It's rather like Learning a Language: Development of talk and conceptual understanding in mechanics lessons

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It's rather like Learning a Language

Development of talk and conceptual understanding in mechanics lessons

Although a broad literature exists concerning the development of conceptual understanding of force and other topics within mechanics, there is little known about the role and development of students' talk about the subject. This paper presents an in-depth investigation of students' talk whilst being introduced to the concept of force. The main research goal was to investigate and understand the process of students' developing understanding of the concept of force as well as the way students use and understand the term 'force'. Therefore we make relation to the research field of students' preconcepts and the field of second language learning. Two classes of 47 students were camcorded during a time period of nine lessons, each transcribed and analysed using a category system. Additional data was obtained via written tasks, logs kept by the students and tests. The detailed analysis of the talk and the result of the tests indicate that students are facing difficulties similar to those when being asked to use a foreign language in language lessons when they are asked to use the term 'force' scientifically. It was Vygotsky who recognised a relationship between learning in science and learning a language. In this paper important aspects of this relationship are discussed based upon empirical data. We conclude that in some respects it might be useful to make reference to the research related to language learning when thinking about improving science education.

Introduction

In recent years the role of language in science education has been emphasised by many authors (Bellack, Kliebard, Hyman, & Smith, 1966, Bennett, 2003, Brown & Ryoo, 2008, Jones, 2000, Lemke, 1990, Mortimer & Scott, 2000, Rodrigues & Thompson, 2001, Roth & Lawless, 2002, Scott, 1998, Sutton, 1998). In particular, the research field of discourse analysis of classroom talk provides an interesting insight into the way meanings are shaped and shared in classroom talk. Some earlier contributions refer to classroom talk as a 'language game' in which every participant highlights a special role defined by permitted moves inside the game (Bellack et al., 1966). Thus the metaphor of the language game is a vehicle of describing and analysing the flow of discourse. The term 'language game' is essential for the writings of Wittgenstein (Wittgenstein, 1958). Wittgenstein used the term 'language game' as a framework to explain how words acquire their sense: Words do not *have* any sense themselves – they acquire it in the course of a language game. Those language games are activity structures where people act and talk together, and words take on their sense according to their function within this game. The well known book of J. Lemke 'Talking Science' (Lemke, 1990) refers to this philosophical framework (p. 185) and extends it to a theory of social semiotics with respect to science education. Lemke claims that the 'triadic dialogue' (p. 217) is a very common form of interaction, also known as I-R-F-pattern ('Initiation - Response - Feedback', Mehan, 1979, Edwards and Mercer (1987)) or as I-R-E pattern ('Initiation - Response - Evaluation', Sinclair & Coulthard, 1975). He identifies other recurring patterns, for example the student-questioning dialogue or the teacher-student debate. Such social 'activity structures' (p. 186) serve as tools for meaning-making. In this view meaning can be thought of as a result of social activities. Learning science therefore includes learning to speak like members of the social community of scientists. In consequence Lemke asks teachers to 'model scientific language by explaining to students how they themselves are combining terms together in sentences' (p. 170). Thus Lemke recommends that the so called meta-discourse to play an important role in science education. With reference to Lemke, Jones (2000) explains that the 'dominance of low-level IRF activities often presents science to students as if it is objective [...] and not the study of what people have [...] said about nature' (p. 94). Sutton (1992) recommends teaching science as a way of 'inducting someone into new ways of seeing and new ways of talking' about nature.

In addition to this strand focusing on discourse analysis another strand exists concerning the quality and nature of a teacher's explanations in science education: Ogborn, Kress, Martins, and McGillicuddy (1996) point out that the 'act and art of explaining to a class is much less discussed than scientific ideas to be explained' (p. 2) and develop a framework for what they call a scientific explanation. This framework is governed by the metaphor of a 'story', although not thought of as a narration but rather as a set of cooperating protagonists, each of them characterised by special capabilities. Within this framework, terms like 'force' or 'energy' form protagonists which are capable of 'doing' something with other protagonists. In this view a scientific explanation is a 'story' about these protagonists, operating within their cooperation and by this means explaining causal connections (p. 9). Sutton (1998) draws upon the metaphor of 'science as a story', too, also not implying narration. Sutton recommends emphasising in science education that scientific knowledge is a result of social interactions: 'The word 'story' has many advantages in comparison with 'fact' or 'truth'. It involves learners and invites them to think 'Is it reasonable?"(p. 37).

