production of semiotic resources. In other words, how the experience of physics meaning is *construed* from and through semiotic resources. My research has involved a mapping of the relationships in the different strata that are realised in text, and which are analytically captured through the generation of "thematic patterns" (Lemke, 1990; see Section 2.3.7).

2.3.4 Meaning potential of language

2.3.4.1 Syntagmatic and paradigmatic organisation

An important distinction that is made in SFL and social semiotics is that between syntagmatic and paradigmatic organisation of language. The term syntagmatic refers to those parts of a text that are combined and work together, contextualising each other and acting together, to make up the text. This is referred to as (text) structure (Halliday & Matthiessen, 2004; Martin, 1992). This structure is achieved in the process of realisation, where a choice is made (although not necessarily consciously) from a given paradigmatic system. For example, a clause typically contains a (grammatical[14]) process and one or more (grammatical) participants, and often one or more (grammatical) circumstances. Thus, for example, in the sentence "I ran", "I" is the grammatical *participant*, and "ran" is the grammatical *process*. Syntagmatic in this case refers to the existence of both a participant and a process.

Paradigmatic refers to the options/oppositions in the system network that (by some probability) are chosen from in order to make up a part of a given text (see, for example, Chandler, 2007; Halliday & Matthiessen, 2004; Hodge & Kress, 1988; and Martin, 1992, for more about syntagmatic and paradigmatic organisation). So, in the above example, the term paradigmatic refers to the options that are available in language that could have been used instead of the "I" and the "ran" (for example, if referring to the same situation, the terms chosen could have been, *the man*, instead of *I*, and *jogged* instead of *ran*). Thus, SFL views the process of realisation of language as taking place through a number of choices made between the paradigmatic options in a system network (cf. Martin, 1992).

However, as Halliday (1991) has theorised, in a given context there is a probability distribution for the choices that are available in the system networks (if one wants to make sense in communication). There is a gradual change in this probability as the context is increasingly specified. This is

[14] I will use the word *grammatical* to separate the semantic elements from other uses of the words process and participant.

represented in the “cline of instantiation” (Halliday & Matthiessen, 2004; Matthiessen, 2009; see Figure 2.4). Thus, there is a greater chance of having, for example, “an electric field” being a grammatical *participant* in a clause in a physics context[15], than there is in an everyday context. By restricting the context to a physics one (a situation type), the probabilities in the meaning potential of the network system of language are simultaneously shifted towards those of the applicable subpotential. This subpotential of language is called “register” (see, for example, Halliday & Matthiessen, 2004, p. 27). As can be seen in Figure 2.4, in SFL text is an instance of language.

Description →	Potential	Subpotential/Instance type	Instance
Context →	Context of culture	Context of subculture/Situation type	Context of situation
Language →	System	Register/Text type	Text

Instantiation →

Figure 2.4. The cline of instantiation (Halliday & Matthiessen, 2004; Matthiessen, 2009).

According to the SFL model, the system network of choices is what gives language its meaning potential, that is, the system network determines what meanings can be made with language. Given that language is taken to be an important aspect of learning, the meaning potential of language becomes crucial. However, due to the stratification of language, the meaning potential of language is not constrained by the system networks in one stratum; there are ways to increase the meaning potential of language. Ways in which this can be achieved are introduced in the following sections.

2.3.4.2 Rank

Related to the stratification of language, is the “rank scale” (Halliday & Matthiessen, 2004). Rank is a way to classify language according to “structural units.” Thus, in lexicogrammar, the rank scale, from highest to lowest is: clause, phrase (that is, a "contraction of a clause", p. 311) or group (that is, an "expansion of a word", p. 311), and word. The corresponding rank scale of the semantic stratum is “figure” and “element (of figure)”

[15] Note that context here is not defined as much by the physical environment, as by what has been presented in the preceding discussion. The physical environment may nevertheless change the probability that a particular context becomes realised. For example, a driver of a car passing two people with their thumbs up on the side of the road is more likely to interpret this as them trying to hitch a ride, than as two students discussing a physics problem. Whereas in a physics laboratory, there is a bigger chance that the thumb means some physical quantity, such as the direction of an electrical current.

(Halliday, 1998, p. 189). These units form complexes (e.g. clause complexes in the lexicogrammar, or sequences of figures in the semantic stratum), which together make up spoken and written texts. Thus, for example, a sentence may have one or more clauses.

One important point here, in relation to learning the ways of making scientific meaning, is that a common way to increase the meaning potential of language is through the process of "rank shift" (Halliday & Matthiessen, 2004; for rank shift in mathematics, see O'Halloran, 2005; and for visual rank shift, see O'Toole, 1994; 1995). Through a rank shift, a higher rank, for example, a clause, is shifted towards a lower rank – a phrase, group or a word[16]. Although this implies a loss of information (cf. 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, 2004, p. 426) in the surrounding language. This is a "semogenic process" (Halliday & Matthiessen, 1999, p. 17), which means that it is one way that the meaning potential of language gets expanded.

Rank shifts are abundant in physics textbooks. For example, consider the clause "kinetic energy … is conserved" (Young & Freedman, 2004, p. 300). What makes this piece of text a clause is the verb group "is conserved." This clause can be rank shifted to a word 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 become a part of a new clause, and this is what is meant by becoming embedded.

Note that while increasing the meaning potential of language, rank shift is simultaneously one of the ways that scientific language is made increasingly compact, abstract and opaque (Martin, 1992; Martin & Veel, 1998). Thus, this is an instance where those aspects that make scientific language powerful for the discipline, may pose significant learning challenges for science students.

2.3.4.3 Nominalisation, technicalisation and grammatical metaphor

Two other common processes that increase the meaning potential of (scientific) language are nominalisation and technicalisation (Halliday & Martin, 1993). Nominalisation is the process by which verbs (grammatical *processes*) become nouns (grammatical *participants* such as *things/objects*) and thus constitutes a form of "grammatical metaphor" (Halliday, 1998; Halliday & Matthiessen, 2004). For example, consider the parts of the sentences from Young and Freedman (2004, p. 300) in the previous section where the verb group "is conserved" (grammatical *process*) is turned into the noun "conservation" (grammatical *participant*). Another example of

[16] SFL does not consider rankshifts in the other direction, that is "upward rankshift" (Halliday, 1966; McGregor, 1991).

nominalisation is that the grammatical *process* “refracts” becomes the grammatical *participant* “refraction” in the disciplinary discourse of physics (see Section 2.2.3 for a description of disciplinary discourse). The grammatical *process* – refracts – is termed a “congruent construal”, and the grammatical *participant* – refraction – is termed a “metaphorical reconstrual” (Halliday & Matthiessen, 1999, p. 272). Technicalisation is when such a nominalisation becomes *technical* within a discipline. This means that it gets accorded a taken-for-granted meaning by the community that makes up the discipline.

The effect that nominalisation and technicalisation have on science learning has been explored in Brookes and Etkina’s (2007) work with students’ difficulties with language in quantum physics. Particularly, Brookes and Etkina 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.

However, nominalisation significantly enhances the meaning potential of language by allowing processes to become thematised[17] in a way that facilitates their receipt of a central, foregrounded position in spoken or written language (Halliday, 1996; Halliday & Matthiessen, 1999). This allows them to be further elaborated and/or specified. Also, nominalisation allows a more diverse taxonomy[18] of processes, when they are expressed as things (op cite).

2.3.5 Metafunctions of language

Another important aspect of SFL’s description of language is the division (or diversification, cf. Halliday & Matthiessen, 1999) into three different “metafunctions” of language. These are called the *ideational*, the *interpersonal* and the *textual* metafunctions. These metafunctions are largely interwoven, and can be seen to be simultaneously performed by language. The ideational[19] metafunction relates to which processes, participants and circumstances are involved in the text. The interpersonal metafunction relates to the relationships between people involved in the text, including the reader and writer (or the speaker and the listener). The textual metafunction relates to the role of language in the realisation of the other metafunctions in

[17] Similar thematisation is currently being investigated in mathematics (Doran, 2012).
[18] Taxonomic relationships include, for example, meronymic (part-whole) and hyponymic (subclass-class) relationships, and antonymy (”contrast pairs”) (cf. Halliday & Matthiessen, 1999, pp. 82-95; and see Lemke, 1990, p. 222). Furthermore, there are taxonomies of participants, processes and circumstances (Halliday & Matthiessen, 1999).
[19] In SFL, the ideational metafunction is sometimes divided into an experiential component and a logical component, but following Kress (2010) I do not make or use this distinction in my analysis.

the text, and deals with issues such as coherence and cohesion of texts (Halliday & Matthiessen, 2004; Hasan, 1984; Martin, 1992, 2001).

2.3.5.1 Referencing

One of the responsibilities of the textual metafunction is to create cohesion between different parts of a text. One possibility for accomplishing this with language is that of referencing or "phoricity" (Halliday & Matthiessen, 2004, p. 89). Reference in an oral discussion may begin with what is called "exophoric references" which (except for signalling that the primary analytic focus is spoken language) means reference to what is outside of the spoken text, yet physically present (the discussion of reference here is built upon Halliday & Matthiessen, 2004; and Martin, 1992). Exophoric reference is often accompanied by a simultaneous physical pointing at the item referred to. "Endophoric reference", on the other hand, means reference to something which is *in the text*, and may be of one of two different kinds: an "anaphoric reference", which refers to something that has already been established in the text, or a "cataphoric reference", which refers to something that is to come. For an example of how referencing is done by students participating in physics discussions, see my dynamic analysis in Section 4.4; and for an interesting discussion of the simultaneous use of different kinds of references, see Martin (1992).

2.3.6 Introduction to the analysis of spoken and written text in SFL

In SFL, language[20] is both described (its potential) and analysed (the realisation in spoken and written text) (Matthiessen, 2009). Text analysis in SFL is primarily based on the division of language into the different metafunctions (ideational, interpersonal and textual; see Section 2.3.5). Of these I am, in this thesis, mostly interested in the *ideational metafunction* (see also Footnote 19 on p. 26) – which describes who, what and when, etc.

Text analysis is also based on the unit of analysis – clause complex, clause, phrase, (word-) group, and word, etc. In the clause, the analytical focus is in the semantic stratum. As is mentioned in Section 2.3.4.1, each clause consists of process, participants and circumstances, ordered from the more "central" to the more "peripheral elements"[21] (Halliday & Matthiessen, 2004, pp. 175-176). The analysis of the semantics of a clause thus includes, for example, examining the process, participant and circumstance elements. These elements can be further categorised (Halliday & Matthiessen, 1999).

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[20] In SFL the detailed analysis only takes spoken and written language into consideration.

[21] I want to remind the reader that an element is the lowest rank in the semantic stratum (cf. Halliday & Matthiessen, 1999, pp. 49, 177).

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 possible. For example, the type material ("doing") can be divided into *action* ("doing") and *event* ("happening"), and the type relational (which deals with "being") can be divided into *attribution* and *identification*, and is particularly important in science texts (Halliday, 1998).

Participants can be further divided into (in SFL's *transitive model*[22]) for example, the common participant elements *actor* ("the one that brings about the change") and *goal* (the one that "'undergoes' the process", "the goal of impact", Halliday & Matthiessen, 2004, pp. 179-181)[23]. Here, in the clause "Chaplin ate the shoe", "Chaplin" is the *actor*, "ate" is the *process*, and "the shoe" is the *goal*[24].

Circumstances can be divided into, for example, the types *extent* and *location,* 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)[25]

When (word-) groups are the unit of analysis, the analysis typically focuses on categorising the roles of different words in the verbal, nominal and adverbial groups, which typically realise processes, participants and circumstances, respectively (Halliday & Matthiessen, 2004, p. 177). The roles of words in word-groups can be categorised based upon their functions. For a nominal group, for example, the main categories are "*deictic, numerative, epithet, classifier and thing*" (Halliday & Matthiessen, 2004, pp. 312-320).

The brief introduction to text analysis that has been presented here, is the basis for an analytical tool, which Lemke (1990) has called a *thematic pattern*. This analytical tool is presented in the next section.

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[22] An "organisational" model where "a process is acted out by one participant" (*actor*) and may "impact another participant" (*goal*) (Matthiessen, Teruya, & Lam, 2010, p. 232).

[23] Other participant roles are, in material process types "Recipient, Client; Scope; Initiator; [and] Attribute"; in relational process types "Carrier, Attribute; Attributor, Beneficiary; Identified, Identifier; Token, Value; [and] Assigner"; and in other process types "Behaver; Behaviour; Senser, Phenomenon; Sayer, Target; Receiver; Verbiage; [and] Existent" (see Halliday & Matthiessen, 2004, p. 260).

[24] There is also a more general alternative to the transitive model, called the ergative model. Here, "Chaplin" would be agent, the "external cause" (Halliday & Matthiessen, 2004, p. 285), who is responsible for the process, and "shoe" would be medium, as in "the medium through which the process is actualized" (p. 284). (In the ergative model, in a material clause, medium may replace either actor or goal, agent may replace actor, and range may replace scope (Halliday & Matthiessen, 2004, p. 291).)

[25] Other circumstance types are "Cause; Contingency; Accompaniment; Role; Matter; and Angle" (Halliday & Matthiessen, 2004, pp. 262-263).

2.3.7 Thematic patterns in science

Lemke[26], drawing on Halliday's systemic functional grammar (Halliday & Matthiessen, 2004) developed a way of representing semantic relationships in the form of what he called thematic patterns (Lemke, 1983, 1990). Such thematic patterns are analytically generated through the identification of the role or meaning words have in relation to each other. Lemke (1990) elaborates on this as follows:

> *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)*

The meaning of a word is thus context dependent. In thematic patterns, categories denoting particular kinds of thematic or semantic meaning are used to label relationships linking thematic items (words) used in spoken or written language. The thematic patterns are thus constituted to represent a distillate of the meaning conveyed by different words that can be used to denote the same 'thing'. Thematic patterns can be seen to have similarities to "concept maps" (Novak & Cañas, 2008), in that they connect different items/words, but they are not derived from propositional statements nor do they necessarily have the same hierarchical structure:

> *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)*

A thematic pattern is an instance of what is called a "synoptic" perspective, which is described in the next section.

2.3.7.1 Dynamic and synoptic perspectives

There are two complementary perspectives that are necessary for an analysis of text. Lemke (1990) calls these perspectives "dynamic" and "synoptic." The dynamic perspective looks at how we can interpret what is said or done on the basis of what has been said or done before, or how the meaning of what was said or done before can be re-interpreted due to that which is new, and how the making of meaning develops with time. A synoptic perspective is a time *independent* analysis (note, not space independent, which is often meant by the word synoptic). This perspective thus tells us "how things turned out in the end" (p. 197). Thematic patterns represent the time

[26] 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.

independent (synoptic) interpretation of the relationships that have been realised in (spoken or written) text.

Next I will describe some of the more recent research that uses thematic patterns as an analytical tool.

2.3.7.2 Application of thematic patterns

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[ed] meaning of a scientific concept through the integration of different modalities"[27] (p. 1778). The conclusions drawn from the Tang, Tan and Yeo study are, 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, they went on to conclude that teachers need to point out the relationships between different semiotic resources, the students' fluency in and the "seamless integration" of which is often taken for granted by teachers.

This development of social semiotics towards the analysis of the realisation of thematic patterns through different semiotic resources is very interesting and important given the aim of my research that is described in Section 1.1. My own use of thematic patterns will be described in Chapter 3. As a necessary preamble, *multimodality* is introduced in the next section.

2.3.8 Multimodality

2.3.8.1 Introduction

In this section I will introduce how the social semiotic perspective has developed from dealing almost exclusively with language, to dealing with a 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, as exemplified by the Tang, Tan and Yeo (2011) study mentioned in the previous section, these other resources can be referred to as those to which exophoric references[28] are made (see, for example, Martin & Rose, 2007). This amounts to saying that some information is realised by the written text, and other information, to which the text refers, may be realised

[27] What is meant by "different modalities" here is different kinds of semiotic resources, cf. the discussion in Section 2.3.2.
[28] I want to remind the reader that an exophoric reference refers to something outside written or spoken text (see section 2.3.5.1).

by another semiotic resource, such as image. Therefore, I argue[29] that other information may be given by the interrelation of, for example, the two semiotic resources language and image, or with, for example, image alone. Here, I agree with an important observation made by van Leeuwen (2011, p. 169), regarding the relationship between language and other semiotic resources: "what is marginal and what is central will depend on the cultural and situational context."

One of the central aspects for this thesis is aptly characterised by Martin and Rose (2007) as "how semantic patterns at the level of discourse[30] are realised as visual patterns at the level of image" (p. 322). This is similar to Halliday and Matthiessen's (1999, pp. 354-355) 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.*

In a similar spirit, I have extended my analysis beyond the attributes of language and image to suggest the possibility (even necessity) of the realisation of semantic (or thematic) patterns that include multiple semiotic resources, including gestures, diagrams and mathematical formalism, that is, multimodal text[31] (cf. Section 1.1).

The "orchestration" of a multiplicity of these semiotic resources, is then collectively referred to as multimodality (see, for example, Kress, 2010; Kress, Jewitt, Ogborn, & Tsatsarelis, 2001; Kress & Van Leeuwen, 2001, 2006). Multimodal theories 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 English language, adhere. The social semiotic multimodal approach proposed by Kress (for example, 2010), builds on the social semiotic part of Halliday's SFL, but essentially ignores grammatical aspects. (See Jewitt, 2009, for an elaboration on the different theoretical "flavors" of multimodality.)

Following O'Halloran, I have applied the multimodal extension of Halliday's notion of language (which was described in Section 2.3.3) to other semiotic resource systems including, for example, gestures, diagrams and mathematical formalism. Viewing text as not restricted to that which can be realised by spoken or written language, enables the analysis of meaning-

[29] However, I am not suggesting that Martin and Rose would not agree with this.
[30] By "discourse semantics", Martin and Rose (2007) are referring to what Halliday calls "semantics" in his model of stratification of language described in Section 2.3.3.
[31] This would then have analytical consequences for the abstraction of thematic patterns from multimodal text as well.

making with other semiotic resources as well. Furthermore, Kress (2010) points out that these other semiotic resources also can fill ideational, interpersonal and textual functions. As mentioned in Section 2.3.6, in this thesis I focus on the ideational content[32] of the (multimodal) texts produced in physics education.

2.3.8.2 Semiotic resources as motivated metaphors

Semiotic resources can be characterised as metaphors. From a multimodal perspective Kress (2010, p. 55) 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'. This is 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) also claims that a sign is always "motivated" (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 are present, and to what extent these characteristics are typical for what we know as busses and cars respectively. However, signs that were once motivated (or "transparent", Hodge & Kress, 1988, p. 23; that is, to understand why it is used as a sign) can, with time, change to become more "opaque" (in a way similar to how scientific language may change, cf. Halliday, 2004; Halliday & Martin, 1993). For a common example, consider the icon for saving a document in Microsoft Word – an iconic symbol for the now obsolete diskette (see Figure 2.5). The motivation for this icon may 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 or USB drives to save/transfer their work). For illustrative examples from physics consider the symbols used to denote common quantities. For example, the (vector) quantity force is denoted by the (bold) abbreviation/character ***F*** – here the motivation for this may be more obvious if one is English speaking. Whereas for Swedish speakers, the word for force is "kraft", and the symbol motivation is immediately less transparent. In both cases the emphasis (bold) aspect representing the vector nature of force is not obvious at all, but based on a convention. The motivation for a semiotic resource may thus be veiled to an outsider by its referencing of things that are specific to certain cultures (such as those that share a language, or a particular scientific discipline), that are not well known outside these cultures (cf. Halliday's, 1978, discussion about "antilanguages").

[32] The ideational metafunction relates to which processes, participants and circumstances that are involved in the text (cf. Section 2.3.5).

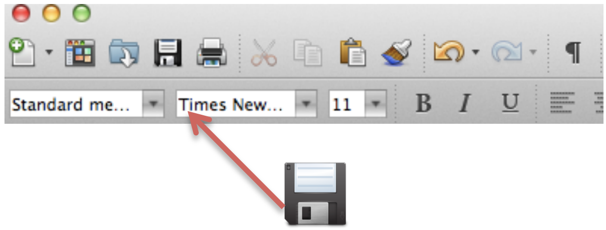

Figure 2.5. The motivation for the icon for the "save this document" option in Microsoft Word may be transparent for some people, but may not be for others.

2.3.8.3 Increasing the meaning potential of multimodal text

Closely related to the discussion about metaphor in Section 2.3.8.2 above, and to ways of increasing the meaning potential of language described in Section 2.3.4.3, is O'Halloran's (2005) discussion of "semiotic metaphor" in multimodal text[33]. *Semiotic metaphor* is introduced in relation to inter-semiotics (that which goes on between different kinds of semiotic resources, such as translation[34]) and intra-semiotics (that which goes on within a single kind of semiotic resource based upon its 'grammar'), and is described as having "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) make a similar argument in the area of chemistry. Thus, the meaning potential of the extensively researched semiotic resource of language can be further enhanced by its interrelation with other semiotic resources.

In the next section I will introduce a new construct – *disciplinary affordance*, which I claim is useful when talking about the meaning potential that different semiotic resources provide.

2.3.9 Disciplinary affordance

A construct that is important for my discussion of the generative research questions is "disciplinary affordance." In Gibson's (1979) "ecological approach to perception" he introduces a notion of *affordance*. Gibson 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

[33] I would like to remind the reader that I am using the term multimodal text here to emphasize that I refer to text as constituted by different kinds of semiotic resources and not only spoken or written text (cf. Section 1.1).

[34] 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.

to attainment of it" (Gibson & Pick, 2000)[35]. 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 simultaneously a potential inherent in the object itself. A different view on affordance was presented by Norman (1988), who 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 order to emphasize the discipline-specific affordance of a given semiotic resource, I have created a new construct, *disciplinary affordance*, which was introduced in Paper II. Here the disciplinary affordance of a semiotic resource is defined as "the inherent potential of that [semiotic resource] to provide access to disciplinary knowledge" (Paper II, p. 658). I will return to why and how I consider disciplinary affordance to be a useful analytic construct in Section 6.6.

2.3.10 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 (cf. Paper II). By persistent I mean a semiotic resource that leaves a persistent "trace" (Woolgar, 1988) of its production in the medium in which it was produced. Thus, examples of persistent semiotic resources are images, diagrams, equations, and written text (cf. "inscriptions", see, for example, Roth & McGinn, 1998, p. 35). Examples of non-persistent semiotic resources are gestures and spoken language, which 'vanish' from the medium in which they were produced directly after their production.

Having introduced semiotic resources, I will now go on to introduce the relationship between an individual student and the discipline using a 'scientific literacy' metaphor.

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[35] Note that this quote comes from James Gibson's wife, Eleanor Gibson.

2.4 Scientific Literacy

2.4.1 Introduction

For my thesis I want to make a case for relating the description of meaning-making, which I described in Section 2.3, 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) to treat scientific literacy as a special case of "literacy in its fundamental sense."

2.4.2 Vision I and Vision II

Roberts (2007a, 2007b) has made a distinction within the 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 my thesis I talk about Vision I scientific literacy.

2.4.3 Multimodal scientific literacy

Norris and Phillips' (2003) "fundamental sense" of literacy can be characterised as having similarities to Halliday's (1996) conception of literacy as "the making of meaning in [written] language" (p. 367). However, Norris and Phillips, although focusing on reading, include in their view of scientific literacy "the panoply of literate objects including not only printed words, but also graphs, charts, tables, mathematical equations, diagrams, figures, maps, and so on"[36] (Norris & Phillips, 2003, p. 228). These "objects", which I have called different kinds of semiotic resources (see Section 2.3.2), are an integral part of what Airey and Linder (2009) call disciplinary discourse. In Airey and Linder's (2009) discussion of how scientific literacy can be achieved, an important aspect that is pointed out is that students need to "become fluent in a critical constellation of the

[36] 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).

different semiotic resources" (cf. Airey & Linder, 2009, p. 28)[37]. This perspective, which could be called *multimodal scientific literacy*, is problematised in Paper IV.

Before I can move on to describing the methodology of this thesis, I will introduce a number of useful terms and concepts in the following section.

2.5 Standing fast, intertextuality and appresentation

2.5.1 Standing fast

In Paper II, I draw on Wittgenstein's notion of *standing fast*[38] (e.g. Wittgenstein, 1979, §152 and §234) to denote that which is 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.