In the course of the last decade many contributions to the role and practise of language in science education have been influenced by the writings of L. S. Vygotsky: Scott (1998) and Bennett (2003) point out that the increasing impact of Vygotsky's writings could account for the growing interest in the role of language in science education. Vygotsky claimed that 'higher psychological structures (such as scientific conceptual knowledge) appear, 'first between people as an interpsychological category and then inside the child as an intrapsychological category" (Vygotsky, 1978, p. 128). Within the strand of research projects informed by Vygotsky's writings Mortimer and Scott (2000) characterise content, form and patterns of utterances based upon their 'flow of discourse analytical framework' (Mortimer & Scott, 2000, p. 129). They expand the I-R-F-pattern by differentiating as to whether students' utterances match the intended learning goal or not (content) and attributing it to either a description, explanation or generalisation (form). In addition, the nature of teachers' (and students') interventions is described (pattern). These interventions are divided into three major groups: 'developing scientific knowledge; supporting student meaning-making; and maintaining the teaching narrative' (Mortimer & Scott, 2000, p. 131). Mortimer and Scott distinguish two social languages used in the classroom – the scientific and the spontaneous, or everyday, language. 'This, of course, can lead to teacher and students talking about the same phenomenon in quite different ways.' (Mortimer & Scott, p. 128). These two languages have been discussed already by Vygotsky (1986): He compared the relationship between these languages with the relationship between the native and a foreign language of a speaker. Primarily we will draw on this comparison in this text. Furthermore, we will discuss to what extent learning science can be compared with learning a new language.

Theoretical framework

In addition to the subject-specific terminology many morphologic and syntactical features particular to the scientific language can be identified. These features distinguish scientific- from everyday language. At first glance it might seem that the difficulties experienced by students with the scientific language follow from these rare features with which students are not familiar. But Bennett (2003, p. 153) explains 'Whilst the research has confirmed that the language of science can pose difficulties for pupils, other research has suggested that the problem is less to do with the technical vocabulary of science than might be expected.' So it may be assumed that these difficulties emerge not in the first place from the technical vocabulary but from the fact that scientific conceptualisations (in many cases so far from everyday experience) are closely connected to scientific language. On the other hand, everyday language is connected to typical and well known pre-instructional conceptions (pre-concepts) informed by everyday experience (e.g., Hestenes, Wells, & Swackhammer, 1992). Thus the difference between scientific and everyday language reflects in large part the differences between scientific concepts and those ideas used and expressed by the students.

Langage and (scientific) concepts

Similar to Brown and Ryoo (2008) we disaggregate science instruction into 'explicit conceptual and language components' (p. 534), because we assume that students experience at least two developments whilst being taught science: They become familiar with scientific concepts and a new language connected to these concepts – not only single new words. Related to this distinction our perspective onto what is happening in the classroom is informed by two perspectives:

Our first point of departure is the research field concerned with students' preconcepts about mechanics (e.g., Jung, Wiesner, & Engelhardt, 1981; Wiesner, 1994; Hestenes et al., 1992), which is closely connected to the educational research on conceptual change (e.g., Duit, 2003). The knowledge provided by this research field offers a profound insight into students' pre-instructional ideas about force, energy, momentum, velocity or acceleration. The study is based on a teaching sequence concerning an introduction into the concept of force, therefore we mainly draw on the knowledge about students' pre-instructional conceptions about force and their difficulties with the scientific concept of force. These pre-instructional conceptions are in large part expressed by common ways to use 'force' in everyday conversation. Dependent upon the context it is used synonymously with energy or momentum in addition to many other uses. It's in this broad range of meanings from informal everyday use to more scientific uses that the problem of polysemy arises which challenges both teaching and learning (Strömdahl, 2007). The pre-instructional conceptions expressed within vernacular often have the distinction of 'force' as a property of a single object: 'She is a very forceful person' could serve as an example. Teaching the concept of force in mechanics lessons includes stimulating and supporting students not to replace but to complement the informal ideas by a scientific concept of force which expresses an interrelation between at least two objects. More details concerning the various features of pre-instructional conceptions will be discussed later in this text when the system of categories used to analyse transcribed videotapes will be explained.

In addition to the research of pre-instructional conceptions the framework is founded on the research field of second language learning. If we start from the assumption that students experience a language learning process we need a framework which allows us to map observations made in mechanics lessons to theoretical or empirical results in the research field of second language learning.

An extensive literature research in the field of (second) language learning bears some remarkable contributions which help us to understand what happens in science lessons. We will summarise the most important topics which we will draw upon in the following sections:

The role of formulaic phrases

Language learners such as native speakers generate their sentences by far not only by using grammatical rules. Much of everything we say consists of phrases not formed creatively but retrieved wholesale from memory (Bärenfänger, 2002). These phrases can be regarded to some extent as automated or formulaic. Language learners such as native speakers profit from the use of formulaic phrases: Memorising and using formulaic phrases permits language learners to extend their abilities to communicate. These formulaic or automated phrases free them, to some extent, from using their limited vocabulary and knowledge of grammatical rules, thus they are able to express complexities which they would not be able to do based on their knowledge of rules and vocabulary. Such formulaic phrases serve to some extent as 'islands of reliability' (p. 126) – as they do not ring false for language learners because they are retrieved wholesale from memory. Native speakers accelerate their production of sentences by using formulaic phrases. They do not have to be complete sentences – often they consist of only a few words. Consequently, it is recommended that language learners memorise short phrases or at least some words that belong together rather than single words: 'So this (phrase) is another piece of information about a new item which it may be worth teaching. When introducing words like *decision* or *conclusion* we may note that you *take* or *make* the one but usually *come* to the other' (Ur, 1996, p. 61). Similar state Bleyhl and Timm (1998), p. 263: 'A single word is like nothing, it requires a linguistic environment'.[1]

[1]translated by author

Either following grammatical rules or communicating with somebody – a common conflict

Edmondson (2002) p. 62 summarises that learning outcomes while learning a new language depend on the quality of cognitive and affective processing achieved by the learner. The deeper the learner engages, cognitively and affectively, the higher the achievement. On the other hand, this engagement effects higher cognitive loads and thus limits the learning outcomes. So it can often be observed that learners decide whether to concentrate on following grammatical rules or on communicating a specific content. This decision can be seen as a process of assigning resources either for processing rules or contents. Edmondson concludes that learning grammatical rules or communicating with somebody, are in many cases mutual exclusive alternatives whereas it can be frequently observed that the learner decides to concentrate on the content and neglect grammatical rules (van Patten, 1996).

Native language - interlanguage - second language

Novices (in terms of a new language) may use their language in quite a simple manner due to the limitations in their knowledge. But simplicity is not the most significant feature of a novice's spoken or written sentences. Novices develop to some extent an individualised language which is influenced not only by the language to be learned but also by their native language. It was Selinker (1972) who introduced the term 'interlanguage' to label this specific language used by and depending on the learner. He described it as variable, flexible and to some extent self-reliant and systematic. Later in this text we will make reference to the interlanguage while analysing the language used by the students in science lessons.

Diehl, Pistorius, and Dietl (2002) observed that language learners have to master fundamentally three steps or phases on their path from beginners to becoming advanced users: During the first phase they tend to memorise short phrases and use them in a formulaic manner. According to Diehl et al. the second phase is triggered by a cognitive overload caused by the increasing amount of formulaic phrases to be remembered. Thus the learners begin to seek for new methods to master their communication needs. They start to work their way through the variety of linguistic forms. Diehl et al. call it the 'turbulent phase', because the learners behave like they have never been taught language, and there is no avoiding this phase. During the third phase, the learners fit their interlanguage to the target language, as long as they are disposed to discard temporary self-made 'rules' which belong to their interlanguage.

The study

Research question

The main research goal was to investigate and understand the process of students' developing understanding of the concept of force as well as the way students use and understand the term 'force'. Moreover the study asks to what extent results of language learning research can help us to understand the empirical data. This means that the study asks to what extent observations made within students' classroom talk in physics lessons can be linked to language learning processes.

Design: Sample and teaching method

47 students participated in the study. They were 14 years old and came from two classes of two public secondary-schools. Both classes were taught by the same teacher. The underlying teaching sequence covered an introduction to the basic ideas of mechanics. The first section (about eight lessons) focused on the description of motions. Thus an introduction into the dynamic concept of force was prepared which, at the end of the second section (about nine lessons), resulted in the 'second Newton's law' $\vec{F} \cdot \Delta t = m \cdot \Delta \vec{v}$. A teaching sequence structured in a similar way was already proposed for example by Wiesner (1994) and evaluated with positive results by Wodzinski and Wiesner (1994).[2]

[2] A detailed description of the whole material including all texts and tasks can be found in Rincke (2007) or via internet using the persistent identifier urn:nbn:de:hebis:34-2007101519358, for example by typing https://kobra.bibliothek.uni-kassel.de/handle/urn:nbn:de:hebis:34-2007101519358