However, I do not only want to be able to talk about those aspects that are standing fast in a discussion between people. I also want to talk about those things which are presupposed by a piece of text – the extra information that has to be brought in order to make sense of that text, and which is explicitly or implicitly referenced by that text. Here the term *intertextuality* can be useful.

2.5.2 Intertextuality

Intertextuality (cf. Kristeva, 1980) is about how "[e]verything makes sense only against the background of other things like it" (Lemke, 1990, p. 204). This means that texts make meaning (only) by relating to other texts. Of course, texts do not come into being by themselves, but are produced and interpreted by people. However, from a text analysis perspective, different texts can be seen to make up a web or a pattern of interrelationships. As such, different texts can be based on the same thematic pattern[39] (see Section 2.3.7). Lemke (1990, p. 204) calls such texts "cothematic."

In relation to intertextuality, a discussion about interpretation of grammatical metaphor and nominalisation is provided by Halliday and Matthiessen (1999, p. 271). They provide an example of an instance of language use where a grammatical metaphor has already been introduced in

[37] Airey (2009), equates such fluency with scientific literacy, and also claims that students become scientifically literate with respect to a given physical phenomenon through repetition.
[38] 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 II.
[39] In other words, a particular thematic pattern can be seen as a 'blueprint' for such texts.

the preceding text in its congruent form (cf. the example from Young & Freedman (2004, p. 300) where the (congruent) clause “kinetic energy … is conserved” precedes the rankshifted grammatical metaphor “conservation of kinetic energy”[40] (p. 300) in Section 2.3.4.3). In the congruent form a (grammatical) figure consists of process, participants and circumstances and can be called a “configurational pattern” (Halliday & Matthiessen, 1999, p. 271). But this pattern is altered by grammatical metaphors. Halliday & Matthiessen 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. (Halliday & Matthiessen, 1999, pp. 271-272).*

Considering that physics text is amongst the most technicalised of texts, and is amongst those that have the largest amount of nominalisations, the need for “unpacking” (Halliday & Matthiessen, 1999, p. 256) of the disciplinary metaphors that is brought out in the quote is highly relevant from an educational point of view. I suggest that this problem of construing the configurational pattern from the metaphor is amplified in a technicalised discipline such as physics where semiotic resources other than spoken and written language are abundant.

This discussion can be seen to be closely related to the concept of *appresentation*, which I discuss next.

2.5.3 Appresentation

In phenomenology[41] that which cannot be perceived in the physical environment, but of which one is nevertheless aware – in particular, the awareness of another person’s subjective experience and self (Husserl, 1931, 1973; Schutz, 1962), is called *appresentation* (for more references and further description of the concept, see Paper III). The notion of appresentation has been taken up in educational research in phenomenography. Marton and Booth (1997) exemplify appresentation using a person’s simultaneous awareness of the legs of a table even when the legs cannot be seen, for example when the table is viewed from above. In

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[40] “Conservation of kinetic energy” is an example of nominalisation.

[41] Phenomenology is a philosophical (and psychological) perspective that takes as its object of study people’s subjective experience.

other words, although the table's legs cannot be directly seen, they are known (and experienced) to be there as an extension of the recognition of the object as a table. Airey and Linder (2009) have suggested that the term appresentation applies to more abstract entities as well, particularly in an area such as physics. For example, a person may simultaneously be aware of a particular semiotic resource, when encountering particular physics content, such as the refraction of light. Here, the relationship between content aspects and an appropriate choice from one's repertoire of semiotic resources is important. Using the term appresentation to describe this relationship indicates that the relationship has become almost "automatic", "second nature" (Airey & Linder, 2009, p. 33) or to use a cognitivist metaphor "proceduralized" (cf. Anderson, 1982).

From a text (production) analysis perspective, it is interesting to examine whether a semiotic resource represents those aspects that are critical for the understanding of a particular piece of content. Here, it may be useful to borrow Peirce's terminology (see, for example, Chandler, 2007) and characterise semiotic resources as an *icon*, *index* or *symbol*, depending on their different relationships to the objects that they represent. An *icon* has a relationship of likeness with its object, an *index* has a relationship of physical connection between the sign[42] and the object that it points to, and *a symbol* stands in a more or less arbitrary relationship between the sign and the designated object: "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 example, showing only one aspect of why the above quote is important, is presented in the discussion in Section 6.6.3. Here, there is a risk that what was intended as a symbolic image by its producer may be interpreted by a viewer as a realistic image. (In Peirce's terms, a realistic image of a scientific object could be categorised as an iconic sign, whereas a schematic image may be seen as a symbol.)

The point of this discussion is that there may often be a difference between that which is actually represented by a semiotic resource, and that which is needed for the constitution of meaning. I see a link here to the SFL concept *context of situation*, which was introduced in Footnote 12, p. 22, and is further discussed in the next section.

2.6 Context of situation

The SFL concept *context of situation* (see Footnote 12, p. 22) can be described as "a particular context or situation-type [where] the semantics is

[42] Sign is the word that Peirce used to denote what I call a semiotic resource, cf. the Van Leeuwen quote in section 2.3.1.

specific to that situation, the reader knows where he is, construes the situation in the particular instantial form, …and perhaps varies his actions in accordance with this construction" (Halliday & Matthiessen, 1999, p. 354). That is, a particular context of situation is indicated by a piece of text (and thus the semiotic resources that are part of it), and there is a constitutive relationship between the text/semiotic resources and the context of situation. Conversely, in a particular situation, certain meanings would be expected to be made (with the semiotic resources that pertain to them; cf. the instantiation of register, see for example Hasan, 1995; and Section 2.3.4.1). Following from this discussion, a particular situation always brings with it aspects that may or may not be immediately obvious and that are taken for granted, although this may include different appresentation aspects for different people. What makes a conversation possible in a given context, is that there is sufficient agreement on what is taken for granted, something that stands fast – a baseline upon which the conversation or discussion can be built (cf. Marton & Tsui, 2004).

Having introduced my theoretical framework I will next describe the methodology that I use in this thesis.

3 Methodology

3.1 Introduction

The articles upon which this thesis is based, all use the same video data of student interaction in a physics setting. However, the focus of each article is on different aspects of this interaction. Paper I gives an overall description of the field of multimodality and suggests a method of representing the dynamic development of a student discussion about a physical phenomenon. In Paper II, the data is used to illustrate a theoretical argument regarding the importance of choosing an appropriate (set of) semiotic resource(s) in a student discussion aimed at enhancing learning. Here the construct "disciplinary affordances" of semiotic resources is introduced and facilitates the discussion of the results. In Paper III, aspects that are (often) taken for granted in semiotic resources in physics educational environments are problematised. Paper IV is written in Swedish and takes a literacy perspective on physics learning, illustrated by the same data, which is discussed in English in this thesis. Thus, each paper uses the same dataset to deal with semiotic resources in physics with a variation in analytical focus. The method of data collection is therefore common to all four papers. What follows is an unpacking of the chosen methodology in order to clarify and warrant its choice.

3.2 Generative Research Questions

In Section 1.2 I outlined how the idea of *generative* research questions arose as part of my research journey. These generative research questions are derived[43] from the research questions in Papers I-IV as follows:

1. What roles do semiotic resources play in disciplinary meaning-making during interactive engagement in a university physics setting?
2. In relation to the *choices of persistent semiotic resources*:
   2.1 Which persistent semiotic resources are used by a group of students when engaging interactively in explaining the refraction of light?

[43] What I mean by this is that, when necessary, these have been slightly modified here to improve readability and the logical flow in the listing of the questions.

2.2 What differences in disciplinary affordances of the persistent semiotic resources used by the students can be observed in such an explanation?
2.3 What aspects of persistent semiotic resources can account for disciplinary affordance differences in an explanation of the refraction of light?
2.4 To what extent can a particular persistent semiotic resource present the critical aspects that a student needs to be aware of in order to understand the represented phenomenon in a disciplinary manner?
2.5 For a given situation, how do students select a persistent semiotic resource around which to interactively engage?

3. In what way can the semiotic resources chosen to explain scientific phenomena be related to scientific literacy?

As detailed in Section 1.2 all these questions are dealt with in Papers I-IV and an outcome summary of them is given in Chapter 5. The Discussion Chapter 6 is essentially about important observations relating to my Analysis Chapter 4, which starts to address my overarching research question:

> *In what way can social semiotic theory be instrumental in the characterisation of disciplinary knowledge as it is realised in interactive engagement in an undergraduate physics setting?*

The discussion in Chapter 6 also deals with the generative research questions in such a way that I can use all the research questions – overarching and generative – to create a discussion about implications for the teaching and learning of physics.

Before introducing my method, in the next section I discuss the possible alternative analytical perspectives that I encountered on my research journey.

3.3 Alternative analytical perspectives

3.3.1 Introduction

Across all of my work I have used a social-semiotic based meaning-making perspective, which is outlined in Chapter 2. However, my research journey included looking at possible alternative analytical perspectives. In the following sub-sections I outline the most relevant of these and my reasons for deciding not to use them.

3.3.2 Ethnomethodology and conversation analysis

Ethnomethodology was introduced by Garfinkel (cf. 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 semiotic resources in their daily work. This work can then be related to theories about how scientists and science work as proposed by researchers in the philosophy of science (Sharrock, 2004). Ethnomethodology took a quasi-empirical route to accomplish this, by employing detailed descriptions of scientists' use of signs (semiotic resources) and equipment, etc.

Closely related to ethnomethodology is conversation analysis (CA). CA has developed into a detailed method for investigating spoken language (Sacks, 1992). Some of the criticism levelled at CA lies in its development from having been an open search for patterns in spoken dialogic language, to a detailed method that 'must' be (or always is) followed. For an example of a CA transcript, see Appendix B. I decided to transcribe a part of my data 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 use it.

There do not appear to be any important tensions between ethnomethodology and social semiotics (described in Section 2.3). See, for example, how well known social semioticians have used ethnomethodology in their studies in Bezemer, Murtagh, Cope, Kress, and 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. Thus, for this thesis, I chose a social semiotic rather than an ethnomethodological or CA perspective.

3.3.3 Cognitive science

Both Systemic Functional Linguistics and social semiotics share their interest in language and 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 (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). However, the theoretical perspectives and focus of the two paradigms are in many ways very different. SFL and social semiotics take on an inter-individual perspective (Halliday, 1978), focusing on the role of semiotic resources in communication. Cognitive science on the other hand, although deeply interested in learning, mostly takes an intra-individual perspective. This means that its focus is on the different parts that together make up an individual. Much 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, namely the psychological. Common metaphors in cognitive science include abstract 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). I see these constructs to be of relatively little value for my work as I have portrayed it.

While expressing the possibility of a probabilistic interpretation of language (Halliday, 1991), SFL and social semiotics generally appeal to a qualitative research grounding. Cognitive science, on the other hand, with its positivist leanings, relies mostly on quantitative research methods, such as pre- and post-tests, etc. Thus I conclude that my research aim is better dealt with by employing qualitative research methodologies, and as such is a further reason for me not drawing extensively on cognitive science.

3.3.4 Sociocultural and cultural-historical activity theories

As mentioned in Section 2.2.1 an array of socio-cultural and cultural-historical activity theory 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 field has incorporated influences from other theoretical perspectives, such as pragmatism and ethnomethodology (cf. Engeström, 1999).

Although both perspectives described above have much in common with a social semiotic perspective, they have different theoretical constructs and frameworks. Since I have chosen to focus on the role of the semiotic resources themselves, rather than on the psychological mechanisms such as internalisation, the theoretical framework of social semiotics is more appropriate for my analysis.

3.4 Method

3.4.1 Introduction

In order to start investigating my overarching research question – *in what way can social semiotic theory be instrumental in the characterisation of disciplinary knowledge as it is realised in interactive engagement in an undergraduate physics setting?* – I chose a social semiotic perspective, which I introduced in Chapter 2. In particular I found Lemke's (1990) notion of thematic patterns useful – especially as it also offered me the possibility to extend the interpretation of thematic patterns in terms of being realisable by semiotic resources other than only spoken and written language. An example of this developmental potential can be found in how Tang et al. (2011) used thematic patterns in their research (see Section 2.3.7.2). My own development and use of thematic patterns is presented in Section 3.4.4.

The choice of the physics content area of refraction was made because, despite research having been done in the area before (see, for example, Harrison, 1994; Harrison & Treagust, 1993; Sengören, 2010; Singh & Butler, 1990), what has been done has not dealt with the learning aspects examined in this thesis. Comparatively, little has been done in the area of refraction when set against other areas of introductory university physics, and almost nothing in relation to the different semiotic resources that are used. Furthermore, what has been done has mainly been carried out at school level and not at university level.

The decision to investigate group work where students engage interactively was made based on the PER findings about the positive impact that such interactive engagement methods can have on student learning (see Section 2.2.2).

3.4.2 Data collection

When I started out on my research journey, I was guided by my research aim – to explore the roles that semiotic resources play in the representing and sharing of disciplinary knowledge in physics. Following this I set up a data collection scenario where three highly regarded third-year university physics students (voluntary participation[44]) were asked to provide an appropriate explanation for the refraction of light.

The tasks given were as follows (translated from the original Swedish version, which is given in Appendix A).

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.

The second task was a repeat of this, except this time 'the friend' was said to be a peer student asking for help to get a reasonably holistic understanding of the physics in the situation.

The discussion took place in a physics laboratory where the students had access to many different kinds of equipment and a blackboard and chalk. In a very limited way I, in my role as researcher, also participated in the discussion from time to time as deemed appropriate for non-intrusive clarification purposes.

The students' discussion was video recorded and later analysed. A single video camera with a built in microphone was used. The camera was positioned on a tripod on a bench in front of the blackboard, as shown in Figure 3.1.

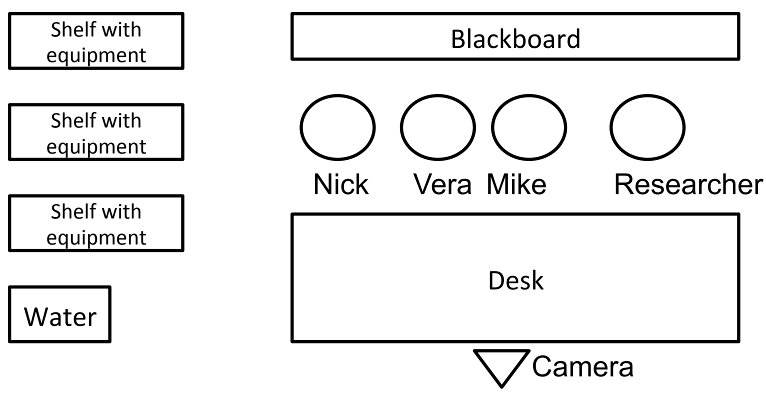

Figure 3.1. The physical organisation of the laboratory where the data was collected.

[44] The students signed an ethical consent form – "participation agreement" (Rundgren, 2008) – to allow me to use the video data for my research reporting providing that their anonymity was guaranteed. A copy of the consent from is given in Appendix D.

At this junction I need to point out that I have not included any group dynamics that were part of my data. This omission is a consequence of the ethical agreement that I formulated with the participants. In my subsequent PhD work I will address this potential limitation (for a discussion about how group dynamics might affect students' problem solving in groups, see Heller & Hollabaugh, 1992)

3.4.3 Multimodal transcription

The first step in my engagement with the data was the verbatim transcription of all the spoken text in the student discussion into an Excel spread sheet. This transcript is presented in Swedish in Appendix A[45]. This introductory engagement with the data showed that one sequence of the video data appeared to have particular significance for the students' agreement that they had now provided a sufficient explanation for the phenomenon of refraction. This sequence was chosen for a deep analysis, which included a verbatim transcription of all other semiotic resources produced by the students (including spoken and written language, mathematical notation, images, gestures, etc.; cf. Section 2.3.2). In other words, a complete multimodal transcript (cf. Baldry & Thibault, 2006; Bezemer & Mavers, 2011; Jewitt, 2006) was produced. This is presented in Chapter 4 (the sequence used was translated from the original transcripts). The multimodal transcription of this sequence 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. The gestures were described carefully in written text rather than reproduced as still images. (This was to a large extent a bi-product of the use of Excel.) However, the drawings that the students produced on the blackboard were carefully reproduced (see, for example, Figure 3.2), and the analysis was later made with the transcription together with the actual video so that a fuller appreciation of the roles of the different semiotic resources became possible. The analysis was conducted iteratively, comparing each step in the analytical process with the video data itself, until a refined analysis was reached (see Section 4.2 for more detail about the analysis process).

[45] This excludes the preamble presentation of the tasks to the students.

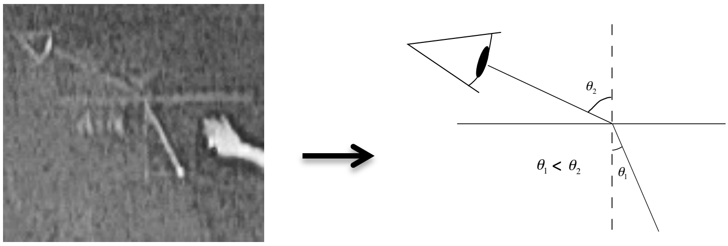

Figure 3.2. An illustration of the reproduction of the students' drawings.

3.4.4 Synoptic analysis

Here, I will present the methodology of my synoptic analysis (cf. Section 2.3.7.1). This includes *my* formulation and use of thematic patterns as a research tool, in relation to the theoretical background presented in Chapter 2. I also explain how such thematic patterns can be interpreted (cf. Tang, 2012).

3.4.4.1 Thematic patterns

A thematic pattern displays the analysis of the spoken or written text in a diagrammatic form (cf. Section 2.3.7). A "material clause"[46] is analysed so that an appreciation of the items (words) that realise the processes, participants and circumstances involved is reached. For example, *actor*, *process* and *goal* are common elements of the ideational metafunction of language (in a transitive interpretation) (Halliday, 1978; see section 2.3.6). Reusing the example given in Section 2.3.6, in the clause "Chaplin ate the shoe" then, "Chaplin" is the *actor*, "ate" is the *process*, and "the shoe" is the *goal*. These thematic items are then linked by the names of the semantic elements that the items realise (conventionally abbreviations of these element names are displayed in the thematic pattern). In this way the kind of relationship that is realised between two items is categorised. As an illustration, consider the items 'Chaplin', 'ate' and 'the shoe' from the example above – the clause made up of these terms could be illustrated in a thematic pattern as:

```
              Ac/Pr          Pr/G
CHAPLIN————————ATE————————THE SHOE
```

where Ac = *actor*, Pr = *process* and G = *goal*.

[46] "[M]aterial clauses construe doings" (Matthiessen, et al., 2010, p. 135), (cf. the discussion of material processes in Section 2.3.6).

In the ergative model (see Footnote 24, p. 28), where 'Chaplin' would be the *agent* and 'shoe' would be the *medium*, the analysis could be illustrated in a thematic pattern as:

Agent/Pr Pr/M
CHAPLIN————ATE————THE SHOE

where Pr = *process* and M = *medium*.

In fact, a sentence such as "light hits the water", which is similar to one that can be found in the transcripts that I present in Section 4.3, could be analysed in systemic functional terms in the ergative model. Because of the imminent risk of a clash between the language of physics and that of SFL, with their different uses of the term *medium* that could confuse a reader, I decided, in consultation with my supervisors, to intentionally deviate from the SFL terminology in Paper II, and in Figures 4.5 - 4.7 in Section 4.5.1. For example, the term "*object*" is simply used instead of *actor, medium* or *thing*, and "*property"* instead of *epithet* or *manner.*

3.4.4.2 Multimodal thematic patterns

In order to visualise the ideational content (cf. Section 2.3.5) of the students' discussion, a diagrammatic representation was constructed based upon Lemke's (1990) notion of thematic patterns, and how Tang and colleagues used thematic patterns in a multimodal physics setting (see Tang, 2011; Tang, et al., 2011). The first version of my formulation of thematic patterns was a synoptic, time independent, description of the multimodal transcript – see Figure 3.3.

At the top of the thematic pattern in Figure 3.3, the terms *Part* and *Hits* can be seen (in blue boxes). 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 over *Faster* (on the right hand side of the figure) is left in the thematic pattern in order to show that amongst the paradigmatic choices available at the time (and indeed first made by one of the participants in the student discussion), was the word *Faster* (for which the circumstance type Manner would be the appropriate analytical category). However, the word *Faster* would not fit into the coherent and logical explanation for the phenomenon of refraction that the students in my data were seeking – and was thus quickly changed to *Slower*, by another student (see the transcript in Table 4.3 in the next chapter).

This first analysis also took as its object the meanings made with semiotic resources other than spoken language. This included action (such as gestures), mathematical notation and images. The thematic pattern in Figure 3.3 shows these different kinds of semiotic resources using different colours.

The thematic pattern then underwent an iterative process that included the reordering of the items (cf. the description to be presented in Section 4.2) chronologically presented in the discussion, whilst still retaining their original functional meaning and internal (grammatical) relationships. An increasingly focused diagrammatic representation of the discussion thus emerged in my analysis.

During the iteration process, the references to gestures and different kinds of actions were phased out from the thematic pattern, and what remained was a characterisation of the content that had been realised in the student discussion. The information about the kind of semiotic resource that represented different content ended up being presented in text, or juxtaposed with the thematic pattern. The final thematic patterns are shown in Figures 4.5-4.7.

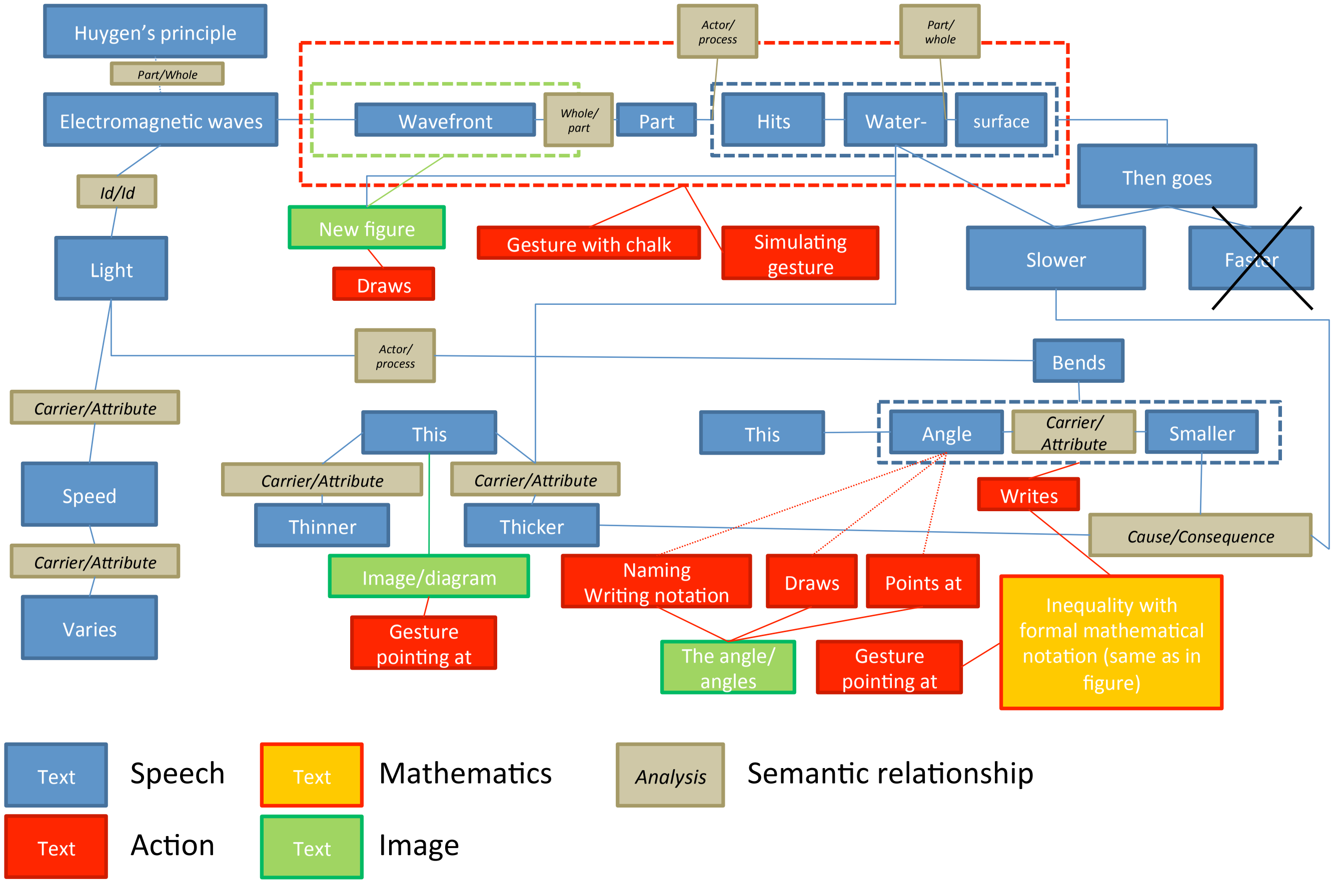

Figure 3.3. The first version of my formulation of a thematic pattern (Fredlund & Linder, 2010). Different colours show different semiotic resources. Refer to the key at the bottom for how the different kinds of semiotic resources are encoded.