In addition to the suggestions of Wiesner and Wodzinski two further features were applied to the teaching sequence presented here whereas the whole teaching sequence was piloted with 55 students before being used within the study:

Firstly, everyday and scientific language were clearly differentiated. It was explained to the students that any scientific use of the term 'force' explicitly denotes at least two partners involved in an interaction, for example 'the ball exerts a force on the ground'. Thus the students were given an easy-to-use criterion to indicate any scientific use of the term force. In all tasks and texts used during the teaching sequence mixing up the different languages was studiously avoided. Thus a well known problem common in textbooks was avoided, namely that everyday and scientific use of specific terms appear within the same text without any appropriate explanation to the different language uses, see for example Bennett (2003, p. 169) referring to English textbooks or Rincke (2004) for German ones.

Secondly, the meta-discourse suggested by Lemke (1990) played an important role: The aim of the meta-discourse was to engage students in a discussion about language including syntactic and semantic features of informal everyday talk or formal scientific use of the term 'force'. Thus the simple criterion of differentiating between scientific and everyday language explained above was accompanied by profound discussions about what the meaning of a given description could be or to what extent it describes what was to be described. Students were encouraged to discuss the differences between everyday and scientific use of the term 'force', referring particularly to the different ideas associated with the the given statements.

This teaching method is not only influenced by Lemke but also by Noam Chomsky who introduced the deep structure and surface form to model the relationship between language and thought (Chomsky, 1957). Chomsky's idea of the surface form of language is related to the criterion mentioned above: In the first step a scientific use of the term 'force' in this teaching sequence can be identified by searching for (at least) two interacting objects. This interaction normally is described by the phrase 'one object exerts a force on the other object'. Thereby this criterion refers only to the surface form. Chomsky's idea of the deep structure of language is related to the meta-discourse. During this meta-discourse students discuss the ideas related to a given statement. Appropriate descriptions of the motion of a ball or a skater are identified and inadequate uses of the term 'force' are revealed even if two interacting objects seem to appear in the text.

Examples

At the beginning of the second part of the teaching sequence the students themselves camcorded several scenarios, for example playing with a ball, riding a bicycle or skating. Afterwards these films were analysed using a personal computer. This analysis aimed at the best accuracy in describing the motion. Therefore, for example, speeds and directions of the motions were measured. While analysing the filmed motions students realised that a velocity of a person or a ball never changes without the influence of another object, i.e. the ground, a staircase, the air, the earth or anything else.

After having filmed and analysed some motions in the described way the phrase 'one object exerts a force on another object' was introduced to the students. This introduction was closely connected to the examples given by the videotapes by 'translating' the interaction of the bodies viewed in the videotape into 'scientific' descriptions: The statement 'the earth pulls the ball down' was translated into the sentence 'the earth exerts a force on the ball downwards'. Then students had to write down some statements about their films using 'force' in the 'scientific' way. Thus the term 'force' was not introduced by a definition in the way found in several textbooks; it was introduced by giving examples which showed how the term 'force' interacts with other terms within a given phrase. This way of introduction was brought through Wittgenstein's idea of 'language games' (Wittgenstein, 1958) as activity structures determining the word's sense.

The scene shown in figure 1 fell within the scope of one lesson (note that all lessons discussed in this paper refer to the second section of the teaching sequence – so lesson 1 in figure 1 refers to the first lesson of the second section of the teaching sequence). The overarching question was to understand the risk of a neck fracture in a head-on collision. Firstly students watched a movie showing a crash test in slow motion. Then the scene was described and discussed using words and expressions without any support from the teacher. Firstly the students talked informally. Then figure 1 was presented to focus on the motion of the head of the dummy. The vector difference $\Delta\vec{v}$ of the two given arrows (velocities) was marked in the picture, indicating that there must be something exerting a force on the head of the dummy. The students were now asked to refer to the motion of the dummy and to use the term 'force' scientifically.

[Insert figure 1 about here]

Figure 2 refers to a similar task presented in the test at the end of the teaching sequence. Students had to make a statement using the term 'force' scientifically and referring to the motion of the ball during the time period from 1 to 2. The accompanying text emphasised that the statement must not refer to the beginning of the motion (i.e. the action of the sportsman).

[Insert figure 2 about here]

Figure 3 gives examples of tasks involving students in a meta-discourse. They are given four statements and have to explain whether the term 'force' is used scientifically or not. In addition they are asked what else (other) the speakers may talk about if it is not 'force' in a scientific sense. Thus different understandings of the word 'force' could be discussed. Students were given the chance to talk specially about their preconcept and its possible contrast to the scientific concept of force.