3.4.5 Dynamic analysis

Whilst the thematic patterns produced a synoptic analysis, as described in Section 2.3.7.1, there was also a need for a dynamic analysis of the student discussion. Such analysis provides the possibility to, for each point in time, look back at what went before and contextualise each new action or utterance.

For the dynamic analysis of the student discussion that was represented in Paper I the work of Bloom and Volk (2007) was drawn on – in particular their "metapattern analysis of complexity in students' argument about density" (p. 56). My focus in using this analysis was the chronological development of the students' discussion. At the same time, I categorised the students' utterances into the thematic categories of "Speed", "Light", "Wavefronts", "Density" and "Bending" as shown in the different columns in Figure 4.3[47] labelled with these headings. I did this as a function of frequency of use[48]. The analysis also shows in which semiotic resource a given thematic category was represented (Figure 4.3). In this way I used my version of Bloom and Volk's "metapatterns" to show where in the students' discussion the new thematic categories emerged (with reference to what semiotic resources were employed whilst this emergence took place). This analysis is shown in Section 4.4.

3.5 Credibility, transferability, dependability and confirmability

Traditional quantitative research uses concepts such as generalizability, reliability and validity for judgements of quality. In qualitative research these terms have been replaced with the notions of credibility, transferability, dependability and confirmability, which were proposed by Lincoln and Guba (1985). In general terms these conditions (especially transferability) are met by providing a sufficiently detailed description (cf. "thick description", Geertz, 1973), which allows a reader to follow how the data and analysis were dealt with in detail. This detail then provides the basis for equivalent judgements of quality. For example, the terms "fuzzy generalization" (Bassey, 2001) and "naturalistic generalization" (Stake & Trumbull, 1982) refer to readers noticing parallels to their own situation, a "vicarious experience" (Lincoln & Guba, 1985, p. 359). This accentuates the importance of careful transcription, as it provides both a way that readers can recognise what went on in the analysis and the basis for my discussion

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[47] A diagrammatical illustration of the dynamic analysis.

[48] Since these aspects were first collected from an inventory of the most frequently occurring items in the original thematic pattern, the speed of light was left out in Paper I. However, it has been added in Figure 4.3, in order to show its 'emergence' in the discussion.

(see Chapter 6). In the early days of qualitative research in education it was considered necessary to have spent long stretches of time with the participants in the study to produce a thick description. My thick description is more contemporary in that it is set in the detail of my careful transcription of, and other engagement with, the data set. This was made possible by the collection of video data (cf. Robson, 2002, p. 171; which was not as easily achieved in the early days of qualitative research) and by the researcher both being present in the room whilst the data was collected and then personally transcribing all the data.

When discussing issues around credibility, transferability, dependability and confirmability, Gee, (2005), however, uses a term which he calls validity, where "some aspects of convergence, agreement, coverage, and linguistic details" are met (p. 114). "Convergence" here 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 is. "Coverage" is how appropriate the analysis is for describing other instances of similar situations. As for the "linguistic details", the analysis is more valid if the functions of the grammar of the language have been paid due attention. It is thus argued here that the inclusion of a focus on the different semiotic resources employed by the participants in the presented study further adds to its validity. The agreement aspect is to some extent provided by the fact that the two co-authors of Paper II, and the peer review process, support my analysis of the situation. It is also important to note that all the authors of Paper II, including myself, have experience of being both students and teachers of physics. The coverage aspect is considered, for example, by the recognition that the re-formulations of the detailed explanation of waves travelling from one medium to another that the students made individually, did "not affect the thematic pattern […] but rather served to confirm and cement the relationships between the physics concepts that had already been fruitfully established" (Paper II, p. 663). The linguistic details are part and parcel of the analysis of this student discussion, and thus contribute to the validity of the analysis.

The participation of the researcher in the situation where the data is collected is common in qualitative research. Data collection will in general, irrespective of whether the data is qualitative or quantitative, necessarily imply that the situation is affected in one way or another (Robson, 2002).

4 Analysis

4.1 Introduction

In this Chapter I present the data analysis for my overarching research question:

In what way can social semiotic theory be instrumental in the characterisation of disciplinary knowledge as it is realised in interactive engagement in an undergraduate physics setting?

This analysis draws extensively on Papers I, II, III and IV. I begin by describing my 'research journey', and how my research question was developed from my aim to *explore the roles that semiotic resources play in the representing and sharing of disciplinary knowledge in physics?* (Cf. Section 1.1.)

4.2 Developing my overarching research question

In this section I describe how my engagement with the data led to the formulation of the generative research questions that I introduced in Section 1.2, listed in Section 3.2, dealt with in Papers I-IV, and an outcome summary of them is provided in Chapter 5. Furthermore, I provide insight into how the answering of those questions informed my research journey.

The iterative process that took me back and forth between analysis and the formulation and answering of the generative research questions led to a refinement of my original aim into my overarching research question. I will now briefly describe the process through which this new research question emerged.

Having completed my initial multimodal transcription, the result of which is presented in Section 4.3, I wanted to attempt to further analyse this data through crafting a thematic pattern (Lemke, 1990). The result became my original thematic pattern, given in Figure 3.3, where contributions from different kinds of semiotic resources were indicated using different colours.

My reading about the dynamic and the synoptic perspectives[49] on text production then led me to attempt to produce a dynamic analysis of the

[49] The dynamic perspective is time-dependent whereas the synoptic perspective is time-independendent (cf. Section 2.3.7.1).

student discussion, that had been synoptically illustrated in my original thematic pattern. As described in Footnote 48, p. 51, this analysis was based on the most frequently occurring items in the original thematic pattern. For my dynamic analysis I drew on Bloom and Volk's (2007) metapatterns, which offered an appropriate way to illustrate *when* new aspects of the student discussion emerged (irrespective of whether these aspects were of a content character or of a meta-representational character, that is, *about* the semiotic resources used (cf. diSessa, 2004).

Both the original thematic pattern and the first dynamic analysis were in essence attempts to illustrate the way in which the chosen methodology could be fruitful for dealing with my research aim. In my dynamic analysis it became possible to illustrate the referencing that goes on between different semiotic resources. This in turn allowed me to begin to formulate and answer my generative research questions.

Revisiting the video data for further analysis led to the refinement of my thematic pattern. In this process I noticed that I had overlooked the importance of *Faster/Slower* in my dynamic analysis, which was based on prevalence of use. Therefore, I returned to the dynamic analysis and added this aspect. This then allowed me to see how the *chronological order* that different semiotic resources were used or referenced was important for the progression of the student discussion – especially together with an element of agreement about which semiotic resources were relevant, cf. "conceptual convergence" (Oliveira & Sadler, 2008; Roschelle, 1992).

This identification of the criticality of different semiotic resources also led me to posit that this is an important aspect of scientific literacy (see generative research question 3).

I also found that Gibson's (1979) notion of "affordance", as it had been used by, for example, Kress, et al. (2001) and Airey and Linder (2009), could be used for describing the 'usefulness' of a semiotic resource. This was eventually operationalized through the construct "disciplinary affordance" (see Paper II). This allowed me to pose further generative questions (answered in Paper II), regarding the disciplinary affordances of the persistent semiotic resources, using my refined thematic pattern to illustrate this disciplinary affordance.

Noticing that certain aspects of the thematic pattern were not particularly "unpacked" led me to pose the next generative question regarding the extent to which different semiotic resources actually present those aspects that are critical in a given physics situation.

The dynamic process of refining the analysis and the research aim, including constituting and working with my generative research questions, eventually led me to formulate my overarching research question in a stringent way. This overarching research question is thus essentially the same as the original research aim, but now formulated with my theoretical framework in mind:

In what way can social semiotic theory be instrumental in the characterisation of disciplinary knowledge as it is realised in interactive engagement in an undergraduate physics setting?

Having presented the process through which the generative research questions were formulated and the role that that formulation and answering played in the constitution of my overarching research question, I now go on to present the analysis of my data. In so doing I provide a partial answer to this overarching research question. The remainder of my PhD will be spent on further addressing this question.

4.3 Multimodal transcript

In this section I present an illustrative extract of the students' discussion in order to provide a "thick description" (cf. the discussion in Section 3.5) of the kind of deep analysis that I undertook. (It is not possible to include such detail in published papers).

The discussion, where the students explained why the refraction of light takes place, was video recorded and a particular extract of this video data, in which a sudden insight appears to take place, was chosen for further analysis. The analysis began with multimodal transcription, as described in Section 3.4.3.

In order to present my analysis, I will first introduce the illustrative extract from the student discussion[50] by presenting my multimodal transcript (see Tables 4.1-4.3). (Parts of the transcript in Tables 4.1-4.3, and Figures 4.1, 4.2, and 4.5 -4.7 appear in paper II, and Figures 4.3-4.4 appear in Paper I.) 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 4.1).

[50] Note that the students previously had used a glass tank of water, and a washing-up brush (as an exemplar linear object that could be immersed in the water). They had also attempted to use a laser pointer, and to add milk to the water in order to make the laser visible. However, the students did not have enough milk for this to work. Later Mike drew rolling wheels (cf. Section 2.2.4) on the blackboard. See the transcript in Appendix A.

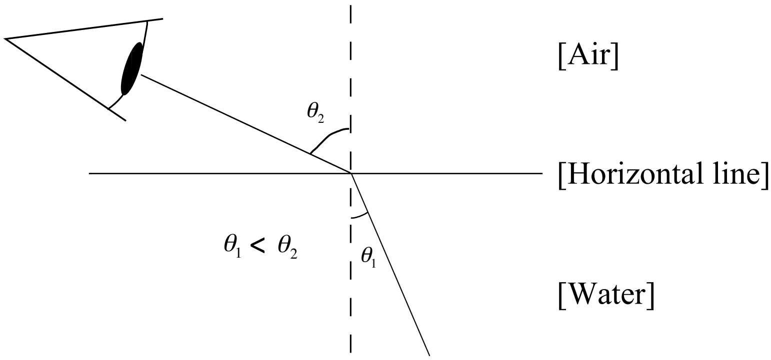

Figure 4.1. A reproduction of the ray diagram sketch that was produced by the students. I have added the written text in square brackets for clarification.

At this point, the discussion given in Table 4.1 took place.

Transcript-line	Agent	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 like a wavefront would be drawn.
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 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 (cf. Figure 4.1) then below the horizontal line.
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 in the mathematical notation θ_1 and θ_2 in the figure.
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,

			$\theta_1 < \theta_2$
9	Vera:	Why is it, why is this smaller and not bigger?	Points at the θ_1 in the inequality she just drew.
10	Nick:	Well, because this is denser, kind of.	Points to the medium below the horizontal line
11	Vera:	Why, why does that happen because it is denser?	Shrugs her shoulders

Table 4.1. Multimodal transcript of the first part of the extract from the student discussion. Descriptive notes in square brackets.

In the discussion extract in Table 4.1 both persistent semiotic resources (mathematical notation) and non-persistent semiotic resources (spoken language and gestures) are produced.

After the discussion presented in Table 4.1, the students seemed to have reached a dead end, a stalemate. The discussion had not progressed further than this, although it had been ongoing for approximately 30 minutes[51]. At this point, the following exchange occurred (see Table 4.2).

Transcript-line	Agent	Semiotic resources	
		Spoken language	Other
12	Mike:	Well, then one has to start thinking of Huygen's principle or…	Looks at the black board, 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…	

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 use of "It's" in Transcript-line 15).

The part of the extract presented in Table 4.2 was followed by a section where the students started to explore the properties of wavefronts (see Table

[51] Note that a considerable portion of this time was used for illustration of refraction using the glass tank of water etc.

4.3). Here the students used non-persistent semiotic resources whilst referring to the persistent ray diagram drawn on the blackboard (Figure 4.1).

Transcript-line		Semiotic resources	
	Agent	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… [meaning the medium 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 *slower* in the water.	Pointing to the medium below the horizontal line (water)
24	Nick:	Yes.	
25	Mike:	Yes, that's right! It's denser which means it's going slower there.	Pointing to the medium 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!	

Table 4.3. The properties of wavefronts are explored. In Transcript-line 28 a direct link between light and wavefronts is made. Descriptive notes in square brackets.

This part of the extract ends as Mike is about to draw a new diagram, a wavefront diagram (see Figure 4.2).

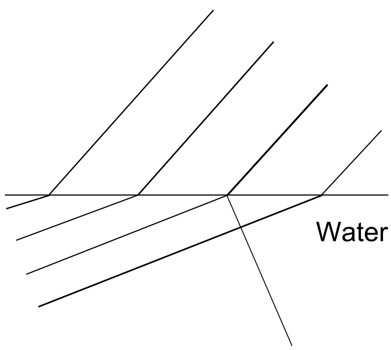

Figure 4.2. A reproduction of the detail given in the wavefront diagram eventually drawn by the students. Here, the word “Water” was written in the diagram.

In the next section the results of the dynamic analysis are presented.

4.4 Dynamic analysis

Turning now to the dynamic analysis of the extract of the students' discussion described above, I give my diagrammatic construction of the interplay between different semiotic resources, shown in Figure 4.3, where the letters in the "Image"-column refer to the letters in Figure 4.4. My analysis suggests that the most important section in this extract of the discussion is what happens in Transcript-line 22 in Table 4.3. This is when the grammatical *participant* "a part of the wavefront", which was finally agreed upon in Transcript-line 20 in Table 4.2, is said to start going "faster" (grammatical *process*; although it is quickly corrected to going "slower" by Vera). This culmination of insight of the relevance (or 'sense') that the going "faster" provides, is accompanied by a gesture by the hand (a non-persistent semiotic resource) showing the movement of the wavefront as it increases its speed. In other words, Figure 4.3 shows the dynamic development of the discussion leading up to Mike's drawing of the persistent wavefront diagram. The labels "Speed", "Light", "Wavefronts", "Density" and "Bending" at the top centre of Figure 4.3 are those that turned out to be most frequently occurring after a categorisation of the 'items' in my original thematic pattern was made.

The analytic approach used to obtain Figure 4.3 draws on Bloom and Volk (2007) and is described in full in Section 3.4.5.

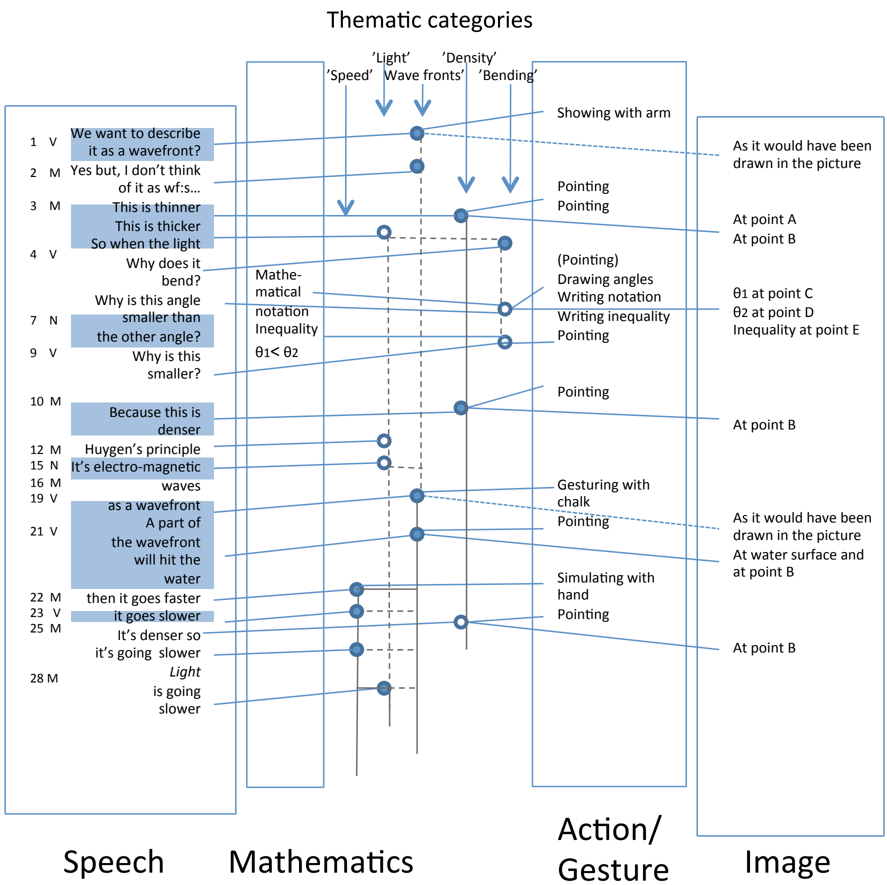

Figure 4.3. A diagrammatical illustration of the dynamic analysis. This figure shows who is acting or saying something, what is said, what semiotic resource(s) are used, and which aspect of the content or form of the discussion that the action is contributing to, here referred to as thematic categories. Dashed lines indicate those segments that are not agreed on, nor explicitly linked to another item – only a mentioning, or a potential linking. Unfilled circles play a similar role. The letters (such as "point A") in the image-column refer to positions shown by the same letters in the ray diagram shown in Figure 4.4. In line 22 the speed of light aspect is introduced. Note that the line numbering is the same as in the multimodal transcripts in Tables 4.1-4.3.

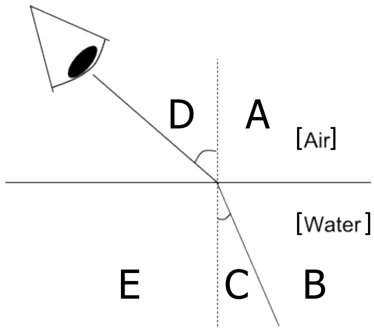

Figure 4.4. Letters showing positions in the ray diagram referred to in Figure 4.3.

4.5 Synoptic analysis

The dynamic analysis of the students' discussion presented in the previous section shows the development of the student-discussion that led up to the emergence of the concept of the speed of light being identified and agreed upon as an important factor (or rather, a critical aspect) in the students' explanation of refraction. By looking at which semiotic resources were referred to at this point in the students' discussion, the importance of wavefronts and the wavefront diagram was identified. This led me to construct three separate thematic patterns[52] from the original thematic pattern in Figure 3.3. These *final* thematic patterns are shown in Figures 4.5-4.7.

4.5.1 The final thematic patterns

My first attempt to make a thematic pattern of the student discussion is shown in Figure 3.3 in Section 3.4.4.2. The patterns shown in Figures 4.5 to 4.7 emerged through an iterative analytical process. These thematic patterns represent a synoptic analysis at different points in the thread of the students' discussion. The first thematic pattern (Figure 4.5) represents what happened before the identification of speed of light as a critical aspect (cf. Table 4.1), the second thematic pattern (Figure 4.6) deals with how light is related to a wave concept in physics through Huygens' principle (cf. Table 4.2), and the third (augmented) thematic pattern (Figure 4.7) displays the whole discussion, with the dimension of the speed of light added (cf. Tables 4.1-4.3). (How these thematic patterns were constructed was described earlier in Sections 3.4.4).

[52] At the time of writing this thesis I have not yet come up with a name for my thematic patterns, and therefore, for the moment being, I will refer to them as my *final* thematic patterns.

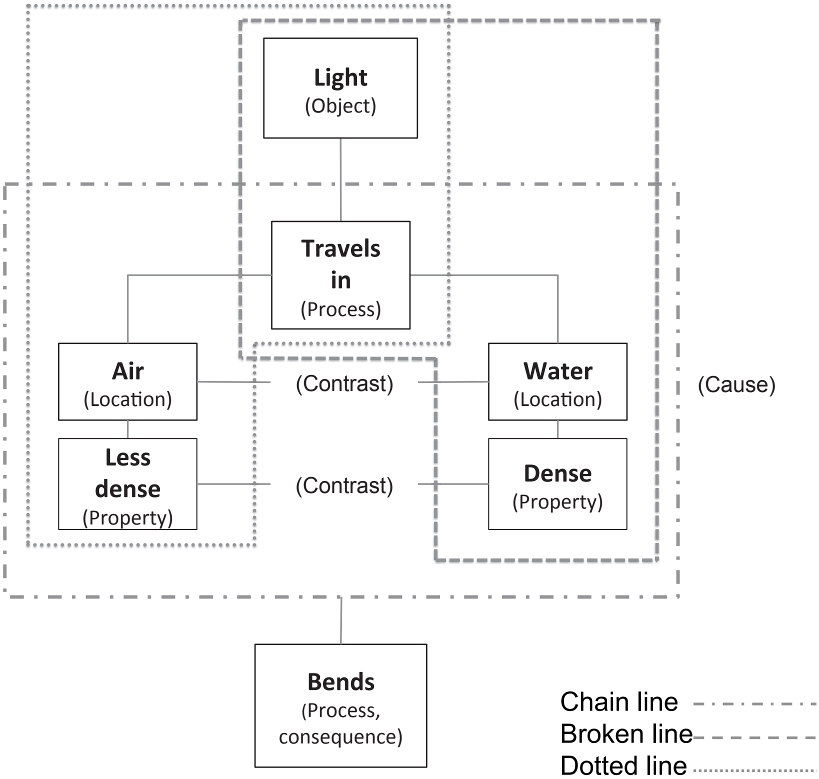

Figure 4.5. Thematic pattern for the first part of the discussion extract (cf. Table 4.1). The chain line encapsulates the cause of refraction as it appeared in the students' explanation. The broken and dotted lines encapsulate the physics meanings that were contrasted in the discussion (cf. Paper II).

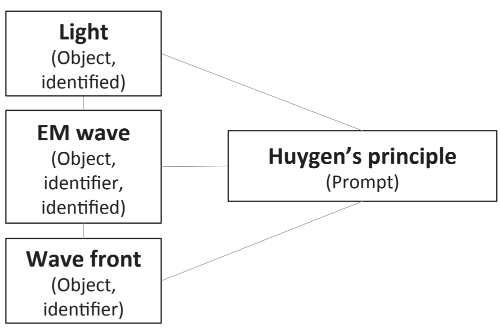

Figure 4.6. Thematic pattern for the students' transition to a wave model of light (cf. Table 4.2).

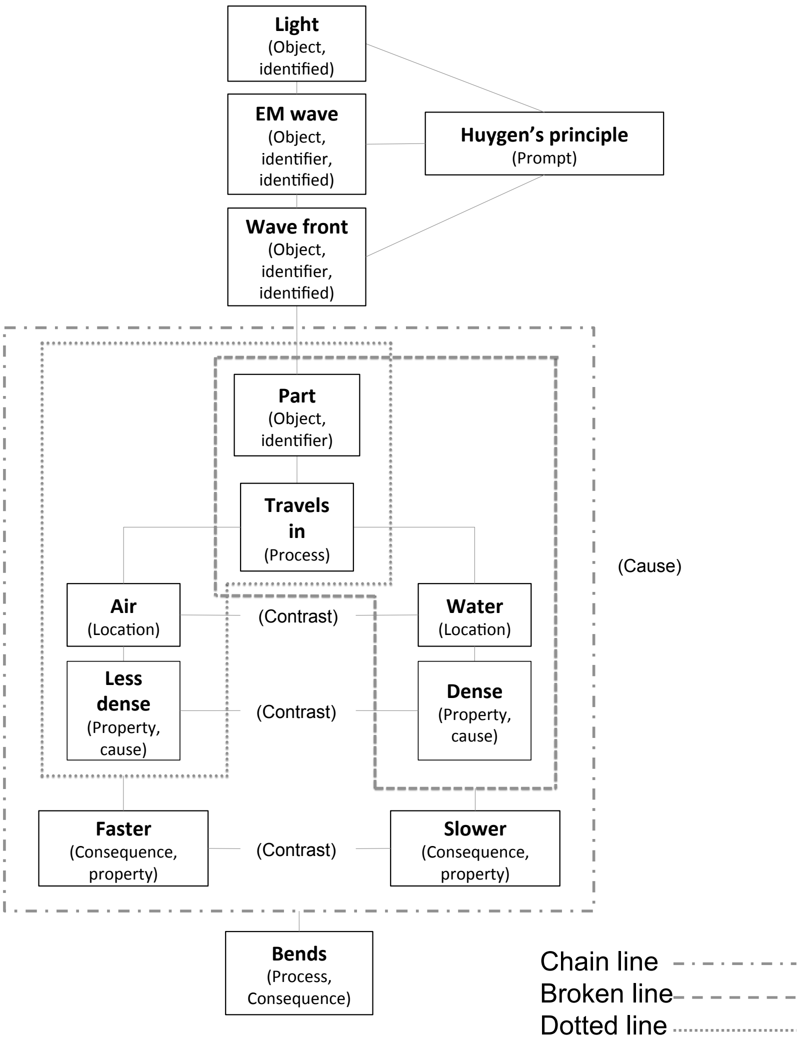

Figure 4.7. My augmented thematic pattern for the whole extract of the students' discussion (cf. Tables 4.1-4.3), after the speed of light has been identified as a critical aspect for the refraction of light. The chain line encapsulates the cause of refraction, as it appeared in the students' explanation. The broken and dotted lines encapsulate the physics meanings that were contrasted in the discussion (cf. Paper II).

The thematic patterns show the relationships between the different thematic items that were abstracted from the students' discussion. The comparison between Figure 4.5 and Figure 4.7 shows the effect that the introduction of wavefronts had on the discussion – it enabled the students to become aware of the significance of the aspect of the speed of light for the development of their explanation (and eventually enabled them to agree on having provided an appropriate explanation).

My analysis shows that the persistent semiotic resources (the ray diagram, the wavefront diagram, and the mathematical notation) and the non-persistent semiotic resources (spoken language and gestures) that the students used realise different aspects of the thematic pattern.

At this stage I need to point out that the characterisation of the different items in the thematic patterns above does not strictly follow SFL terminology. The reasons for this were discussed in Section 3.4.4.1.

4.6 Results of the analysis

The three different *final* thematic patterns in Figures 4.5-4.7 together make it possible to show the effect that the introduction of wavefronts had on the progression of the student discussion. The augmented thematic pattern in Figure 4.7 brings together my whole analysis of the student discussion as the final result of my analysis. In essence, this thematic pattern constitutes the answer to the "characterisation of disciplinary knowledge" aspect of my overarching research question[53]:

In what way can social semiotic theory be instrumental in the characterisation of disciplinary knowledge as it is realised in interactive engagement in an undergraduate physics setting?

From my analysis, I see *my* thematic patterns as having two important attributes:

1. as an analytic tool; the final augmented thematic pattern given in Figure 4.7 is an analytical abstraction of 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 thematic pattern is, in certain respects, characteristic of the disciplinary knowledge that needs to be realised through the production of semiotic resources in order to constitute an explanation at an undergraduate physics level of why the refraction of light takes place.

In summary, a social semiotic perspective provides a theoretical framework that facilitates a deep linguistic analysis of the physics content as it is realised in a physics discussion. As an analytic tool *my* thematic patterns provide a graphical synoptic overview of the different aspects of the text that is dynamically produced. Here, the content is also realised in different ways through the production of different semiotic resources, which enact different

[53] At the same time this answer gives rise to new questions, which I intend to address in future research (see Chapter 8).

aspects of the thematic pattern according to their different disciplinary affordances.

In my discussion in Chapter 6 I show how the constructs of disciplinary affordance and persistent and non-persistent semiotic resources can become useful in discussing the teaching and learning implications of my research.

4.7 Final comments

It should finally be noted that after the particular extract of the discussion presented above, each of the students went up to the blackboard and drew, pointed, and described with words, in detail, how the wave could change direction as it changed speed in passing from one medium to another. This did "not affect the thematic pattern […] but rather served to confirm and cement the relationships between the physics concepts that had already been fruitfully established" (Paper II, p. 663).

After all of this, Vera continued to pursue a viable explanation of refraction by questioning the 'spread-out' nature of light, and how refraction of light could be described if light was seen as a point particle. However, the other students did not take this up.

In the next chapter I present a summary of my generative questions and their answers.

5 Generative research question outcomes

5.1 Introduction

In this chapter I summarise my answers to the generative research questions presented in Section 3.2. The process that led to the formulation and answering of these questions is described in Section 4.2.

5.2 Answers to the generative research questions

1. What roles do semiotic resources play in disciplinary meaning-making during interactive engagement in a university physics setting?

For my purposes, the distinction between the persistent and non-persistent nature of semiotic resources was found to be educationally important. The analysis indicates that in interactive engagement *persistent* semiotic resources radically affect the meaning-making by serving as the central hub around which non-persistent semiotic resources get coordinated. In this respect, persistent semiotic resources both constrain and enable the possible meanings that can be made. Non-persistent semiotic resources play a more provisional role. In other words, they are used to negotiate meanings before they are realised in a persistent form. Once such meaning has been realised in a persistent form, non-persistent semiotic resources are then 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.

2. In relation to the *choices of persistent semiotic resources*:

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

In the data that I have presented the students produced a ray diagram, a wavefront diagram, a drawing of wheels that turn and mathematical notation on the blackboard. They also used a glass tank of water, and a washing-up brush (as an exemplar linear object that could be immersed in the water). The students also attempted to use a laser pointer, and added milk to the water to try and make the laser visible.

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

The two most central persistent semiotic resources produced by the students facilitating their agreement on having produced an appropriate explanation for the refraction of light were the ray diagram and the wave front diagram. These were found to have different disciplinary affordances. The ray diagram was found to afford access to the direction of propagation of light and the various angles of refraction. However, the ray diagram did not afford the students access to the (changing) speed of light. The wavefront diagram 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.

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

Ray diagram

A ray diagram is a geometric, spatial, illustration of the direction of propagation of light in relation to the surface between two different media. The ray diagram is specialised in showing this direction. The different media involved would have to be named and labelled through the use of other semiotic resources (such as spoken and written language, pointing gestures, etc.). This possibility is provided by the ray diagram. Furthermore, it is possible to insert different angles and other constructs such as the *normal to the surface* in the ray diagram. However, there are no aspects of the ray diagram that can afford access to the speed of light.

Wavefront diagram

Wavefronts in a wavefront diagram are perpendicular to the direction of propagation of light. An analogical relationship (proportionality) can be seen between the distance between the wavefronts and 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 using verbal language.

Mathematical notation
Mathematical notation is formal and leaves less room for alternative interpretations and ambiguity. Mathematics is specialized in making quantitative meaning (cf. Lemke's 1999, "topological" meaning). In the case of refraction, mathematics gives access to the relationships between the physical variables and provides the possibility to calculate their values – what Duval (2008) terms treatment.

Equipment
The glass tank of water and the washing-up brush provide an illustration of the "real" situation, which is in turn represented in the ray diagram and the wavefront diagram. There is nothing in the glass tank, the water or the straight object that illustrates the actual light path, the speed of light, or wavefronts. Instead, its main affordance is to illustrate the observable effect that the change in speed of light has on the apparent position of objects that are immersed in water.

Note
For each of the persistent semiotic resources used by the students there are conventions governing how they should be interpreted (cf. grammar). These conventions have an immense impact on the disciplinary affordances of the semiotic resources. Becoming aware of these conventions is an integrated part of becoming fluent in the use of the particular semiotic resource at hand. Thus it is not necessarily particular features of the semiotic resource *per se* that provide the disciplinary affordance of a semiotic resource, but rather these features together with the conventions that have been established for their interpretation.

2.4 To what extent can a particular persistent semiotic resource present the critical aspects that a student needs to be aware of in order to understand the represented phenomenon in a disciplinary manner?

Generally, a single semiotic resource can only present a subset of the critical aspects of a physical phenomenon. Different semiotic resources have different disciplinary affordances. For different persistent semiotic resources, this means that they provide access to different aspects of disciplinary knowledge. In other words, different semiotic resources are useful to different extents for the realisation and/or enactment of certain thematic patterns. Semiotic resources reciprocally contextualise each other. Moreover, the disciplinary affordances of each semiotic resource can depend on the context in which the semiotic resource is used.

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

There is some evidence that the extent to which students perceive different semiotic resources to be relevant and useful for providing access to disciplinary knowledge in interactive engagement can be related to the frequency of use of these semiotic resources in teaching and learning contexts such as lectures, tutorials and physics textbooks.

3. In what way can the semiotic resources chosen to explain scientific phenomena be related to scientific literacy?

Airey (2009) has claimed that students become scientifically literate with respect to a given physical phenomenon through repetition. Airey and Linder (2009) go on to argue that this repetition is needed to in order to become fluent in a critical constellation of semiotic resources. They then equate scientific literacy with this fluency (cf. Airey & Linder, 2011). In this thesis there is evidence for a further complementary aspect of scientific literacy, namely that students also need to know which persistent semiotic resource has the appropriate disciplinary affordances for solving the problem at hand. Thus it is not enough to be fluent in a set of semiotic resources – some knowledge about which persistent semiotic resources are called for in a given situation is also essential component of scientific literacy.

6 Discussion

6.1 Introduction

In this chapter I take the discussion of my analysis (presented in Chapter 4) further in order to provide a richer background for my discussion about the potential implications of my work for the teaching and learning of physics. This also builds on the outcome summary of the generative research questions given in Chapter 5.

6.2 Observations about my *final* thematic patterns

The interplay between the generative research questions and the analysis presented in Chapter 4 culminated in the development of my overarching research question and my final thematic patterns. In this thesis I have illustrated how my final thematic patterns can be used as an *analytical research tool* that makes the meaning that is enacted in a particular piece of text analytically visible. Looking back on my analysis I can also see an anatomy of *disciplinary knowledge itself* that can be characterised as an aggregated, and possibly nested, series of thematic patterns. Seeing disciplinary knowledge in this way facilitates a characterisation of disciplinary learning in terms of an enactment of such a series of thematic patterns.

6.3 The role of persistent and non-persistent semiotic resources in realising a thematic pattern

In this section I discuss how my final augmented thematic pattern in Figure 4.7 was realised (in the sense of being 'enacted'; cf. Section 2.3.3.1) in the student discussion. (For convenience, this thematic pattern is replicated in Figure 6.1.) Importantly, the difference between the role that persistent and non-persistent[54] semiotic resources play in the realisation of the thematic pattern is made clear.

[54] I want to remind the reader that by persistent semiotic resources I mean those that do not 'vanish' immediately after they have been produced, but 'remain' in the 'medium' in which they were produced. Examples of persistent semiotic resources include drawings, sketches,

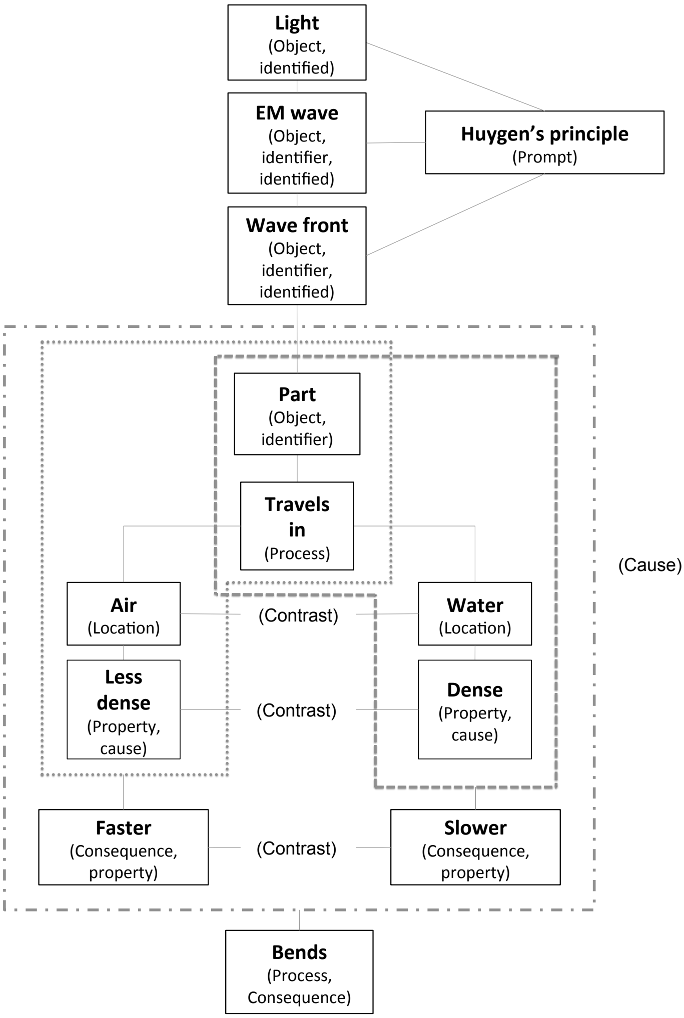

Figure 6.1. A replication of the thematic pattern presented in Figure 4.7; reproduced here for reference purposes.

Consider the items taken from Figure 6.1 that make up Figure 6.2. Here we can see how the realisation of the grammatical *participant* light (here labelled "object") is achieved metaphorically in the form of a ray of light in the ray diagram (a persistent semiotic resource). From an analytic point of view, this can be seen to occur through a (conventionalised) translation or "transduction" (cf. Kress & Van Leeuwen, 2006, p. 39) from spoken

graphs and written language. In my data, the ray diagram is an example of a persistent semiotic resource. Non-persistent semiotic resources, on the other hand, are those that do 'disappear quickly', such as gestures or spoken language (cf. Section 2.3.10).

language (“the light”; non-persistent semiotic resource) to a diagram (persistent semiotic resource). Similarly, the grammatical *process* “bends” is realised through the geometric difference in the directions of the drawn ray of light.

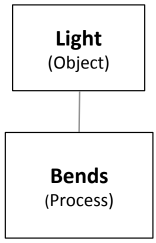

Figure 6.2. A section of the thematic pattern in Figure 6.1, showing the essential observation about refraction that the students were trying to describe and explain, namely why ‘light bends’. (For the analysis see Chapter 4.)

Interestingly, the ray diagram can be seen as a synoptic (time *in*-dependent; see Section 2.3.7.1) description of the (dynamic; time dependent) *process* “bends” – a process that in my data is traced out by a piece of chalk as the ray in the ray diagram is drawn. The ray diagram itself only shows a persistent trace of the process-nature of bending.

The interpretation of a ray diagram may be seen to be unproblematic and taken for granted for someone who is already familiar with the conventional discipline-specific interpretation. A number of possible alternative interpretations of the ray diagram could be posited, for example, that the light ray ‘has a bend’, in which case the process that light undergoes would be interchanged for a property of the ray itself. I will further discuss different conventions of interpretation of discipline specific semiotic resources in Section 6.6.3.

The ways that the bending of light is realised through the use of different semiotic resources include some redundancy. By this I mean that the different semiotic resources, to some extent, independently realise the same meaning. In the case of the refraction of light, the same (grammatical) *process* that is realised by the ray diagram is also realised by, for example, mathematical notation.

While I see the different semiotic resources being both to some extent redundant, they are in important respects dependent on each other, and different semiotic resources play crucially different roles in the realisation of disciplinary meaning. For example, as shown in Figure 6.3, the question “[W]hy is this [angle] smaller and not bigger” (cf. Transcript-line 9 in Table 4.1) posed through the use of (non-persistent) spoken language is clarified by referencing the (persistent) mathematics ($\theta_1 < \theta_2$). The mathematical notation is, in turn, dependent on the possibility to juxtapose or embed the quantities that it potentially realises (that is, the symbols denoting the angles) in the geometric and spatial ray diagram, thus essentially eliminating any ambiguity about *which* angle is quantified by *which* symbol. The meaning that is made through a given non-persistent semiotic resource, then, may be dependent on referencing one or more persistent semiotic resources. Here, gestures can fill a complementary role. For example, the intended referent[55] of the spoken "this [angle]" (cf. Transcript-line 9 in Table 4.1) was made explicit by the simultaneous pointing gesture at the mathematical notation, (which in turn, as mentioned above, is made unambiguous by its location in the ray diagram). The dynamic analysis in Figure 4.3 shows several examples of how different semiotic resources can be used to reference each other.

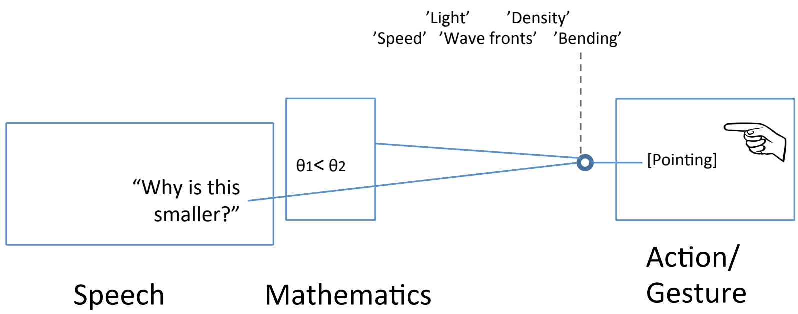

Figure 6.3. A piece of the dynamic analysis from Figure 4.3 showing how "Bends" is realised in the student discussion. The three different boxes show (non-persistent) speech, the (persistent) mathematical inequality, and the (non-persistent) pointing gesture (the image of a pointing finger is added here for clarification purposes).

I now turn to the roles that the non-persistent semiotic resources play. My analysis suggests that non-persistent semiotic resources fill two important functions:

1. non-persistent semiotic resources are used to negotiate, in the sense that they act as a precursor to, the production of persistent semiotic resources. For example, before the drawing of the wavefront diagram, which is a far less often used refraction of light representation than the ray diagram (Hüttebräuker, 2010), negotiation was needed and this was undertaken through the use of non-persistent spoken language and gestures contextualised by the (persistent) ray diagram; and,
2. non-persistent semiotic resources can be used to either:

a) reinforce or disambiguate the meanings that have already been realised in a persistent semiotic resource (this is what happened in my data just after the wavefront diagram in Figure 4.2 was drawn,

[55] By "referent" I mean what is referred to or referenced.

when each of the students used the wavefront diagram to provide an explanation of refraction using gestures and speech); or to,

b) re-negotiate the meanings that have already been made (for example, the correction that takes place from “faster” to “slower” when the speed of light is first brought up in the discussion in Transcription-lines 22-23 in Table 4.3 (see Section 6.4 for further discussion of this correction).

In spite of what I suggested in point [1] above, during the student discussion the ray diagram was drawn without much negotiation, I interpret this to be a consequence of the ray diagram being one of the most commonly occurring semiotic resources in university physics textbooks (cf. Hüttebräuker, 2010; see Section 6.7). There appears to have been no perceived need by the participating students to explicitly discuss *what* the ray diagram represents nor *why* it could be useful in the given situation that they were discussing – in other words, the ray diagram was ‘privileged’ in this respect.

This underscores the possibility that for the representation of the scientific knowledge that is at stake here, the semiotic resources that are more *frequently encountered* in physics textbooks or other educational texts (including lectures etc.) are more likely to be regarded to be apt by students. The less often used semiotic resources, such as the wavefront diagram, would be more likely to be deemed as a less apt choice for a student, and would thus require more negotiation before it gets used.

For my research, the description of what students (or teachers) do with the semiotic resources that they choose to use in meaning-making, is closely related to how they work with disciplinary knowledge. However, my theoretical framework shows that much of the disciplinary knowledge is ‘packed’ (cf. Section 2.5.2) in the metaphors that are used in physics. Following from my theoretical perspective, which sees (especially iconic) semiotic resources to be special cases of metaphor, the disciplinary knowledge can be seen to be ‘packed’ in different ways in different semiotic resources. The ‘unpacking’ that would then be necessary for learning to become possible can be accomplished by the use of sets of semiotic resources, and different semiotic resources, in different ways. For example, as has been pointed out by other researchers (see, for example, Kress, 2010; and Roth & McGinn, 1998), non-persistent semiotic resources are more provisional and are in a sense coordinated around persistent semiotic resources, which play the role of a central ‘hub’. An example of this is presented by Woolgar (1988, pp. 174-175), who described researchers investigating “structural changes” in “amorphous alloys” using a “pen chart recorder”, and noted that “talk takes place over and around the pen chart recorder.” However, the case I am making is centred on the disciplinary knowledge that becomes possible to share with particular (sets of) semiotic resources. This is in contrast to arguing for how the semiotic resources are used *per se*. Thus, I am suggesting that the negotiation of exactly which semiotic resources are *appropriate* for propagating further discussion is important. This is because an appropriate choice of semiotic resources facilitates efficient and fruitful discussions to get constituted; access to disciplinary knowledge to be provided; and, the thematic patterns that govern the disciplinary knowledge to be realised with limited ambiguity.

In the next section I will discuss an aspect of the realisation of a thematic pattern that emerged during the analysis, I refer to this aspect as symmetry.

6.4 Symmetries in realisation of thematic patterns

In the thematic pattern in Figure 6.1 three different contrast-pairs can be identified. Each of these denotes one aspect of refraction: *Air (medium 1) – Water (medium 2)*; *Less dense – Dense*; and, *Faster – Slower*. The items to the left in each contrast-pair of the thematic pattern in Figure 6.1 are all related and co-variant: *Less dense* is a property of *Air* (in contrast to the density of water), and *Faster* is a property of the propagation of light that travels in air (in contrast to the propagation of light in water). Likewise, the items to the right in the thematic pattern in Figure 6.1 are related to each other in a congruous way. The realisation of this thematic pattern also has to align with this left and right division of the different relative values of the different contrast-pairs. Thus, for example, a wavefront (which was eventually identified with light in my data) would have to go faster when it is in air, and slower when it is in water. Consequently, the light would have to start going *faster* when it crosses the water-air boundary from water to air, and would start going *slower* when it crosses from air to water. In other words, the *direction* of propagation of light and the properties of the different media determine whether *faster* or *slower* is the appropriate term to characterise the change in the speed of light in the transition between the two media. In the ray diagram in Figure 4.1 an eye was drawn by the students to indicate that the light would be propagating towards it. However, the direction was taken for granted to be towards the eye from below the water (this was the direction that the ray was originally drawn; see the Swedish transcript in Appendix A for more detail).

In Transcript-line 22 in Table 4.3 Mike states that light travels *faster* as it crosses the air-water boundary. He is immediately corrected by Vera, and draws the conclusion that “it’s denser which means it’s going slower there”. It is interesting to speculate whether Mike originally intended to mean that light travels faster as it crosses the air-water boundary from the water to the air. However, the gesture he simultaneously made indicates differently, since it was a waving gesture moving downward from above. Whatever the case, he quickly clarified his explanation by making the connection between slower and denser, although the motivation behind this connection was never explicitly presented.

The point I want to make with this part of my discussion is how the realisation of the thematic pattern followed the symmetries that I am now proposing exist within that thematic pattern. As a generalisation of this outcome I propose that if one aspect of the thematic pattern gets changed, such as the chronological order between air and water in the above example, other related quantities and qualities will need to be changed accordingly. So, there is the possibility that what was interpreted as the *incorrect* comparative value in a contrast-pair ("faster" instead of "slower"), arose from some kind of 'miscommunication' of the taken for granted order of a *different* contrast-pair (such as the direction of propagation – which is manifested in my analysis by a reading of the thematic pattern from left to right or from right to left). It may well be the case in physics classroom situations that teachers and students occasionally get to 'miscommunicate' in this way because the contextualisation is not explicit, but taken for granted.

An implication for the teaching and learning of physics of this "lack of common ground" (Tsui, 2004, p. 165) could be that a student could be deemed by a teacher to be proposing an incorrect answer whilst the student is, in fact, putting forward a reasonable answer. This could have detrimental interpersonal and emotional consequences for the student. Another implication could be that a student may have become aware of an aspect (maybe even a *critical* aspect) of a phenomenon (such as speed for the refraction of light), but that student's realisation of this aspect may be rejected if the student does not proceed to mention the expected relative value (such as the "faster" instead of "slower" in my data). In a given physics situation it could be the case that from a teacher's or peer's point of view, it is easier to notice whether an appropriate value is mentioned (where by value I mean, for example, faster or slower), than to notice a student's identification of the critical aspect itself (cf. 'the speed of light').