[Insert figure 3 about here]

Design of the study: Data collection

All lessons belonging to the second section of the teaching sequence were audio- and videotaped, then transcribed (approximately nine lessons in each group). In addition, the students kept a log. Here they wrote down their ideas to some of the given tasks, they also had to do some tasks in pairs and to write down their findings. Thus at the end of the teaching sequence every written or spoken sentence could be assigned to its speaker and was accessible in the following rule-based analysis. Owing to the large amount of the text material, a smaller group of students had to be chosen for this analysis. This choice was made according to the number of words uttered by the students. In the first class (19 students in total) seven students were selected, whose utterances amounted more than six percent ($\approx 1/19$) of the total number of words spoken in all lessons. This smaller group of seven students covered about 80 percent of all words spoken. In the second class (28 students in total), 13 students were selected, whose utterances covered more than three percent ($\approx 1/28$) of all words spoken, thus this smaller group covered approximately 80 percent of all words spoken, also. So the utterances of a group of 20 students in total were included into the detailed analysis.

The investigation of the text material was done by means of a content analysis following the approach of Philipp Mayring (Mayring, 2000, 2003; Kohlbacher, 2006; Krippendorf, 1980). This approach to content analysis aims at a rule-based, traceable process of unveiling implicit properties of a given text corpus. It is centred on the development and application of categories which fit the research interest. This system of categories has to fulfil quality factors, expecially concerning its reliability. For this study the system of categories was developed through a long lasting process beginning with a pilot study (55 students) undertaken one year before the main study began. The main goal of this pilot study was to improve and tweak the teaching sequence, especially in respect the tasks to be used. However, as in the main study, all lessons of the second section of the teaching sequence were camcorded and transcribed during this pilot study also. This was necessary to be able to begin with the development of the category system. The result was a draft-version which was further developed in accordance with the following steps:

- About $50\ \%$ of the text material was read (according to the recommendation of (Mayring, 2003), p. 75).
- A summary of this part of the text material was generated in a rule-based manner: Therefore a set of criteria was established determining which utterances from students should contribute to the summary. The criteria were deduced from the theoretical background explained above.

These criteria concerned utterances in the text indicating to what extent speakers

1. feel secure while using the phrase ‘to exert force on’ (see ‘island of reliability’),
2. use the phrase ‘to exert force on’ in a seemingly automated or formulaic manner,
3. seem to suffer from a conflict between the claim to use the word ‘force’ scientifically and their communication aims,
4. apply known pre-instructional ideas about force to a given task,
5. reveal a correct scientific concept when being asked to talk scientifically.

The summary extracted by this procedure showed that many utterances referred to the criteria No. 2, 4 and 5. The first and third criterion appeared to be unsuitable, because conflicts or the impression of security emerge from single utterances very seldom. However, later we will show that there are manifesting conflicts when looking deeper into the data. Now it was possible to establish a refined set of criteria which resulted in a new system of categories: No. 4 and 5 (see above) resulted in the categories we will from now on refer to as ‘type 1’, see table 1. Criterion no. 2 resulted in the categories of ‘type 2’ (table 1).

[Insert table 1 about here]

Thus the category system is divided into two parts: Categories of the first part (type 1) concern the use of the term ‘force’ by students. It is therefore related to situations in which students were explicitly asked to use the term ‘force’ scientifically, see for example figure 2. The second part of categories (type 2) refers to the way students talk about their own understanding of the term ‘force’. It is therefore related to situations in which they were involved in a meta-discourse. During this meta-discourse students were, for example, given a few different short texts describing a motion. In the texts the word ‘force’ was either used scientifically or as in everyday discourse, see figure 3. Students had to explain how the use differentiated.

The whole text material (all utterances of 20 selected students in total) was divided into four portions all of which were analysed independently by four pairs of investigators. One part of the text material (about eight percent) was analysed by all pairs of investigators and Cohen's Kappa was computed ($\kappa_1 = 0.81$, $\kappa_2 = 0.64$, $\kappa_3 = 0.86$, $\kappa_1 = 0.72$) to provide security for a sufficient level of reliability. The reached level can be seen as satisfactory, especially with respect to the fact that some categories ask the investigator to interpret to some extent.