I further suggest that my discussion here can be seen as a corollary to what Airey and Linder (2009) describe as "discursive fluency without a corresponding experience of the associated facets of a disciplinary way of knowing" (p. 38), by which they mean that students can be interpreted as being correct when they have still a way to go before they have fully achieved an appropriate and holistic understanding. In contrast to this, I claim that students can also be interpreted as being *incorrect* when they are, in fact, expressing their increasing awareness of important aspects of physics phenomena.

6.5 The use of semiotic resources in descriptive and explanatory phases of the discussion in my data

In this section I describe the differences between the semiotic resources that were initially used in the student discussion and those that were later used.

The first part of the student discussion about refraction can be characterised as descriptive (in the sense that it is illustrative). Later, in the section of the discussion that I extracted for my deep analysis, the discussion had a more explanatory character. Accordingly, the semiotic resources that the students used can be divided into two distinct sets: the descriptive (the what and how of refraction) and the explanatory (the why of refraction). The descriptive semiotic resources were given in Chapter 4 (see Footnote 50, p. 55) and include, for example, a glass tank of water, a washing-up brush immersed in the tank of water, a laser pointer, and milk that was used to try to make the laser visible in the water. These semiotic resources all were intended to illustrate the apparent bending of the object that is a *result* of the refraction of light. When the students drew on the blackboard, still in a descriptive mode, the ray diagram, conventionally used in physics, was used to *describe* the previously illustrated situation (Figure 4.1).

The *explanatory* semiotic resources that were used include the wavefront diagram and the mathematical notation. Analytically, aspects of the descriptive phase illustrations mentioned above can be seen to be transduced (cf. transduction, see Section 6.3) into the explanatory phase semiotic resources, which then provides access to *different* disciplinary knowledge than that provided by the semiotic resources used in the descriptive phase.

Using the notion of disciplinary affordance that I introduced in Paper II (see Section 2.3.9), I discuss the difference in access to disciplinary knowledge provided by different semiotic resources in the next section.

6.6 Disciplinary affordances

6.6.1 Disciplinary affordances of persistent semiotic resources

I now turn to discuss what I earlier outlined as the *disciplinary affordances* of semiotic resources. This discussion will centre on *persistent* semiotic resources, since my analysis shows that the choice of appropriate persistent semiotic resources is particularly important for optimising interactive engagement as a learning resource. For this discussion I will first compare and contrast the ray diagram and the wavefront diagram. After that I will discuss the mathematical notation.

My analysis shows that after the ray diagram was drawn, no reference to it was made in terms of the dynamic process of movement of light. There is, in fact, nothing in the ray diagram that shows any process other than light bending, nor is there anything in the ray diagram that can be metaphorically linked to the speed of light. This is because the ray diagram manifests as a *synoptic* representation of the physical situation. However, as the analysis in the thematic pattern in Figure 6.1 shows, it is the *difference* in the speed of light travelling in different media that is key to the explanation of the refraction of light. In the ray diagram the speed of light could conceivably be added as a quantity juxtaposed with the light ray, similar to the way that symbols are inserted to make possible both the identification and quantification of the angles referred to in the discussion.

In the data that I collected, the students did not, at first, access the speed of light aspect. My analysis suggests that this is a consequence of them deciding to use a ray diagram as a starting point. The suggestion that wavefronts would be an apt semiotic resource for the explanation of refraction eventually brought the speed of light aspect to the fore.

The agreement on the use of wavefronts provided something (a thing or an object) that could move. This 'something', which manifested as a wavefront, constitutes a more specified referent for the grammatical *participant*, light, namely a metaphor which can be seen to suggest its physical shape according to a (well motivated) convention (in an analogical relationship to an everyday experience of waves). In particular, I see the demonstration of the 'speeding up' of light to have been made possible by the introduction of this more specified referent. Such a detailed description of the grammatical *participant*, light, had not been presented before in the student discussion, or at least it had not been agreed upon. Note that an explicit link between wavefronts and light was not made until Transcript-line 28 in Table 4.3. This identification of light with waves is represented by the filled dot in the dynamic analysis in Figure 4.3.

After the wavefront description of light was agreed upon, a wavefront diagram became an integral part of the discussion. In that the wavefront diagram shows a periodic pattern of wavefronts, it explicitly shows 'objects' that can be moving, whereas the ray diagram does not.

The wavefront diagram can be perceived as ambiguous in terms of whether it is the *same* wavefront that is shown at different times (in which case it would be a synoptic representation) or *different* wavefronts at the same instance in time (in which case it would be a time dependent 'snapshot').

The orthogonal distance between two wavefronts in a wavefront diagram is proportional to the speed of light at that particular location. Thus, the possibility to create an analogy between the distance between wavefronts and the speed of light is created. Through this distance between the wavefronts, such a diagram can provide critical access to the speed of light. The contrast between "faster" and "slower" that is shown in Figure 6.4 is realised by, and can be seen analogically in, the difference in the distances between wavefronts on either side of the water surface in the wavefront diagram (see Figure 4.2).

Figure 6.4. A part of the thematic pattern from Figure 6.1 showing the contrasting aspects of "Faster" and "Slower".

It should be noted that there is nothing in the analysed data that indicates that this distance between wavefronts would have had any particular importance for the outcome of this discussion. However, the possibility of becoming aware of this feature of the wavefront diagram exists, whilst the ray diagram does not afford a corresponding possibility. This provides a plausible explanation for why there is a difference in disciplinary affordance between the two diagrams. On the other hand, the wavefront diagram may become 'too crowded' and take what is perceived to be an unnecessarily long time to draw in order to be practically useful for calculations of, for example, the angle of refraction. Here, the ray diagram may be more useful.

Once the wavefronts were agreed upon, the student discussion took important steps towards an appropriate explanation of refraction. This is indicated in my analysis by the addition of the aspect of speed of light (see Figure 6.4) to the thematic pattern Figure 4.5, forming the *final* thematic pattern Figure 6.1. This led the students to what can be called "conceptual convergence" (Oliveira & Sadler, 2008; Roschelle, 1992), that is, a situation where they could agree that they were satisfied with their explanation.

As far as mathematical semiotic resources are concerned, they are generally more formalised and arguably present less room for alternative interpretations and ambiguity. Thinking about the use of mathematical representation in this way offers an explanation for why the students chose not to use these semiotic resources at a stage when their meaning-making was tentative and contingent.

6.6.2 Packing

As Halliday and Matthiessen (1999) have pointed out, much of the "configurational pattern"[56] that governs a scientific text is often hidden or 'packed' (this section is related to the discussion of appresentation in Paper III; see also Sections 2.5.2-2.5.3). For this reason, many important scientific aspects and details are often left out of a particular text: "Usually the configurational pattern will have been built up over long stretches of text, or

[56] That is, the relationships between the processes, participants and circumstances involved in a situation.

(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" (Halliday & Matthiessen, 1999, p. 271). A student's awareness of critical aspects of such a configurational pattern (cf. my thematic patterns) governing particular disciplinary knowledge would also most likely enhance and guide the student's capability to appropriately *represent* disciplinary knowledge. However, the *motivation* for the use of a particular semiotic resource (cf. the disciplinary affordance of the semiotic resource) may not be transparent to all individuals involved in a given discussion (even if this semiotic resource is, in fact, appropriate in the given context). Therefore, different individuals participating in interactive engagement would, at different times, conceivably perceive the usefulness of a semiotic resource in different ways. This may be a contributing factor to the initial disagreement amongst the participating students in my study regarding which semiotic resource to use.

Furthermore, *any* disciplinary text[57] is likely to leave out things that may occasionally be needed in order for a person to become aware of all the important aspects of the configurational pattern that governs that text. In my study, the participating students could thus be expected to leave certain things out – things that were taken for granted, but that may nevertheless be important from a physics learning point of view. For example, the change in the speed of light that was mentioned in Transcript-line 22 in Table 4.3 was something that the students must have met in educational situations prior to the discussion that I recorded because they did not *derive* that conclusion themselves. The leaving out of important aspects can also be seen in the mentioning of "thinner" and "thicker" in Transcript-line 3 in Table 4.1. Note that this description of density contains almost no redundancy in its realisation in the different semiotic resources; and the relationship between density and the speed of light did not go on to be further developed. Furthermore, in the students' discussion, important details and aspects of Huygen's principle were also omitted. Generalising from this observation I suggest that in similar educational discussions, participants would have to bring omitted or not-yet-unpacked aspects in themselves.

In the next section I discuss how the sharing of disciplinary knowledge is dependent on conventions of interpretation of discipline-specific semiotic resources.

6.6.3 Disciplinary conventions of interpretation

Following years of extensive research the grammar of spoken and written language is well known. Kress and van Leeuwen (2006) have attempted to

[57] This is surely true for all texts, but I have emphasized *disciplinary* texts because of Halliday and Matthiessen's argument in the previous paragraph.

extend the notion of grammar, in particular Systemic Functional Grammar, to other semiotic resources, and especially to images. However, almost no research has been done on the grammars of discipline-specific semiotic resources. Due to the enormity of such a task I cannot attempt to engage with it in this thesis. But I can use the discussion of my generative research questions to suggest that for many of the discipline-specific semiotic resources, it may be more useful to talk about a *convention of interpretation*. In other words, the meaning that is realised by a semiotic resource does not always make up an iconic relationship[58] between the materialisation and what it refers to, but may often be governed by a particular *disciplinary convention of interpretation*. (From a physics point of view, this discussion can be seen to be related to how important content aspects get 'left out' in the 'packing' of information in semiotic resources, which was discussed in the previous section.)

For an example of when a convention of interpretation can enable the sharing of disciplinary knowledge despite important information being left out, consider Snell's law ($n_1 \sin\theta_1 = n_2 \sin\theta_2$)[59]. In its classic formalism, $n_1 \sin\theta_1 = n_2 \sin\theta_2$, one of the angles θ is the angle of refraction, and the other is the angle of incidence – both defined by convention as lying between the ray and the normal to the surface. However, the information about where those angles are located in a ray diagram is not given in this formalism of Snell's law, but the information is embedded in the convention of interpretation of the law. (This is another instance that shows that different semiotic resources are needed for different functions).

The context-dependency of the convention of interpretation can be problematized, for example, by considering the set of images in Figure 6.5, all representing a light bulb. Whereas the first two images to the left in Figure 6.5 are schematic symbols (cf. Peirce's use of the term *symbol*, see Section 2.5.3) commonly used in electric circuit diagrams, the next four are more realistic (cf. iconic) depictions of bulbs, which show different amounts of detail. The image to the far right is a photograph of a light bulb with yellow and blue arrows indicating where the two contacts of the light bulb have been soldered, one to the aluminium base (yellow) and the other to the tip of the base (blue), insulated from the first.

58 That is, a relationship of likeness with its object cf. Section 2.5.3.
59 Snell's law was only used towards the end of the student discussion presented in this thesis.

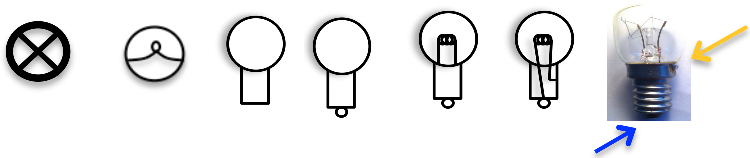

Figure 6.5. A series of different images representing light bulbs. Different conventions for interpretation are appropriate for different images. Yellow and blue arrows point at the different electrical contacts.

The way these images are used to represent a light bulb is often, if not always, taken for granted – without conscious consideration to the convention of interpretation. The information guiding the decision as to which convention of interpretation is appropriate for a given instance is provided by the context of situation as indicated by the semiotic resources at hand (exemplified in this example by the particular image of a light bulb that is used). However, I would argue that it cannot be taken for granted that students know which convention of interpretation is appropriate. I also argue that appropriating such knowledge is an important aspect of becoming fluent in the use of semiotic resources (cf. Airey & Linder, 2009). It thus seems important that students get the opportunity to practice and come to appreciate which disciplinary conventions of interpretation are appropriate in relation to the particular semiotic resources being used – all in relation to the particular context of usage. I argue that this is particularly important in order to avoid students and teachers using conventions arising from non-disciplinary contexts in disciplinary settings (cf. diSessa, 2004). The increasing trend in, for example, social media and the day-to day use of symbols to make up new conventions for communication could also be hindering the generation of un-ambiguous communication if used in a scientific discipline such as physics (see, for example, Figure 6.6).

Figure 6.6. The use of a light bulb symbol indicating that a headlamp of a car is broken (a non-disciplinary context).

To illustrate this further I refer to the McDermott and Shaffer (1992) study where students were asked to draw (sketch) how to make an electric bulb light up, with no other equipment at their disposal than a bulb, a battery and a piece of wire. An example of a student drawing that was given in the report of their study (cf. the image to the far right in Figure 6.7) indicates that if the bulb that was drawn had been interpreted as a symbol in a circuit diagram (cf. the middle image in Figure 6.7), then the problem would have likely been solved correctly. However, if the image were to be interpreted realistically (in the iconic sense, cf. the image to the far left in Figure 6.7), the problem would have likely been solved incorrectly. The ambiguity between a realistic (iconic) and a schematic (symbolic) interpretation of a semiotic resource may, thus, possibly lead to teachers misunderstanding students' text, as well as leading students to misunderstand the teaching text[60]. Mixing conventions of interpretation from different contexts of interpretive cultures (such as everyday life and science) may thus be particularly hazardous in physics education. Generalising from this discussion, it can be seen that there may be aspects of a represented object that are critical from a physics learning point of view, but that are not, in fact, depicted. A student must then be able to bring into awareness these aspects herself (for example, from previous experience with similar situations).

[60] This can be further exemplified with the bulbs depicted in Redish (2003, pp. 40-41) in a similar situation as that referred to in McDermott and Shaffer (1992). Here, students would have to infer critical aspects themselves, such as the filament going from one terminal of the bulb to the other, which was, in fact, not visible in the image presented to the students (cf. bulb 3 from the left in Figure 6.5). This particular critical aspect was exactly the one that a tutorial described in Shaffer and McDermott (1992) was designed to provide the students with an awareness of. In this tutorial students were expected to notice that a conducting wire will get warm when there is a current running through it.

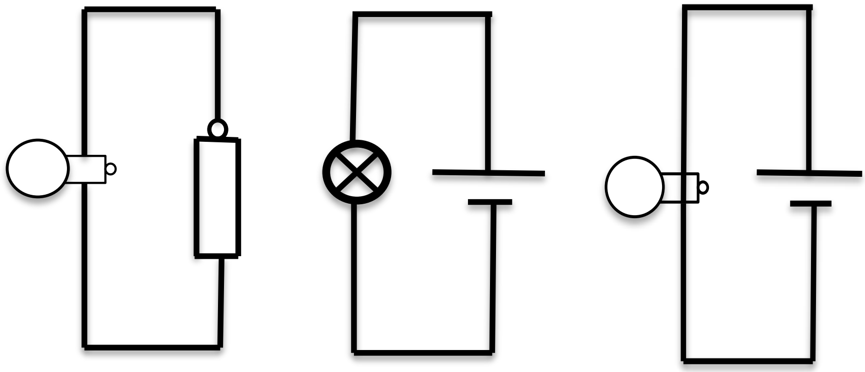

Figure 6.7. Three circuits – the one to the left would *not* light if interpreted realistically, the one in the middle would light if interpreted symbolically, but the one to the far right is ambiguous (based on McDermott & Shaffer, 1992; and Redish, 2003).

6.7 Choosing an appropriate semiotic resource

In this section I discuss how students can choose which persistent semiotic resources to use in interactive engagement. As discussed in Section 6.3 above, the students in my study privileged the ray diagram (the semiotic resource that is more often used in different educational textbooks) before the wavefront diagram (the semiotic resource that has the more appropriate disciplinary affordances for the given situation).

Extrapolating from the cline of instantiation described in the theoretical framework (see Figure 2.4, Section 2.3.4.1) and from my engagement with the data, the privileging of the more often used semiotic resource can depend on the (not necessarily consciously) perceived probability that a particular situation will occur in which this semiotic resource is useful (cf. register, see Section 2.3.4.1). I will discuss this by putting forward one possible explanation by drawing on the SFL notion of a *situation type* (cf. Figure 2.4). Since the situation type is a more general context than the particular context of situation, it is likely that in approaching a new situation that is constituted by and interpreted on the basis of a set of semiotic resources, a person would become aware of the more general situation type before the detailed context of the situation gets fleshed out.

Thus, the immediate awareness of one's repertoire of semiotic resources is likely to be biased by the frequency that different semiotic resources are used in this particular situation type, and thus for the situation that is perceived to be likely to occur [61]. For example, one possible interpretation of the situation that was encountered by the students participating in my study is that they noticed that the situation type had to do with refraction. The most frequently used semiotic resource in dealing with refraction is the ray diagram and consequently, the students chose this route. However, as the discussion started to deal with *why* refraction occurs (as opposed to quantification of the angle of refraction) a different semiotic resource was needed to provide an appropriate explanation (cf. a wavefront diagram). In my analysis it appears as if in the move from a descriptive to an explanatory phase of the situation, critical physics detail (cf. Huygen's principle) had to be pinpointed before the use of the less common wavefront diagram became motivated.

6.8 Implications for scientific literacy

Airey (2009) has argued that students become scientifically literate with respect to a given physical phenomenon through repetition (cf. Footnote 37, p. 36) – what Kuhn (1996, p. 47) called a "process of learning by finger exercise". This repetition, Airey claims, is needed in order to become "fluent in a critical constellation of the different semiotic resources" (Airey & Linder, 2009, p. 28). Airey and Linder (2011) went on to also equate scientific literacy with this fluency. However, as I discuss in Paper IV, there is evidence that such fluency in a constellation of semiotic resources is not sufficient for scientific literacy. For example, in my analysis of the student discussion I found no evidence that the students would have any difficulties with the production of a wavefront diagram. Thus, I argue that the initial choice of the ray diagram and the group's resistance to using the wavefront diagram was not directly a function of their fluency in those semiotic resources. Instead, I claim that it was the interpretation of the situation constituted by some set of semiotic resources, and the judgement about which semiotic resource was appropriate for successfully dealing with the situation, that was problematic (cf. the previous section). Thus, an important aspect of *scientific literacy* appears to be proficiency in judging *which* semiotic resource is appropriate in a given situation. This judging could be achieved through the recognition of situations and situation types based on acquaintance. In more ambiguous situations the engagement in a careful investigation of the situation may be necessary in order to decide whether the situation is more or less typical, that is, students may need to look for which aspects are critical in the thematic patterns that govern the situation at hand.

[61] Note that this will only be the case if the person has had a chance to become acquainted with physics texts to do with the phenomenon or setting at hand, so that the frequency of use of semiotic resources could have been noticed.

Thereafter, students can select semiotic resources that have the necessary disciplinary affordances needed to realise or enact those aspects.

6.9 Further implications for the teaching and learning of physics

The conclusions and conjectures that I make in this thesis have several important implications for the teaching and learning of physics. I now discuss those aspects that I find to be particularly relevant for informing practice that aims to enhance the learning experience.

In physics teaching and learning contexts, access to the physics content can only be provided through semiotic resources. Furthermore, this access can only be enhanced through an appropriate choice of semiotic resources. The access to the disciplinary knowledge that is provided by a particular semiotic resource – within a particular area of physics – constitutes a subset of what I have called the disciplinary affordances of this semiotic resource. An implication of this is that teachers should pay attention to students' skills in interpreting and producing different semiotic resources in given situations. As a teacher it is important to be aware that students may focus on aspects of a situation other than those intended. One way that a teacher can become aware of such a "lack of common ground" (Tsui, 2004, p. 165) is by paying attention to what (sets of) semiotic resources students opt to use in interactive engagement.

A teacher's insightful use of different semiotic resources can extend the "shared space of learning" (cf. Airey, 2006; Tsui, 2004, p. 165) between teacher and students. However, some semiotic resources may be more appropriate than others for a particular purpose in relation to a particular context and a particular object of learning. From an analytical point of view, the role that a semiotic resource plays for dealing with a physics setting, may only be possible to determine through empirical research. Some semiotic resources may be used for contextualisation, referencing and bringing to the fore those aspects with which students are supposedly already familiar. Other semiotic resources may be used to modulate aspects that are already known to students, and others still may help students become aware of new aspects of physical phenomena. Which semiotic resources fill which functions may vary from one physics setting to another, and this in turn will be a function of the disciplinary affordances of these semiotic resources. Thus it is important for teachers as well as for students to enhance their awareness about what semiotic resources have what particular disciplinary affordances. For teachers, it is especially important to continually attempt to find out which disciplinary affordances the students appreciate at any given time, and which they do not.

Another important implication is that teachers should help students in establishing a shared 'baseline' or common ground by providing opportunities for them to produce persistent semiotic resources, so that they can make their interactive engagement more meaningful. Here, there is a risk that "the persistent [semiotic resource] initially chosen by students to stand fast may depend more on its frequency of use rather than its disciplinary affordances for the task at hand" (Paper II, p. 665). Hence, I suggest that creating situations where students are expected to produce persistent semiotic resources to interactively engage around has the distinct potential to contribute in a meaningful way to the development of their appreciation of the disciplinary affordances of semiotic resources. This would, I suggest, enhance their proficiency in selecting appropriate persistent semiotic resources for the task at hand. I intend to investigate this suggestion as part of my future research.

6.10 Concluding remarks

In Chapter 1 I drew attention to two perspectives on learning that have underpinned the work that I have done for this Licentiate thesis, namely a characterisation of learning in terms of becoming "*fluent* in a critical constellation" of semiotic resources (Airey & Linder, 2009, p. 33), and seeing learning as "a change in someone's capability for experiencing something in certain ways" (Marton & Booth, 1997, p. 208). In this chapter I have discussed such "capability for experiencing" a physical phenomenon in a certain way in terms of the awareness of the different aspects of the physical phenomenon that are represented in the thematic pattern that governs it (exemplified by refraction and the thematic pattern in Figure 5.1). I have also discussed how different semiotic resources provide different access to the disciplinary knowledge of a physical phenomenon. I went on to relate this to how fluency in a "critical constellation" of those semiotic resources that provide access to the aspects of the thematic pattern that governs a physical phenomenon therefore is critical for deep holistic learning.

My theoretical framework – social semiotics – has opened up new ways of discussing questions regarding the sharing and agreeing on what the educationally critical aspects of phenomena are and how these may be best represented. That is, how these aspects are accessed through the disciplinary affordances of different semiotic resources. The implications that this work has for my future research plans are presented in Chapter 8.

7 Contributions to PER

7.1 Introduction

In this chapter I present the empirical, methodological and theoretical contributions that I see my Licentiate work making to the broader field of Physics Education Research.

7.2 Empirical contributions

The empirical contributions that I see are:

- that, through an extensive set of interactive data engagements I have worked with Jay Lemke's original thematic pattern design to create a new formulation of thematic patterns that exemplifies how such thematic patterns can be realised through the use of a range semiotic resources, including, but not limited to, language; and,
- that I have exemplified how the disciplinary affordance of a semiotic resource provides access to disciplinary knowledge.

7.3 Methodological contributions

The methodological contributions that I see are:

- I have developed ways to constitute and present both dynamic and synoptic analyses of the multimodal character of interactive engagement. I have shown that when dynamic and synoptic analyses are carried out simultaneously, then they have the distinct potential to pinpoint critical moments in interactive engagement from a physics (content) learning point of view, and can, at the same time, say something about the disciplinary affordances of the semiotic resources used;
- I have exemplified how multimodal transcription of interactive engagement in physics can be achieved and presented in an analytically meaningful way;
- I have developed and demonstrated a fruitful analytical approach, where disciplinary knowledge can be formulated in terms of thematic patterns; and,

- I have adapted Lemke's original model of thematic patterns to generate an enhanced research tool that crystallises the crafting of a geometric layout in a way that dramatically increases their 'user friendliness'.

7.4 Theoretical contributions

The theoretical contributions that I see are:

- I have created a construct that I call disciplinary affordance in order to denote those aspects of thematic patterns that certain semiotic resources are particularly apt to represent;
- I have made a compelling argument that an important aspect of achieving scientific literacy should be to become proficient in making decisions regarding which semiotic resources have the appropriate disciplinary affordances for a given setting/situation;
- I have demonstrated the fruitfulness of systemic functional linguistics (SFL) constructs and concepts for discussing many of the aspects pertaining to scientific text that could present learning challenges for students: dynamic and synoptic perspectives on text; realisation; rank and rankshift; nominalisation, technicalisation and grammatical metaphor; meaning potential; and, unpacking;
- I have suggested that students' initial choice of which semiotic resource to use is a function of its frequency of use in educational settings;
- I have theorised that many important aspects of physics knowledge are not afforded by many of the semiotic resources that are typically used in much of the teaching of physics. Students therefore need to become proficient in filling in those gaps themselves; and,
- I have made the case that the distinction between persistent and non-persistent semiotic resources in relation to their roles in disciplinary meaning-making is important for teachers to know about – this in agreement with research reported by other scholars. In particular, I suggest that more attention should be paid to the persistent semiotic resources that are required in interactive engagement in physics education contexts.

8 Future work

8.1 Introduction

In this chapter I discuss my future plans for continuing on my research journey exploring *in what way social semiotic theory can be instrumental in the characterisation of disciplinary knowledge as it is realised in interactive engagement in an undergraduate physics setting?*

In Section 8.2 I deal mainly with the theoretical grounding for this future research and in Section 8.3 I list some potential research questions that I, at this time, see as being useful steps in this journey.

8.2 Future research areas

In the introductory Section 1.1 I referred to two perspectives on learning – "a change in someone's capability for experiencing something in certain ways" (Marton & Booth, 1997, p. 208) and, becoming "*fluent* in a critical constellation of modes" (Airey & Linder, 2009, p. 33). In the thesis I have shown how the multimodal enactment of disciplinary knowledge can be abstracted[62] to a thematic pattern. (From a text analysis point of view such an enactment *realises* the thematic pattern, enabled by the disciplinary affordances of the different semiotic resources used.)

In different physics settings different thematic patterns may need to be enacted in order to come to understand given parts of disciplinary knowledge. For example, if the problem of explaining why the refraction of light occurs gets replaced by a problem involving the calculation of the angle of refraction, or by a problem regarding what happens when sound is refracted, (either) a different thematic pattern may be needed and/or a different set of semiotic resources may be more appropriate for its realisation. I am therefore beginning to see different thematic patterns as being interrelated and themselves forming patterns in a nested fashion.

For part of my future work I plan to explore how disciplinary knowledge can be mapped onto a set of closely related thematic patterns. Following this intention, disciplinary learning could then be problematised as becoming

[62] What I mean by abstract here is the analytic lifting out of the semantic structure from its concrete realisation.

familiar with the disciplinary 'landscape' that is governed by these thematic patterns and constituted by the different semiotic resources that are used to realise them. An important aspect of students' familiarisation with these thematic patterns could then be described as becoming proficient in enacting those patterns through their use of semiotic resources. I suggest a powerful way to practice the enactment of thematic patterns can be the sharing and negotiation of disciplinary knowledge in interactive engagement, which PER has shown has the potential to enhance students' learning. As part of my future research I intend to explore interactive engagement as a function of the enactment of thematic patterns vis-à-vis student learning.

An important follow-up question becomes how a teacher can design interactive engagement opportunities aimed at optimising learning through the enactment of critical aspects of thematic patterns. I am suggesting that an important step in answering that question would be to analyse problems that teachers can ask students to work with in interactive engagement groups. The analysis should focus on showing what thematic patterns (and parts thereof) would need to be enacted in order for these problems to be solved effectively. This could be extended to an analysis of textbook problems or problems given on examinations to show which thematic patterns are needed for solving those problems. In my future research I intend to analyse a number of tutorial problems in order to determine which thematic patterns would need to be (repeatedly) enacted in order to solve those problems.

Students also need to learn to constitute and recognise appropriate contexts of situation through their production and interpretation of semiotic resources. These contexts could then be used to enhance learning by bringing educationally critical aspects the fore and leaving other less important things in the background. Such learning cannot be achieved by passive consumption of presented knowledge, but must be repeatedly practiced. In this practicing (cf. what Kuhn, 1996, p. 47, calls "finger exercises") fluency in different semiotic resources, then, is a necessary precondition for the work that students need to do in order to become able to experience science content and its associated practices in a disciplinary way. Another part of my future work will involve an investigation of the extent to which students use their fluency in semiotic resources to contextualise physics problems in appropriate ways.

In this Licentiate thesis I have drawn on linguistic research that has shown how written and spoken physics text is often highly "packed" through the linguistic processes of grammatical metaphor and rankshift (Halliday & Matthiessen, 1999, p. 256). I conjecture that in the learning process students need to unpack the rank-shifted and/or nominalised physics content to a more "congruent form" (Halliday, 1998), that is, to a form that does not contain so many nominalisations or other grammatical metaphors. I go on to suggest that different semiotic resources participate in, and catalyse, this process of unpacking. Although SFL does not consider "upward rankshift" (cf. Footnote 16 on p. 25), I suggest that the unpacking to a more congruent form can fruitfully be characterised in terms of *reverse rankshift*. Such reverse rankshift would make the grammatically congruent and more detailed process-, participant- and circumstance-nature of different aspects of physics concepts and phenomena, which would otherwise be packed in highly technical language, available for analysis. The unpacking and re-semiotisation (cf. Iedema, 2003) of physics text for educational purposes could also make it possible for students to notice how different physics aspects are realised through the use of different semiotic resources. Importantly and consequentially, reverse rankshift could also make science text not only available in a form that is easier to analyse, but could also enable students to become aware of the thematic patterns that characterise disciplinary knowledge. Thus, a further part of my future research will include exploring to what extent the process of reverse rankshift helps to make learning possible in interactive engagement settings.

The notion of disciplinary affordance has been an integral part of this thesis. However, in my future work an interesting question that I also want to explore is whether disciplinary affordance should be subdivided into two or more parts. Here I am considering, for example, one part that would provide access to disciplinary knowledge for those who work in the discipline, in other words, a kind of *work affordance*. And if such work affordance exists, is there a different part of disciplinary affordance that deals foremost with the learning of the discipline – a *learning affordance*? And is there an overlap between the two types of disciplinary affordance? Furthermore, what are the potential consequences for teaching and learning of such a categorisation of disciplinary affordance?

In the next section I list some possible research questions that I, at this time, see as being useful contributions to the further answering of my overarching research question.

8.3 Potential research questions

In this section I list a number of potential research questions that at this stage I think could be interesting to pursue as part of my future research.

- What are the educationally critical aspects of a given set of “objects of learning” (Marton & Tsui, 2004) in physics?
    - How are these critical aspects realised by the use of different semiotic resources?
    - How do students become aware of these critical aspects through the use of semiotic resources?
    - Which semiotic resources are best suited to realise which aspects of physical phenomena – and which semiotic resources have the appropriate disciplinary affordances?

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Appendix A

Uppgift 1:
En dag följer en av era kompisar, som inte har läst fysik sedan högstadiet, med till fysiklabbet. Han passar på att fråga om en sak han funderat på. 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. Hur skulle du, från ett fysikperspektiv, hjälpa honom att få en någorlunda helhetlig förståelse av fysiken i situationen? Diskutera gärna.

English translation: Task 1
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.

Uppgift 2:
Den andra uppgiften var en upprepning av Uppgift 1, men den här gången var 'kompisen' en medstudent som bad om hjälp att få en någorlunda helhetlig bild av situationen.

English translation: Task 2
The second task was a repeat of Task 1, except this time 'the friend' was said to be a peer student asking for help to get a reasonably holistic understanding of the physics in the situation.

Transcript

R:Researcher
V:Vera
M:Mike
N:Nick

Uppgift 1 (Task 1)

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 [lärares namn] 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, näej 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 sä 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 siktlinjen 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 Ä, jag vet inte, nä 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 rökmaskin
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 Böjer sig ned tittar snett från sidan
N Det är roligt när man, det här är kul,	M =1 Böjer sig ned tittar lite mer rakt från sidan, N =1 Tittar rakt från sidan M =2 Reser sig upp
om man tittar så här från sidan,(=1) sen så går man dit,(=2) då är den avskuren så här	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 lite snett uppåt och nedåt med höger hand
M =1 aa, =2 aa	
N Att det är, eeh,	M Tittar på N M Tittar på skålen M Böjer sig ned och tittar rakt från sidan N Reser sig upp
M Vill du ha skruven åt andra hållet eller vad =då	
N =Nej, att den, att den är diskontinuerlig	N Visar med händerna, rör den ena handen snett upp från den andra med pekfingret mot den andra M Reser sig upp
M Mm	
	V Kommer in i bilden
V Funkar det	
M Ja, om du =står så här	M Tittar hela tiden ner i vattnet
V =Får man titta från sidan	V Böjer sig ned och tittar rakt från sidan,

M Nej, om du står här	V = Reser sig M = Pekar snabbt mot vattnet
V Aa	V =1 Går mot M och tittar på vattnet, ställer sig och tittar bredvid M
M Då ser man att den inte är rak	N =1 Går mot tavlan,
	N =1 Kommer tillbaka och ställer sig och tittar på vattnet
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'	M Drar sakta upp "pinnen" (diskborsten) ur vattnet, N Läser i uppgiften som ligger på bordet bredvid skålen
N Att att han inte kunde peka på den där han trodde att han skulle göra, om man om man är om man står	M Skakar till "pinnen"
här och tittar och ska peka peta på den med pinnen här	N Pekar på diskborsten och på Ms hand
N Sen så så när man stoppar ner pinnen i vattnet så så blir det fel.	M Sticker ner "pinnen" i vattnet igen
V Okej, ja, man ser ju att den böjer sej så då ändrar man ju vart man tror att man ska peka	N Backar mer åt höger
M = Ja	M drar upp "pinnen" 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 uppgiften på
	N Går närmare V och tittar på papperet, tittar ner i vattnet,
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	N Går mot tavlan, går iväg
inte gick att peka rakt emot den plats där ringen såg ut att ligga om han skulle träffa den	M Skakar "pinnen" som klingar mot skålen
	V Lägger ner papperet, tittar på M,
M Mm, men, men problemet är ju att nu	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 "pinnen" M Sticker ner "pinnen" 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
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?)	M Drar upp och sticker ner "pinnen" ett par gånger, drar upp den och håller den uppe
	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 kompisen observerade väl den skillnaden kanske V Kan du inte ta den	M Drar upp pinnen, sedan ner igen, upp igen
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 nånting när den går ner i vattnet	V Tittar på M
	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]	-14.18

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 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 såhära 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 tillexempel.
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 härа.
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 häll i det då
V Häll i mjölken, men då,
N Vi bara,
V vi kan hälla 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 [dflkgj?] 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 dom 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 härа 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

Uppgift 2 (Task 2)

M Mm alltså ja jag brukar tänka när det är vatten att eller jag har liksom en minnesregel för hur det funkar om man om det beroende på hur tjockt	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)
det här materialet är liksom du kommer ihåg att vi pratade om brytningsindex	N Tittar åt sidan
	M Upp och ned ytterligare en gång med varje hand, tittar mot R
R Ja just det	R tittar fortfarande på M, nickar, vrider huvudet mot vattnet och nickar
M Om att det är ett mått på	M Tittar på vattnet, två gånger med vänster hand upp och ner och en gång med höger där emellan
M liksom hur =(a jag vet inte)	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 =A men hur hjälper det ja i och för sig då måste jag lära mig utantill då att	R Kliar sig i huvudet
	V tittar på R, sedan på vattnet
M Ja men du måste alltså man måste ju veta typ att den här har eh den här att att glas eller att att	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 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
N vatten	
M vatten [dörren öppnas] är liksom tjockare än luft liksom	R Tittar på M M Lyfter båda händerna till midjehöjd med handflatan upp, gör en vridande gest med handflatorna vridande uppåt mot sig och sedan ut med händerna
R Mm	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 V = Tittar mot dörren,
V Men brukar =vi inte kunna brukar vi inte kunna tänka på han Huychens eller Huygens	R = Tittar på N eller V N = Tittar mot dörren V = tittar mot M M = Tittar på N eller V N = Tittar på M R Tittar mot dörren, sedan mot N och/eller V igen
M =Hey… Huygens princip	M =1 Sätter armarna i kors V =1 Följer M:s händer med blicken
V Ja och tänka på det att vågen kommer in så här och så nånting och därför så bryts den mot eller från normalen	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
M Ja men det är trögare liksom =det är ju	M Tittar på vattnet, ruskar på huvudet,
V =ja	V tittar snabbt på R sedan tillbaka till M
M vatten är trögare det är ju tjockare än luft liksom	M tittar på R, lyfter vänster och sedan höger hand upp och ned med kupade handflator uppåt
V Är det det du är ute =efter vill du ha nåt slags	V tittar på R, sänker axlarna (som att hon sjunker ihop) M Sträcker sig till bänken efter en krita bredvid skålen
R =Mhm ja just det det är ju ja exakt	V (Följer Ms hand med blicken), tittar på skålen M Går till tavlan
V = eller om du bara vill kunna komma	V Tittar på R, pekar på skålen, R Vrider huvudet, tittar på skålen, sedan tillbaka till V igen
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 ihåg det till nästa gång	V pekar hastigt på skålen
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,
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, måttar med handen ovanför det översta

	horisontella strecket, rör	
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,	
N En boll		
V Bollen jag tänker att det blir jobbigare =då		
M =Ja, ja nä men en nånting ligger här en nånting	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	
M och så kommer ljuset här	M Följer linjen upp till "korset" igen, rör handen upp i sned linje åt vänster och sedan ner igen till korset,	
M och så tittar du här	drar ett streck från korset och snett uppåt åt vänster. V Hostar,	
M här är ditt öga	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.	
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
M Ja fast jag jag jag brukar inte tänka på vågfronter jag brukar liksom bara tänka att men det så när ljuset	M tar ner handen	Yes, but I usually don't think of it as wave fronts, I use to kind of just think that, but, so when the light
	V sätter handen mot munnen	

M här är tunnare och det här är tjockare 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 pricken, 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 pricken	this is thinner and this is thicker, I don't know
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
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) N Sätter sig (avslutar sedan meningen åt V)	this angle
N Mindre än den andra och =1 inte tvärt om	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
R =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
V =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
M 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
V Varför varför blir det så för att den är tätare	V rycker på axlarna	Why, why does that happen because it is denser
M 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
	V Tittar på R, tittar på tavlan, tittar på M,	
V =1 Ja jag har =2 för mig att vi att vi =3 har förklarat det så någon =gång	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
N =3 [det är på] elektromagnetiska	V tittar på N	It's electromagnetic
M =4 Ja, ja eller typ bara [eller] elektromagnetiska vågor	R Tittar på M	Yes, or kind of just, or, electromagnetic waves
N =4 [vågor vid aa]	V Tittar på tavlan	waves at, yes
	R =1 Tittar på N	
	N =1 Sitter och svänger fram och tillbaka på stolen	
	V =1 Tittar på M, sedan tillbaka på tavlan	
R =1 Men testa lite	R Tittar på tavlan	But try a little bit
V =1 Men på nåt sätt tänker vi på det som en vågfront	V Håller upp kritan i midjehöjd och vinkar litegrann med den	But somehow we're thinking of it as a wave front
	M = Backar åt höger	
M Aa	R = Flyttar sig lite åt höger	Yeah
V 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	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
	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	
M 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
V In före =och det går långsammare [i vattnet] N =Ja	V Pekar nedanför horisontella mittenstrecket	Before and it goes slower in the water Yes
M 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	Yes, that's right, it's denser Vhich means it's going sloVer there
	V Tittar på M, tittar på tavlan, Pekar på horisontella mittenstrecket/ vågfronten	
	M Pekar på det nedre sneda strecket	
V =1 Och då kommer det liksom inte		And then it won't kind of
R =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

M =2 Ljuset går långsammare	M = Tittar på R (med kritan upp i luften), R Tittar på tavlan,	The light is going slower
R jaha =3 [så är det]	V Tittar på tavlan	Aha
M =3 så att om du har om du har vattenytan här och så har du en vågfront eh	M börjar rita ett nytt horisontellt streck ovanför till höger på tavlan, pekar mitt på denna, viftar till lite med pennan,	So, if you have the surface of the water here and then you have a wave front eh
R Jag trodde ljuset alltid hade ljusets hastighet	V tittar på R	I thought light always had the speed of light
M 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
V 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.	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 = 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 tvärstreck 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.	
R Mm	V =Tittar på N:s hand/skålen.	Mm
N Det blir nytt ljus	N =Lägger ned handen på bordet.	It is new light
	V =Tittar på R	
	R =Nickar och vrider sig och tittar på V	
	N Vrider huvudet och tittar på M.	
	R Tittar på M	
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.	So the speed of light is constant, but it has to do a lot of other things along the way
	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.	
M Men	V Tar ett par steg närmare M (åt höger i bild).	
M Om vi tänker oss att dom här vågorna kommer och så är det trögt att gå liksom för det är vatten här nere	M Tar ned handen något och sätter den utsträckta handen i linje med tvärsstrecken med handflatan	
	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 Ja just det för det är därifrån ljuset [nåt från] nånting kommer	R Pekar mot tavlan
	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 Det kommer härifrån	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 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	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 uppifrån 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 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.
M Jomen för att det = kom	V Går framåt tavlan
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,
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	och rör händerna något uppåt och nedåt. Tar ner armarna.
	M Tittar på tavlan
	R Tittar på tavlan [/V]
N Den den första biten alltså det är ju liksom att	N Reser sig går mot tavlan
	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 pekfingret) 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 tvärsstreckets korsning), för handen till vänster längs horisontella strecket till korsningen för nästa tvärstreck och följer sedan detta uppåt höger med pekfingret. Tar upp en krita, ritar två prickar på

R Mm	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
N Så att den hinner liksom	strecket han ritat prickar på och horisontella strecket och på en motsvarande korsning två steg till höger med kritan. Rör sedan högra handen med
R Ja just det	kritan vinkelrätt mot de sneda strecken snett uppåt vänster från det horisontella strecket två gånger, tittar på R, sedan en till rörelse med höger
N =Röra sig mer i det här snabbare mediet	hand. Sätter sedan händerna parallellt med strecken ovanför det horisontella strecket och visar med höger hand en snabb rörelse från höger till
R =[så blir det när det går fortare] ja just det	vänster ovanför horisontella strecket. Tar ner händerna, lägger ifrån sig kritan
N Och då liksom =[kfj] upp så	
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	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 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	
M Då kommer ju det =här	
V =Gör ett streck där asfalten är	V Gör en hastig horisontell rörelse med höger hand mot kroppen och tillbaka ut (står vänd mot tavlan med ryggen mot kameran).
M Här är asfalten liksom	M Ritar ett horisontellt streck genom den övre högra ovalen, pekar på den med höger (långfinger?) Tittar på R,
R Mm	
M Det här hjulet kommer ju dra mycket mer	
R Mm	R Nickar
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	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

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 glasen 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, måttar som för att rita något först med kritan, pekar sedan hastigt med de utsträckta fingrarna
N Men	måttar 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	N Ser sig hela tiden omkring runt tavlan, tittar på M
M Så kommer eeh	M Pekar lite, Suddar bort ovalerna
V Men nu tänker du på flera strålar jag tänker på en stråle	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 Ja fast	M Tittar upp mot det tidigare ritade ögat
N Men är inte grejen att egentligen	R Tittar på N V Tittar på N M Tittar på N
M Eh	
N är det en våg som har en slags utsträckning	
M Ja precis kanske	V Tittar på R? N Tittar på dörren V Tittar på M/tavlan
V Jag vet inte riktigt	N Tittar på M V =Backar och sätter sig, tittar på tavlan
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	N =Går till tavlan och tar en krita
	N Ritar ett horisontellt streck på tavlan M Lägger ifrån sig sin krita N Ritar en vågform nedifrån höger upp mot den nyligen

	ritade horisontella 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. Lägger ifrån sig kritan och backar undan åt vänster. [Man hör att kritan faller.]
R Jag tycker det där verkar ganska men det där är ju	R Pekar på tavlan
M Ja alltså	N Böjer sig ner och plockar upp något [en krita, hörs på ljudet] från golvet, lägger på tavlan
R Jag skulle nog kunna tänka mig och vara ganska nöjd med den där förklaringen =faktiskt	M = Kliar sig i huvudet, tittar på R.
M Aa	R = Tittar på V
	V = Nickar
N Då kan man ju	N Går tillbaka åt vänster från tavlan, tittar på skålen, tittar på tavlan, kliar sig i huvudet
R Men kan man säga veta nånting om hur mycket det där är då	M Tittar på tavlan, tittar på R
M Aa	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	M 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 njaej så blir det	N Nickar lite, pekar på det M har skrivit, nickar lite R Tittar på N
M Nej så []	V =Reser sig, går halvvägs mot tavlan
N Så är det så är det	M =Pekar på ekvationen N = Nickar
M =Så att	
	R Nickar, tittar på tavlan, tittar på N/V,
V = Så [att] vad kommer brytningsindex	
M Brytningsindex säger hur mycket långsammare det går	M Tittar på R
	R Tittar på M M Tittar på N V =Tittar på R M =Tittar på R N Tittar på M, tittar på tavlan
R Just det mm	R =Nickar M =Tar ner den pekande handen, lägger ifrån sig kritan, tittar på tavlan
V Och sen finns det nåt samband mellan =brytningsindex och [flgkh] vinkeln	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 V =Lyfter upp handen mot tavlan, gör först en rörelse med handen uppifrån vänster nedåt höger, visar sedan med handen/pekfingret (böjer i handleden) uppifrån höger nedåt vänster, och tar ner handen, tittar på R R =Tittar på tavlan
R =Aa just det det kan jag aldrig lära mig heller hur man ska komma ihåg det	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 sintheta1, fyller på så att det blir n1sintheta1, skriver något (jag tror n1) under, fyller sedan på så att det blir n1sintheta1=n2sintheta2
M Men varför blir det så då	M = Slår ut med händerna lite, handflatorna uppåt, och släpper ner händerna igen N = Skriver n2 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 Lägger 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

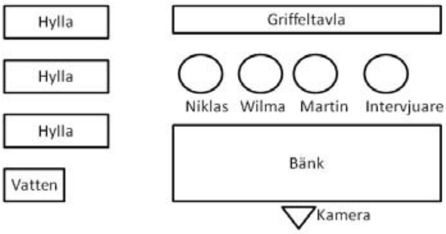
M Va [ohörbart]

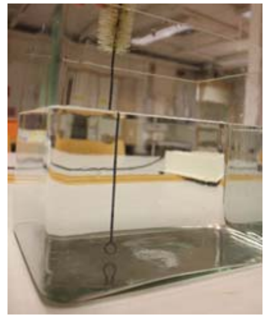
V Skillnaden är ju att i det andra fallet utgår vi ifrån att det vi försöker förmedla i det första fallet redan finns där =alltså tänka på att det är ljus och tanken på att ljuset kan brytas behöver vi ju inte =prata om

M =Nä =nä och jag tänker också att en 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…

Appendix B

Clip 1. Starting at 11.06.





1. Nic Den är alldeles rak härifrån= ((böjer sig
It’s completely straight from here= ((bends down))
2. ned))

3. Mik =A: (.) nu ser den <sned ut> (.) liksom
=Yeah: (.) it looks <skewed> now (.) kind of

3. Nic Här ser den sned ut=
Here it looks skewed=

4. Mik =Här ser den verkligen sned ut (2.0)
=Here it really looks skewed (2.0)

5. Nic ((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. Nic 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. Mik =aa= ((står upp igen))
=yeah= ((stands up again))
10. Nic =sen så går man dit(.) ((flyttar sig i sidled))
=then you go there (.) ((moves sideways))
11. Mik aa
yeah
12. Nic då är den avskuren så här ((visar med händerna))
then it is cut off like this ((shows with his hands))
13. (^t)
(^t)
14. Nic Att det är (0.7) eh: (2.0)
That it is (0.7) eh: (2.0)

15. Mik ((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. Nic [Nej] att den(.) att den är
[No] that it (.) that it is
18. diskontinuerlig(.)

discontinuous (.)
19. Mik Mm(.)
Mm(.)

20. Ver ((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. Ver 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. Nic =m(0.2)
=m(0.2)
26. Ver pinnen=
the stick=
27. Mik ((Böjer sig ned och tittar))
((Bends down and looks))
28. Nic =m(5.0)
=m(5.0)
29. Mik >Hur då,< (1.8)
HoV, (1.8)
30. Ver 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. Mik =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. Nic Nej men om du: (0.8)
No but if you: (0.8)
36. Ver >Nej jag menar liksom att< den är okontinuerlig,
>No I mean kind of that< it’s discontinuous,
37. Nic 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. Mik A: lite grann (0.3) [a]
Yeah: a little (0.3) [yeah]
41. Nic [Om], (.) men om,(.) om du
[If], (.) but if,(.) if you
42. tittar ändå mer (från) [sidan]-
look even more (from) [the side]-

43. Ver [men,] ((byter ämne))
[but,] ((changes the subject))

Ending at 14,03

For a key to the notation, see Schegloff (n.d.).

REFERENCE

Schegloff, E. A. (n.d.). Emanuel A. Shegloff's homepage Retrieved September 28, 2012, from http://www.sscnet.ucla.edu/soc/faculty/schegloff/

Appendix C

An holistically appropriate description of refraction taken from Feynman, Leighton and Sands, 1963, pp. 31-32.

"[A]ll 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 … 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 $\sin n$ or $\lambda_0 = 2\pi c / \omega n$, if $\upsilon = c / n$ 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, R. P., Leighton, R. P., & Sands, M. (1963). *The Feynman Lectures on Physics : Volume I* (Vol. I). Reading: Addison-Wesley.

Appendix D

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, A*vdelningen 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 anknytande 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 anknytande till forskning, förutsatt att mitt namn döljs.
□ Jag medger att *endast stillbildsutdrag* ur upptaget bildmaterial där jag medverkar får användas vid elektronisk publicering anknytande 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 tidsskrifter 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:

Postadress:	Tobias Fredlund Box 530 751 21 UPPSALA
Besöksadress:	Ångströmlaboratoriet Lägerhyddsvägen 1 Å:81407
E-post:	tobias.fredlund@fysik.uu.se

Underskrift:

Namn (textat)	Personnummer
Ort och datum	
Underskrift	

REFERENCE

Rundgren, C.-J. (2008). *Visual Thinking, Visual Speech - a Semiotic Perspective on Meaning-Making in Molecular Life Science.* PhD thesis, Linköping University, Norrköping.

Paper I

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.

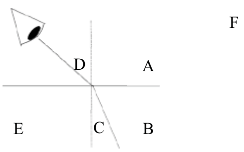

Figure 1. Diagram already drawn on the blackboard, showing a ray of light coming from below water, entering air and reaching the eye. Capital letters are positions referred to in *Figure 2*.

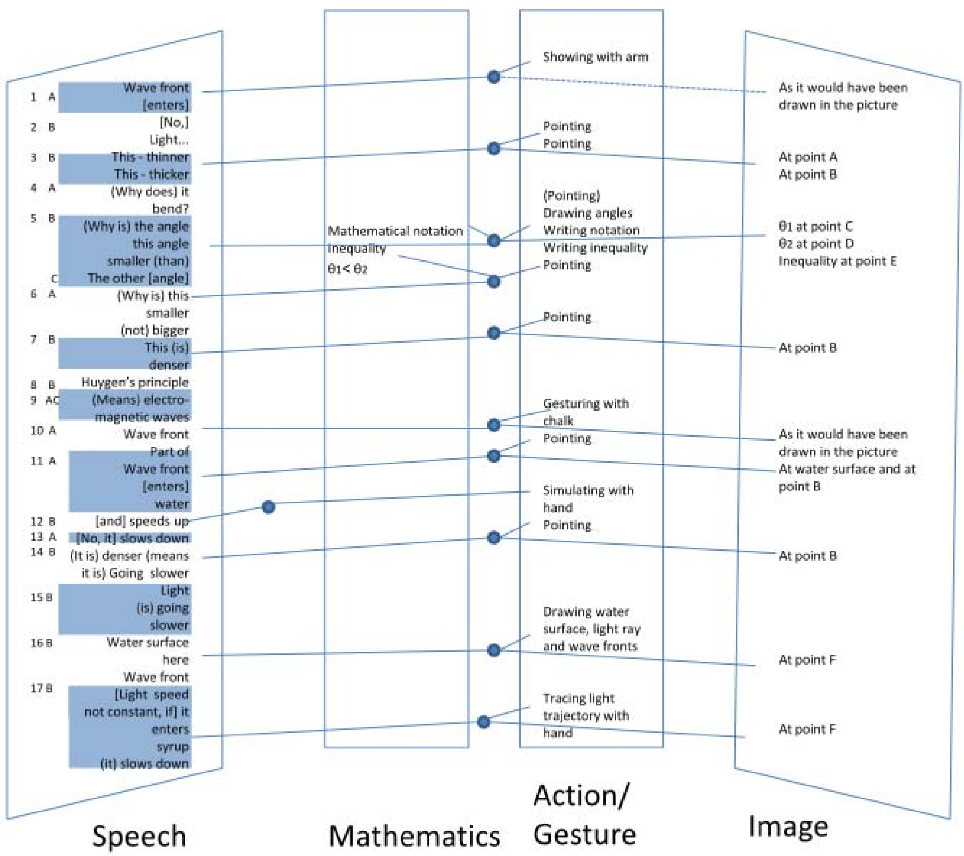

Figure 2. The dynamic development of the discussion. Points A-F are positions in *Figure 1*.

Discussion

Wave Fronts. The use of wave fronts[1] 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 θ (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.

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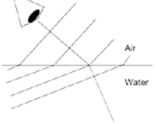
[1] An example of a wave front diagram:



Paper II

IOP PUBLISHING EUROPEAN JOURNAL OF PHYSICS

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Exploring the role of physics representations: an illustrative example from students sharing knowledge about refraction

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Abstract

Research has shown that interactive engagement enhances student learning outcomes. A growing body of research suggests that the representations we use in physics are important in such learning environments. In this paper we draw on a number of sources in the literature to explore the role of representations in interactive engagement in physics. In particular we are interested in the potential for sharing disciplinary knowledge inherent in so-called *persistent representations* (such as equations, diagrams and graphs), which we use in physics. We use selected extracts from a case study, where a group of senior undergraduate physics students are asked to explain the phenomenon of refraction, to illustrate implications for interactive engagement. In this study the ray diagram that was initially introduced by the students did not appear to sufficiently support their interactive engagement. However, the introduction of a wavefront diagram quickly led their discussion to an agreed conclusion. From our analysis we conclude that in interactive engagement it is important to choose appropriate persistent representations to coordinate the use of other representations such as speech and gestures. Pedagogical implications and future research are proposed.

1. Introduction

Probably the most successful teaching–learning approaches informed by physics education research have been based on the idea of interactive engagement. Here the interaction may be between peers (‘convince your neighbour discussions’, Mazur 1997, p 12), or between students and teachers. It has been shown that such interaction has the potential to significantly enhance learning outcomes (see Deslauriers *et al* (2011) for a recent, much acclaimed study; and Hake (1998) for one of the original ground-breaking reports). Highly regarded research-designed physics learning environments that have successfully incorporated aspects of interactive engagement include Active Learning (Van Heuvelen and Etkina 2006), Peer Instruction (Mazur 1997, 2009) and Tutorials (McDermott and Shaffer 2002). Research on these learning environments has shown that their application significantly improves both conceptual understanding and problem solving skills (Redish 2003, McDermott 2001). Recent work by, for example, Rosengrant *et al* (2009), Airey and Linder (2009) and Tang *et al* (2011) suggests strongly that the representations we use in physics (such as diagrams, graphs, equations, spoken and written language, gestures, etc) play a critical role in the effectiveness of the interactive engagement between students in these learning environments. However, little research has been done in this area. In this paper we explore the potential of different representations to enable the sharing of physics knowledge. As an illustration, we present an analysis of an interactive engagement sequence where senior undergraduate students attempt to provide an appropriate and adequate explanation for the refraction of light.

1.1. Affordances of representations

The importance of representations in the learning of physics is increasingly attracting the attention of researchers (Airey and Linder 2009, Hestenes 2003, Kohl and Finkelstein 2006, Kohl *et al* 2007, McDermott 2001, Meltzer 2005, Podolefsky 2008, Rosengrant *et al* 2009, Scherr 2008, Tang *et al* 2011, Van Heuvelen and Zou 2001). The essential underpinning assumption of this growing body of research is that different representations have different potentials for communication, what Gibson (1979) calls affordances.

The affordances of different representations determine the role they can play in communication, and thus in the sharing of knowledge. Mathematical symbolism affords, for example, 'logical reasoning through the precise encoding of mathematical participants and processes in a format which facilitates their rearrangement' (O'Halloran 2010, pp 219–20). Images on the other hand afford, for example, the sharing of spatial and directional relationships (Kress and van Leeuwen 1996). The possibility then arises to choose a constellation of representations that offers the best set of affordances for the situation at hand (Airey and Linder 2009).

In this paper we are particularly interested in the *disciplinary affordances* of representations. We define the disciplinary affordances of a given representation as the inherent potential of that representation to provide access to disciplinary knowledge. Thus, it is these disciplinary affordances that enable certain representations to become legitimate within a discipline such as physics. Physics learning then, involves coming to appreciate the disciplinary affordances of representations.

Another important aspect when thinking about the affordances of representations is the notion of persistence (Kress 2010). Kress relates persistence to the physical nature of certain representations that allows us to readily refer to them at any point in time. Examples of persistent representations are written language, pictures, diagrams, etc. The strength of persistent representations is that they can easily be referred back to, for example by pointing. Non-persistent representations, such as spoken language, gestures and facial expressions, are temporal in nature and therefore more difficult to refer back to effectively in interactive engagement (Wells 1998, Kress 2010).

1.2. Common persistent representations in the area of refraction

In exploring the disciplinary affordances of persistent representations used by students involved in interactive engagement, we will use the area of refraction of light as an example. The most common persistent representations typically used in explanations of refraction, apart from written text and equations, are ray diagrams and wavefront diagrams. In a recently completed review of 93 German and English undergraduate physics textbooks, Hüttebräuker (2010) reported that the same type of ray diagram was almost always presented, and that wavefront diagrams appeared in less than half of the reviewed texts. Research has shown that it is not always clear to students how to represent refraction using the wave model of light. For example, Sengören (2010) found that many first-year university students, despite saying that the wave model of light would be appropriate for explaining the refraction of light, did not appear to appreciate the affordances that wavefront diagrams have for such an explanation and this could be seen in the inappropriate wave representations that were drawn by them.

1.3. Research questions

The background provided in the introduction led us to develop the following research questions:

- Which persistent representations are used by a group of students when engaging interactively in explaining the refraction of light?
- Can differences in disciplinary affordances of the persistent representations used by the students be observed in such an explanation?
- What aspects of the persistent representations used in explaining the refraction of light can account for their differences in disciplinary affordances?

2. Method

2.1. Data collection

In order to address our research questions we present an illustrative case study with a group of third year physics undergraduates who we expected to be well acquainted with the phenomenon of refraction. The group was comprised of three academically successful students, Mike, Nick and Vera (pseudonyms). The students were given the task to provide an appropriate and adequate explanation for the refraction of light to a hypothetical peer student. The students did not know about the task beforehand and therefore had no time to prepare their answer. The interactive engagement between these students took place in the student physics laboratory. This setting was chosen purposefully, so that items such as water, a glass tank, laser pointers, etc, and a blackboard and chalk would be available if needed by the students to help them constitute their explanation. However, since we wanted to observe how the students constituted their explanation, we did not provide explicit access to textbooks or the Internet. This approach was chosen because it is the engagement, complete with dead-ends, and its ultimate progress towards an agreed solution that is of interest for our exploration. Very occasionally, one of the researchers asked a clarification question that the hypothetical peer could have asked. The presence of a researcher provided the possibility of asking the students to take their explanation further, if found to be desirable. The students' engagement with the task lasted for approximately 30 min, and was audio and video recorded. However, the whole transcript of the session is not reported here—only those sections critical for the analysis are presented.

The fundamental value of performing a case study is that it provides in-depth insight, that is 'detail, richness, completeness, and within-case variance', through 'the force of example' (Flyvbjerg 2011, p 314; 305). At the same time, we appreciate that by using a case study to illustrate our exploration, the possibility exists that a different experimental setting, such as having a different group of students, and/or having an actual peer present, could have

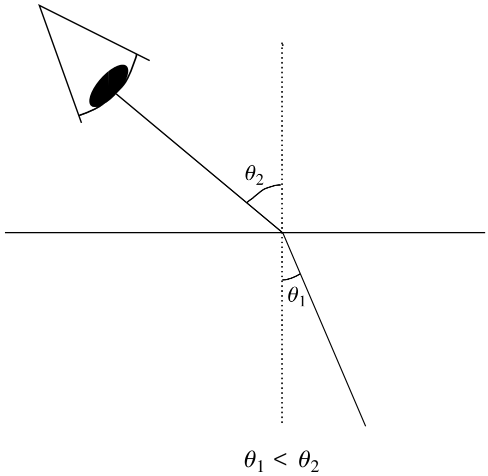


Figure 1. A computer-generated reproduction of the ray diagram drawn by the students (including the mathematical symbolism for two angles and their mathematical inequality that was inserted later).

generated different illustrative aspects. However, the implications that we suggest in section 5 capture what emerged from our case study, and we think this insight will prove fruitful for the development of the teaching and learning of physics.

2.2. Method of analysis

Our analysis was accomplished by first transcribing 'multimodally' (Baldry and Thibault 2006) the audio and video data from the whole 30 min engagement. This means that the spoken and written language, diagrams, equipment, mathematics, gestures, etc, that the students used, were reproduced or described in parallel in a chronological order. By abstracting concepts from the multimodal transcript we then created a form of data mapping that was based upon Lemke's (1990) notion of 'thematic patterns'.

Thematic patterns were first introduced by the physicist Jay Lemke (1990) in order to analyse teacher talk in school science. Rather than presenting data chronologically, as in the case of the multimodal transcript, a thematic pattern approach aims to provide a synoptic, time independent, analysis. Thematic patterns can be thought of as being similar to 'concept maps' (Novak and Cañas 2008) constructed from interviews, in that they display relationships between concepts; however, the analysis is generated in more fine-grained detail. Our goal in using thematic patterns was to present the physics meanings that were negotiated in the students' engagement with their given task. Especially, we have chosen to highlight in thematic patterns one part of the discussion, which we think is particularly decisive for the students' successful task completion. The multimodal transcripts and thematic patterns resulting from our analysis are shown in figures 2–4.

3. Results

The three students, Vera, Mike and Nick, began their explanation of refraction by discussing with speech and gestures what happens to light as it passes an air–water boundary. They then went on to draw a 'canonical' ray diagram (figure 1) on the blackboard. The students

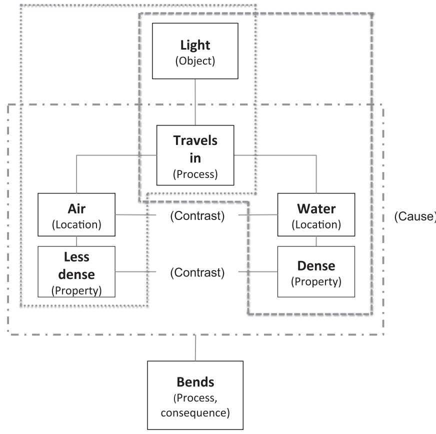
<table>
<tr><th>Transcript of spoken language</th><th>Transcript of other representations</th><th>Thematic pattern</th></tr>
<tr><td>Vera: Why is it, why is this smaller and not bigger?
Mike: Well, because this is denser, kind of.</td><td>Vera: Points at θ_1 in the inequality (figure 1).
Mike: Points below the horizontal line (in figure 1).</td><td>
</td></tr>
</table>

Figure 2. Multimodal transcript (LHS) and thematic pattern (RHS) of the initial part of the discussion. 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.

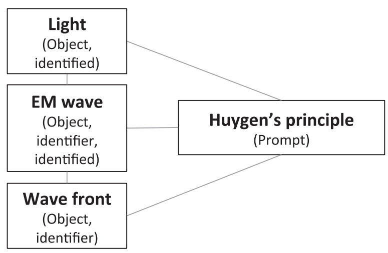
<table>
<tr><th>Transcript of spoken language</th><th>Transcript of other representations</th><th>Thematic pattern</th></tr>
<tr><td>Vera: Why, why does that happen because it is denser?
Mike: Well, then one has to start to think of Huygen's principle, or…
Vera: Yes, I think we have explained it that way some time.
Researcher: What does that mean then?
Nick: It's electromagnetic…
Mike: Yes, or kind of just, or, electromagnetic waves.
Nick: …waves at, yes.</td><td>Vera: Shrugs her shoulders.</td><td rowspan="3">
</td></tr>
<tr><td>Vera: But somehow we are thinking of it as a wavefront.</td><td>Vera: Gestures with chalk how a wavefront could be drawn in the figure (figure 1).</td></tr>
<tr><td>Mike: Yeah.</td><td></td></tr>
</table>

Figure 3. The students' reconceptualization of light as a wave, potentially represented as a wavefront.

also decided to immerse a washing-up brush in a glass tank that they had filled with water. After this, Vera attempted to further problematize why light bends by suggesting the use of wavefronts; however, her suggestion was not taken up by Mike and Nick. Mike instead stayed

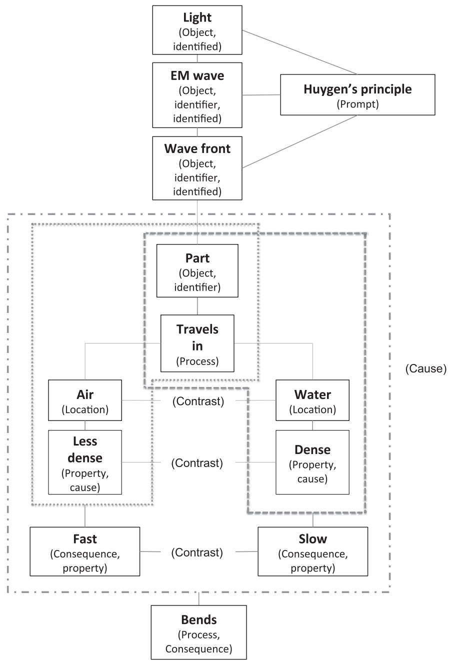
Transcript of spoken language	Transcript of other representations	Thematic pattern
Vera: And then, kind of, a part of the wavefront will hit, I can't do that explanation myself, but a part of the wavefront will kind of hit the water…	Vera: Making a gesture as if drawing a wavefront in the figure (figure 1).	
Mike: …before and then it goes *faster*.	Mike: Simulating movement of wavefront with hand.	
Vera: …before and it goes *slower* in the water.	Vera: Pointing at water in figure (figure 1).	
Nick: Yes.		
Mike: Yes, that's right, it's denser which means it's going slower there.	Mike: Pointing at water in figure (figure 1).	
Researcher: What is going slower then? I don't understand.		
Mike: *The light* is going slower.		

Figure 4. The thematic pattern illustrates how introducing the wavefronts afforded the students' explanatory focus to shift to the speed 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.

with his idea that the reason that refraction occurs is that 'water is kind of thicker than air'. Vera then inserted mathematical symbols for two angles into the ray diagram, and wrote the mathematical inequality below the ray diagram, as shown in figure 1.

The two persistent representations, ray diagram and mathematical symbolism (figure 1), were accompanied by speech and gesture (non-persistent representations) in order to pinpoint what it was that Vera found unsatisfactory in their explanatory efforts (the inability to explain *why* the light bends). This is shown in figure 2, which also shows how the students' explanation at this stage included Mike's assertion that light bends because one medium 'is denser' than the other. At this point the students' explanation appeared to reach a dead end.

The analysis presented in figure 3 focuses on how the students resolved this stalemate. Vera posed the question: 'Why … does [bending] happen because [one medium] is denser?' This led to the mentioning of Huygen's principle and a reconceptualization of light as a wave, which had not been seen as necessary by the group earlier in the discussion. Vera then returned to her earlier suggestion to draw on the idea of wavefronts. This time the other group members acknowledged this as a potentially fruitful way forward.

The mentioning of Huygen's principle (a prompt which was not elaborated further) led the students to bring to the fore their knowledge that linked their conceptualizations of light

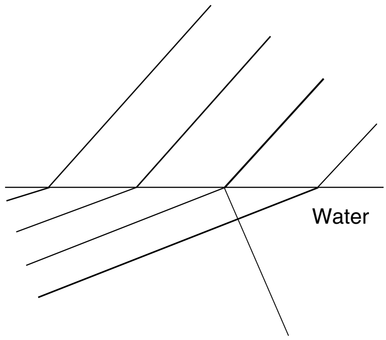


Figure 5. A computer-generated reproduction of the final hand-drawn wavefront diagram that was produced by the students.

as ‘electromagnetic waves’ and a ‘wavefront’. Next, the students continued building their explanation, now based upon the motion of the wavefront (figure 4).

A comparison of the thematic patterns in figures 2 and 4 reveals the differences between conveyed meanings at different times in the students’ discussion. That is, that the contrast between ‘dense’ and ‘less dense’, which earlier appeared to be critical for the bending of light (see the thematic pattern in figure 2), is superseded by contrasting ‘fast’ and ‘slow’ (see the thematic pattern in figure 4), which is the difference between the speeds at which a wavefront would travel in air and water, respectively. Finally, following the part of the discussion that is shown in figure 4, a wavefront diagram was drawn by Mike (see figure 5). All three students then took the opportunity to individually formulate a detailed explanation by coordinating their oral descriptions and gestures (non-persistent representations) around the persistent wavefront diagram shown in figure 5. Our analysis of these individual reformulations is that they do not affect the thematic pattern presented in figure 4, but rather served to confirm and cement the relationships between the physics concepts that had already been fruitfully established.

4. Discussion

The students who participated in our case study used a number of different representations to constitute their explanation of the refraction of light. As we mentioned in the introduction, part of our analytic framework included the notion of disciplinary affordances. We now show how the notion of disciplinary affordances of persistent representations can provide a rich and insightful way to discuss the analysis and to formulate the essence of our interpretation.

In order for the students to reach some sort of ‘conceptual convergence’ (Roschelle 1992, Oliveira and Sadler 2008), they needed to choose as a starting point an aspect of physics knowledge that they could mutually take to ‘stand fast’. By standing fast we mean something that a person or group of people can call upon and ‘use without hesitation or without further questioning’ (Wickman and Östman 2002, p 608), around which, in our case, the participating students build their continued discussion. Thus, in the presented analysis, what we found to be standing fast was initially represented by spoken language (a non-persistent representation), but quickly progressed to being represented diagrammatically as a ray diagram (a persistent representation). We suggest that this shifting to a persistent representation for what is agreed as standing fast is particularly powerful in interactive engagement. As our analysis clearly illustrates, persistent representations can be seen to play a vital role in interactive meaning making by facilitating the coordination of non-persistent representations such as gestures and spoken language (see also Kress 2010).

Our analysis also illustrates how different persistent representations have different disciplinary affordances. Some persistent representations of the same phenomenon appear to be more appropriate than others for the sharing of particular physics knowledge. For example, in the presented analysis, Vera suggested that wavefronts could be a good way to represent light. But since neither of her collaborators, at that stage of the engagement with their task, could appreciate the value of representing light in this way, a 'meaning-making negotiation' took place that ultimately resulted in the students being able to see shortcomings of the ray diagram that they may not have noticed before. The mentioning of 'Huygen's principle' at that stage led the students to quickly reformulate the way they were talking about light, in terms of 'electromagnetic waves' and 'wavefronts'. Mike's simulating gesture representing a moving wavefront made the students aware of one of the critical aspects of a successful explanation of refraction: the change in speed of light upon passing the border between media with different refractive indices. Not until they had finally 'agreed' on wavefronts as an appropriate way to represent light for the purpose of explaining refraction, did the students start to draw a wavefront diagram, which then in turn became the new persistent representation that stood fast. The wavefront diagram was then used to coordinate non-persistent representations in the students' continued efforts to constitute an appropriate explanation for the refraction of light.

In effect, our analysis illustrates how different persistent representations can be better suited to play different roles in interactive engagement, depending on their particular disciplinary affordances. Thus, for the optimization of interactive engagement it is important for the participants to be able to come to a point where they can choose an appropriate persistent representation to stand fast.

As we have seen, the students in our study did not initially choose the wavefront diagram, even though it later turned out to be the most useful representation for the constitution of their explanation of the refraction of light. Hence, we also suggest that there may be a relationship between the persistent representation that is first chosen and the frequency with which that representation occurs in learning resources such as undergraduate textbooks. The ray diagram, which is the most frequently occurring persistent representation in textbooks, did not require negotiation before standing fast—this was a taken for granted starting point. The wavefront diagram on the other hand, needed an engagement of quality before its disciplinary affordances were perceived, and then drawn on.

The fact that different aspects of light are represented in ray diagrams and wavefront diagrams may account for the different affordances they offer for an explanation of the refraction of light. The ray diagram, for example, could be seen as taking an indifferent or 'agnostic' position regarding the wave/particle nature of light, and only affords the (change in) direction of propagation of light to be shown. The wavefront diagram, on the other hand, is dependent on the choice of the wave model of light. This representation of light as being spatially extended enables a division into different parts, travelling at different speeds in media with different refractive indices. The students in our study appeared to experience this as providing a plausible and fruitful mechanism for modelling the bending of light at the interface between the two media. The students could also have become aware of this difference in speed by noticing the difference in distance between wavefronts in the different media. It is interesting to note that the students in our study also produced persistent mathematical representations; however, these were not built upon in their discussion. Therefore in our system of analysis we find no evidence that these particular persistent representations stand fast for the students.

5. Conclusions

We started this paper by noting that when students engaged interactively, extensive research has shown that this opens the way to improving conceptual understanding and problem solving skills. Then we argued that the representations we use in physics play a critical role for the efficiency of this interactive engagement, and presented our illustrative analysis of the use of representations by a group of students working in the area of refraction. Building on these aspects of physics learning, we now highlight what we feel are the most interesting pedagogical implications for potentially enhancing the teaching of physics that are supported by the analysis:

- A critical feature for successful interactive engagement is having something that stands fast for the participants. Persistent representations are particularly useful in this respect.
- Different persistent representations have different disciplinary affordances.
- It is thus educationally critical for students to learn which persistent representations have which disciplinary affordances.

  Based on our analysis of the students' discussion, we also suggest that:
- The persistent representation initially chosen by students to stand fast may depend more on its frequency of use rather than its disciplinary affordances for the task at hand.

6. Future research

We suggest that it would be interesting to investigate our hypothesis that, in interactive engagement, the persistent representation routinely chosen by students to solve physics problems primarily depends on the representation's frequency of use in textbooks and lectures, rather than its suitability for the task at hand (i.e. its disciplinary affordances). This suggestion can be seen to be supported by recent research into how students decide what is relevant for solving problems in physics (for example, see Bing and Redish 2012).

7. Summary

In summary, we argue that students need to develop an understanding of the disciplinary affordances of different physics representations. Similarly, we suggest that in order to optimize physics learning in interactive contexts, physics teachers need to know more about the range of persistent representations available, and their associated disciplinary affordances.

Acknowledgments

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Paper III

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. Appresention 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')[1].

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).

[1]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.

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Paper IV

Att välja lämpliga resurser: en undersökning av studenters scientific literacy

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Sammanfattning

Begreppet Scientific Literacy kan delas upp i två komplementära delar: Vision (I) som innebär scientific literacy för akademiska ändamål, och Vision (II) som innebär scientific literacy för samhället (Roberts, 2007a, 2007b). Enligt Roberts kommer ett naturvetenskapligt program att innehålla en specifik kombination av dessa två delar. Flera forskare förespråkar nu ett synsätt som innebär att literacy innefattar mer än bara läs- och skrivkunnighet (t.ex. Jewitt & Kress, 2003). På motsvarande sätt hävdar bl.a. Airey (2009, p. 45) att en students Vision (I) scientific literacy innebär att studenter dessutom måste behärska en repertoar av andra (mer eller mindre ämnesspecifika) ”semiotiska resurser”, såsom olika diagram, grafer och ekvationer, mm. I detta kapitel diskuterar vi Vision (I) scientific literacy med utgångspunkt i Airey & Linders (2009) tankar kring en *kritisk kombination* av semiotiska resurser. Vi utgår i vår diskussion från en illustrerande analys av ett samtal mellan tre fysikstudenter.

I det exempel som vår diskussion utgår från letar studenterna efter ett adekvat sätt att förklara varför en pinne som sticks ned i vatten ser ut att brytas vid vattenytan (refraktion). Trots att dessa studenter var framgångsrika i sina studier och att de ritade ett diagram som vanligtvis används i samband med problemlösning inom detta område lyckades de inte formulera en tillfredsställande förklaring. Till slut tog studenterna sig an en annan, mindre vanlig semiotisk resurs (ett annat diagram). Detta ledde samtalet snabbt mot en, för studenterna, tillfredställande förklaring.

Utifrån vår analys av studenternas samtal hävdar vi att scientific literacy måste tolkas mer nyanserat. Vision (I) scientific literacy handlar inte bara om att kunna *behärska* de olika ämnesrelaterade semiotiska resurserna, utan också om att veta *vilka resurser* som är lämpliga att använda vid ett visst tillfälle.

Scientific Literacy i högre utbildning

Begreppet Scientific Literacy har internationellt tolkats på olika sätt. Roberts (2007a, 2007b) delar upp betydelsen av begreppet i två synsätt. ’Vision (I)’, som vi behandlar i detta kapitel, innebär Scientific Literacy för akademiska ändamål, och Vision (II) innebär Scientific Literacy för samhället. Dessa synsätt utgör ändpunkterna på ett kontinuerligt spektrum, och enligt Roberts innehåller varje naturvetenskapligt utbildningsprogram en kombination av dessa synsätt. Flera forskare förespråkar nu ett synsätt som innebär att literacy bör tolkas som annat än bara läs- och skrivkunnighet (se t.ex. Jewitt & Kress, 2003). På motsvarande sätt hävdar bl.a. Airey & Linder (2009) att för Vision (I) scientific literacy också kunskaper om andra (ämnesspecifika) semiotiska resurser, såsom t.ex. olika diagram, grafer och ekvationer, etc. är nödvändiga för en funktionell scientific literacy.

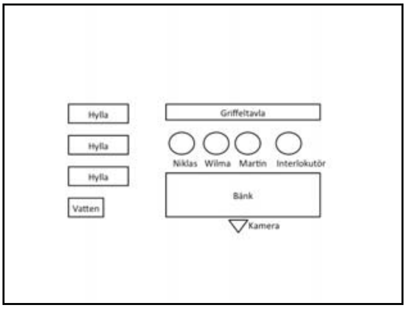
Detta utvidgade perspektiv på text kallas ibland ”multimodalitet” (se t.ex. Kress, 2010; och Kress & Van Leeuwen, 2006), och kommer av att olika semiotiska resurser kan sägas tillhöra olika modaliteter: talat språk, skrivet språk, bilder, etc.

En distinktion som görs av Kress (2010) som är av betydelse för detta kapitel, är mellan beständiga och icke beständiga semiotiska resurser. Beständiga representationer, som t.ex.

skriven text, diagram och grafer, etc. kan lätt refereras tillbaka till, exempelvis genom att en person pekar. Icke beständiga semiotiska resurser, som talad text, gester, försvårar sådan referens. Multimodal teori, som den utformats av t.ex. Kress och van Leeuwen, är baserad på den lingvistiska tradition som härstammar från Halliday (1978). Dess centrala antagande är att språket har erhållit sin funktion från den sociala miljö det utvecklats i. På motsvarande sätt förutsätter multimodal teori att andra modaliteter och dess olika semiotiska resurser, har växt fram i sociala miljöer, och där erhållit olika potential att skapa mening. Airey & Linder (2009) har, baserat på detta tankesätt, hävdat att det krävs en kritisk kombination av semiotiska resurser för en framgångsrik beskrivning av ett vetenskapligt fenomen.

Vårt kapitel tar sin utgångspunkt i detta perspektiv, och vi vill genom en detaljerad analys av en diskussion mellan tre studenter exemplifiera hur olika semiotiska resurser fungerar/samverkar i en förklaring av ett vetenskapligt fenomen. För att åstadkomma en sådan diskussion konstruerades en studie där tre studenter från tredje året på kandidatprogrammet i fysik behandlar ett fysikaliskt fenomen. Ljus som färdas från ett genomskinligt material till ett annat kan, under vissa omständigheter, byta riktning, t.ex. Detta 'brytning' kallas refraktion och ger bl.a. upphov till att en pinne som är nedstucken i vatten ser ut att vara böjd vid vattenytan. De tre studenterna i studien—vi kan kalla dem Nick, Vera och Mike—ombads att förklara varför ljus bryts, och varför det bryts åt det håll det bryts. För att uppmuntra studenterna att diskutera frågan ingående, ombads de att tänka sig att de skulle förklara fenomenet för en medstudent. En av författarna, som vi kallar "interlokutör" fungerade emellanåt som den medstudent som studenterna förklarar för, genom att, mycket sparsamt, ställa förtydligande frågor. Studenternas diskussion filmades med en digital videokamera. Rummets utformning kan ses i Figur 1.

Studien ägde rum i en laborationssal, där olika materiel fanns tillgängliga för studenterna, såsom en behållare av glas, vatten, laserpekare, svart tavla och kritor, etc. Studenterna fick själva välja vilken utrustning de ville använda.



Figur 1. Arrangemanget av rummet.

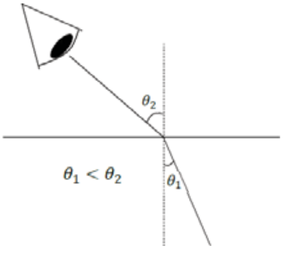
Det första steget i analysen av studenternas diskussion var transkribering av den inspelade videon. Förutom den talade texten, transkriberades även vad som skedde i andra "modaliteter", såsom gester, figurer, utrustning, m.m., jmf. "multimodal transkribering" (jmf. "multimodal transkribering", Bagga-Gupta & St John, In review; Baldry & Thibault, 2006; Bezemer & Mavers, 2011).

Från transkriptionen abstraherades särskilt viktiga element (ord som beskriver viktiga delar av studenternas diskussion). Detta var möjligt genom att kombinera disciplinär kunskap om fysik med ett fokus på de olika modaliteter som förekommer i diskussionen. Så förutom att ta hänsyn till vad som sagts i tal eller skrift, hämtades också information från andra modaliteter som t.ex. gester och från bilder som studenterna ritat. Särskilt fokus hade den del av den multimodala texten som talar om vad som händer, vilka som deltar och vilka förhållanden som råder: dvs.

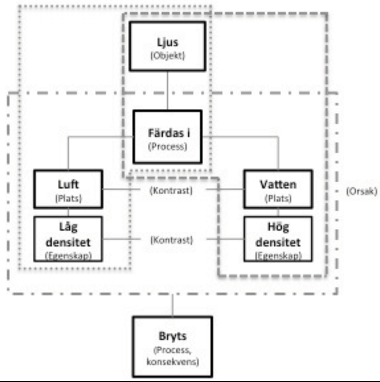
språkets ”ideationella” funktion (Halliday & Matthiessen, 2004). Utifrån detta skapades diagram som visar vilka meningsrelationer som existerar mellan de olika element som erhållits från transkriptionen. Dessa diagram är inspirerade av Lemke's (1990) ”tematiska mönster”, och vi använder också denna benämning för våra diagram. Tematiska mönster användes primärt av Lemke för att visa samband mellan olika delar av talad text, men har här utvidgats till att även visa element som kan ha tillförts diskussionen via andra modaliteter (jmf. Tang, Tan, & Yeo, 2011). På detta sätt kan de tematiska mönstren visa samband mellan olika delar av fysikinnehållet som kommuniceras i diskussionen, men som representeras i olika modaliteter, beständiga såväl som icke beständiga. Medan transkriptionen är en kronologisk representation av studenternas diskussion, det tematiska mönstret är en icke tidsberoende, synoptisk, representation. De relativa placeringarna av elementen i det tematiska mönstret bearbetades sedan i en iterativ process, tills en rumslig organisation av delarna erhölls, vilken väl illustrerade den multimodala meningsbyggnad som framkom i diskussionen. Under denna process sorterades ytterligare de delar som vi önskade visa i det tematiska mönstret fram, medan de delar som vi bedömde inte påverkade innehållet valdes bort. I resultatdelen nedan redovisas analysen i tematiska mönster parallellt med delar av transkriptionen.

Resultat

De tre studenterna började sin förklaring av varför ljuset tycks brytas när det passerar vattenytan genom att diskutera muntligt vad som händer med ljuset när det färdas från luft till vatten eller tvärtom. Tidigt i diskussionen ritade de också den mest förekommande representationen av refraktion (Hüttebräuker, 2010), ett ljusstrålediagram, på griffeltavlan (se Figur 2). En diskborste stacks sedan ned i en behållare som studenterna fyllt med vatten, för att illustrera fenomenet. En av studenterna, Vera, försökte sedan introducera begreppet “vågfronter” i diskussionen. Vågfronter kan representeras som parallella linjer som är vinkelräta mot ljusets rörelseriktning, jmf vågtoppar eller vågdalar på vattenvågor. Varken Mike eller Nick följde dock upp detta spår. Tvärtom sade Mike att han inte brukade tänka på vågfronter. Efter ytterligare en stund försökte Vera förklara varför hon tyckte att diskussionen ytterligare behövde fördjupas. Ljusstrålediagrammet kompletterades då med matematiska symboler, för att identifiera olika vinklar, och en matematisk olikhet skrevs ner, för att tillsammans med tal och gester förtydliga vad i diskussionen som var otillräckligt utvecklat, nämligen *varför* ljuset bryts, och varför det bryts som det gör (i motsats till bara *att* det bryts). I Figur 3 visas denna del av diskussionen. Till vänster i figuren visas den kronologiska transkriptionen, och till höger det synoptiska tematiska mönstret. Diskussionen verkade vid denna tidpunkt ha hamnat i en återvändsgränd. Den följande presentationen fokuserar på hur studenterna agerade för att komma vidare i sin förklaring.

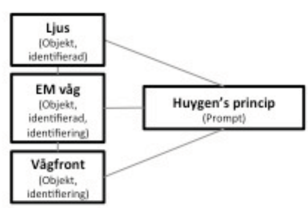


Figur 2. Ett ljusstrålediagram som visar en ljusstråles utbredning mot ögat genom två olika media. Den matematiska olikhet som skrevs ned visas också.

Talad text	Andra semiotiska resurser	Tematiskt mönster
Vera: Varför är den här mindre och inte större? Mike: Ja för att det här är tätare liksom. Vera: Varför, varför blir det så för att det är tätare?	Vera: Pekar på θ_1 i olikheten (se Figur 2). Mike: Pekar under ”vattenytan” i figuren (se Figur 2). Vera: Rycker på axlarna.	

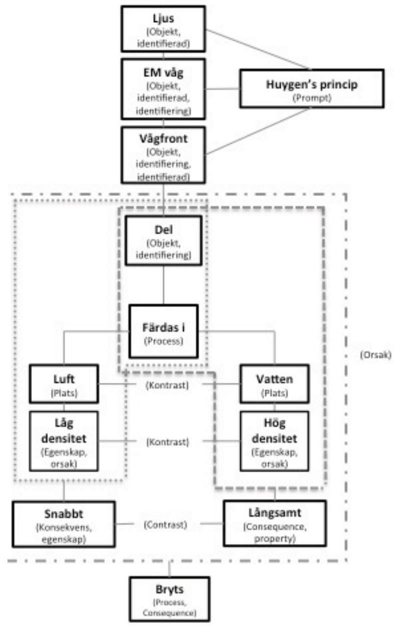
Figur 3. Transkription och tematiskt mönster. Streckade grå linjer omskriver ”orsak”. De färgade streckade linjerna visar delar som tillsammans bildar högre nivåer av mening. Kontrasten mellan ”meningarna” som omskrivs av dessa respektive linjer utgör orsaken till att ljuset bryts.

Studenterna sade att ljuset bryts för att ett medium är ”tätare” än det andra. Veras fråga ”Varför blir det så för att det är tätare?” följdes av en begreppslig omformulering av ”ljus” (Figur 4).

Talad text (kronologiskt)	Andra semiotiska resurser (kronologiskt)	Analys (synoptisk)
Mike: Ja då får man ju börja tänka på typ Huygens princip eller... Vera: Ja, jag har för mig att vi att vi har förklarat det så någon gång. Interlokutör: Vad innebär det då? Nick: Det är elektromagnetiska... Mike: Ja, ja eller typ bara elektromagnetiska vågor. Nick: ...vågor. Vera: Men på nåt sätt tänker vi på det som en vågfront. Mike: Aa.	 Vera: Gestikulerar med en krita hur en vågfront kan ritas i figuren.	

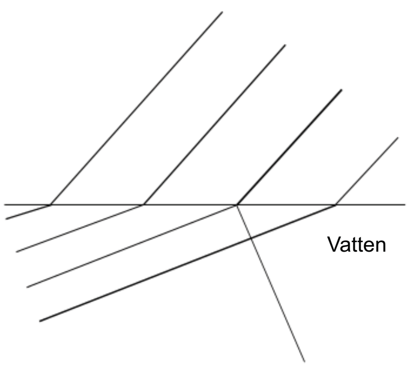
Figur 4. Omformulering/omstrukturering av begreppet ”ljus”.

Vår tolkning är att ”ljus” nu kopplas till ”vågfront” genom nämnandet av Huygen's princip, vilken dock inte utvecklas vidare. Huygen's princip har dock med utbredningen av vågor att göra, och studenterna identifierar ljus med en elektromagnetisk våg. Därefter hänvisar studenterna till den ”utdragna” karakteristiken av en vågfront, och delar upp den i två olika delar, en som färdas i luft och en som färdas i vatten (se Figur 5).

Talad text (kronologiskt)	**Andra semiotiska resurser (kronologiskt)**	**Analys (synoptisk)**
Vera: 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... Mike: ...in före, och sen så går det snabbare... Vera: ...in före, och det går *långsammare* i vattnet. Nick: Ja. Mike: Ja just det, det är *tätare* det betyder att det går *långsammare* där. Interlokutör: Vad är det som går långsammare då? Mike: Ljuset går långsammare!	Vera: Visar ”vågfrontens” rörelse i figuren (Figur 1) med en gest med handen. Mike: Simulerar vågfrontens rörelse med handen. Vera: Pekar på vattnet i figuren (Figur 1). Mike: Pekar på vattnet i figuren (Figur 1).	

Figur 5. Det tematiska mönstret visar hur diskussionens fokus har skiftat från kontrasten mellan begreppen inte så tät/tät till kontrasten mellan begreppen snabb/långsam.

I Figur 5 visas att vågfronten och dess delar identifierades med ljus av studenterna. Vad som dessutom har skett i diskussionen är att de kontrasterande begreppen tät/inte så tät i det tematiska mönstret i Figur 1, nu har bytts ut mot det kontrasterande begreppsparet snabb/långsam. Efter resonemanget som redovisats i Figur 5 ritade Mike ett vågfrontsdiagram (se Figur 6). Alla tre studenterna tog sedan tillfället att i detalj formulera sig, samtidigt som de gestikulerade (pekade och simulerade) i vågfronts-diagrammet, för att visa sin uppfattning om hur de olika delarna i vågfrontsdiagrammet rörde sig, och vad som orsakar vågfronternas brytning när de färdas från luft till vatten eller vice versa. Denna diskussion påverkar inte det tematiska mönstret i Figur 5.



Figur 6. En avbildning av vågfrontsdiagrammet som ritas av Mike.

Diskussion

Studenterna i den beskrivna studien använde en rad olika representationer, varav två olika beständiga diagram (Kress, 2010): ett stråldiagram och ett vågfrontsdiagram. Det först använda stråldiagrammet föregicks av talat språk, men ritades på tavlan utan att ytterligare förhandling var nödvändig. Att detta diagram var lämpligt i situationen tycks ha tagits för givet, det var något som 'stod fast' (jämf. Wickman & Östman, 2002; Wittgenstein, 1953). En bidragande orsak till att användningen av detta diagram inte behövde motiveras ytterligare kan vara att det är så vanligt förekommande. Exempelvis har ljusstrålediagrammet funnits vara det vanligast förekommande diagrammet i en studie av tyska och engelska läroböcker för universitet (Hüttebräuker, 2010). När Vera pekade ut svagheterna hos detta diagram avseende dess användbarhet för att förklara *varför* refraktion uppkommer, fick hon först inte gehör hos de andra studenterna. Det krävdes en diskussion inom gruppen för att komma fram till vad det var ljusstrålediagrammet *inte* kunde bidra med. När ljusstrålediagrammets tillkortakommande stod klart ledde diskussionen, via en omformulering av ljus som en elektromagnetisk våg, till införandet av vågfronter som en lämplig representation. Beskrivningen av vågfronter var först talad och simulerad med gester. Under detta kritiska skede av diskussionen skiftades brytningens orsak från att vara en egenskap hos mediet som ljuset färdades i (tunn/tjock), till att vara en egenskap hos ljuset självt (snabbt/långsamt). Till slut ritades ett vågfrontdiagram av studenterna. Det var nu denna beständiga representation som 'stod fast', som ett "nav" eller en "koordinator" kring vilken tal och gester i deras förklaring av refraktion kunde kretsa. Detta kunde ses i att var och en av studenterna tog sig an det och försökte ge sin egen formulering av hur processen/brytningen av ljuset gick till. Ett par aspekter av vågfrontsdiagrammet som kan bidra till dess framgång i att förklara refraktion är: vågfronternas periodicitet, vilken kan ge en uppfattning om den relativa skillnaden mellan ljushastigheten i de olika medierna (vilken är proportionell mot avståndet mellan vågfronterna), och att vågfronterna är vinkelräta mot ljusets färdriktning (ljusstrålens riktning) och alltså har en rumslig utbredning.

Airey och Linder's (2009) idé om en kritisk kombination av semiotiska resurser för förståelse av fysikaliska fenomen kan skönjas i beskrivningen av studenternas diskussion ovan. Det krävdes både talat språk, gester, matematisk symbolism och olika diagram för att de skulle lyckas genomföra en tillfredsställande förklaring. Emellertid visar analysen att för Vision (I) scientific literacy, dvs. att kunna aktivt delta i akademiska naturvetenskapliga sammanhang, räcker det inte med behärskandet av en kritisk kombination av semiotiska resurser. Begreppet Vision (I) scientific literacy måste istället nyanseras: vissa beständiga semiotiska resurser verkar ha en mer central roll i beskrivningen av ett visst fenomen, och det är runt dessa resurser som användningen av andra semiotiska resurser kretsar. Kunskaper om *vilka* beständiga resurser som är lämpliga i en viss situation blir därför avgörande. Scientific literacy kommer därmed delvis till uttryck i studenternas kunskap om vilka beständiga semiotiska resurser som är lämpliga för att effektivt behandla ett visst fenomen.

Vår tolkning av analysen ovan, och dess betydelse för undervisningssammanhang, är att i strävan att uppnå en funktionell Vision (I) scientific literacy, behöver studenter ges chanser att erfara vilka begränsningar som existerar för vad en viss semiotisk resurs kan åstadkomma. Begränsningarna hos en viss resurs bör samtidigt kontrasteras med möjligheterna hos en annan. Mer forskning krävs för att utröna om det är möjligt att peka ut generella egenskaper hos olika semiotiska resurser, vilket kan ge indikationer om dess användbarhet för olika ändamål. Vi vill också peka på möjligheten att en kombination av semiotiska resurser har andra egenskaper och möjligheter än enstaka resurser. Dessa kombinationer kan dock inte väljas slumpmässigt, utan var representation kan ha sin plats, även om det är svårt eller omöjligt att överskåda hur de fungerar tillsammans. Sammanfattningsvis är det därför viktigt att studenter, under överinseende av lärare eller mer erfarna studenter, får möjligheten att öva på att integrera semiotiska resurser tillsammans med sina medstudenter.

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