Additional data were collected, figure 4 gives an overview: All students were tested with the verbal component of the cognitive ability test (Heller & Perleth, 2000). At the end of the second part of the teaching sequence they had to pass a test related to the contents of the teaching sequence. This test included some basic tasks related to the first part of the teaching sequence (which is not in the scope of this article) and some tasks similar to those which had been discussed during the second part.

[Insert figure 4 about here]

Six months later the students were tested once again. This test (test 3 in figure 4) included a task very similar to the one shown in figure 3. In addition, a new type of task was given. This type was designed to get more information about the way students take into account elements from content or surface form of sentences when reading about 'force'. The main idea of this type of task was that the students had to translate given (common usage) sentences into scientific ones. Firstly they had to decide whether a translation is possible or impossible. The design of the given sentences, i.e. the design of the task shall be explained in more detail. The sentences were manipulated to relate to two assumptions:

1. The first assumption was that sentences following the pattern, subject – transitive verb – object, encourage students translating it into a scientific one because this pattern is the same as using the phrase 'to exert force on'. This assumption relates to the surface structure of the sentence.

2. The second assumption was that sentences denoting an action effected by one object onto another object stimulates the students to translate also. Note that these actions may not necessarily use transitive verbs. This assumption refers to the deep structure of the sentence. The sentence

'the ball is kept by the ballplayer' for example does not follow the pattern subject – transitive verb – object, thus (accepting the explained assumptions) it may not support a translation due to its surface form. But it may stimulate students to translate it similar to 'the ballplayer exerts a force on the ball' because the given sentence communicates an action effecting the ball (intended deep structure stimulates a translation). But a translation like 'the ball exerts a force on the ballplayer' would of course be correct, too. The latter translation may be interpreted as being sustained by the surface form in a more general view i.e. following a pattern like subject – verbs – object.

In the test six sentences were given, systematically varying the two features explained, see table 2. Sentences nos. 2 and 4, the intended deep structure of which do not support a translation, however, mention the word 'force' in an informal sense. These sentences are believed to particularly challenge students' understanding of the concept of force: Those students who are aware of an adequate scientific concept of force are expected to avoid the translation although the word 'force' is explicitly mentioned! The asterisks in the table indicate those sentences which may be translated in two different ways (either sustained by the surface form or the deep structure, similar to the given example above).

[Insert table 2 about here]

Analysis

The category system is divided into two parts as shown in table 1. Categories within the first part are used when students are explicitly asked to use the term 'force' scientifically. Those within the second part are used when students are asked to participate in a meta-discourse. During the teaching sequence six lessons were characterised mainly by tasks asking the students to use the term 'force' scientifically. Thus the utterances had to be categorised by categories of type 1. In the course of two, nearly whole, lessons the students were employed with a meta-discourse, so categories of type 2 had to be applied. In the following sections the results of these lessons will be discussed.

Students' use of the term 'force'

To gain a systematic insight into the way students use the term 'force' the group of 20 selected students was further divided into five additional subgroups I-V. This division was made in each of the six lessons and was related to the assigned categories as it is shown in table 3. Subgroup (I) includes those students who mainly used the scientific phrase (or attempted to do so), i.e. their utterances belonged to *interaction* or *attempt* more often than to *quantity*, *actor* or *others*. Subgroup (II) includes students whose utterances belonged to the categories *actor*, *quantity*, *others* equal or more often to *interaction* or *attempt*. Subgroup (III) denotes those students who never used the term 'force' to express an interaction between different bodies (i.e. no scientific use in the course of the lesson). Table 4 offers an overview over the results: Student nos. 1, 2, 6, 7, 9 and 13 use the scientific phrase or try to use it quite often (three or more times subgroup (I)) Student no. 17 belongs four times to subgroup (II). This means that scientific and everyday use of the term 'force' are quite mixed (see table 3). Students 8 and 16 belong four or five times to subgroup (III). This means that they almost never use the term 'force' in the way the teaching sequence intended to. Overall the table gives the impression that students use the term 'force' in a very heterogeneous way. Surprisingly, there is little, if no evidence that students had progressed towards becoming familiar with scientific use over time. It is therefore reasonable to investigate in more detail under which conditions students imply an interaction while using the term 'force' and under which conditions they tend to fall back into everyday speech. The following examples of students' utterances are translated into English as close to the original as possible. All utterances can be found in the original work Rincke (2007) (available via internet). In Rincke (2007) each utterance is counted. We will give the original number in parenthesis, thus the interested reader can examine each utterance in its original language.

[Insert table 3 about here] [Insert table 4 about here]

The dilemma between surface form and communicative interest

The following examples show that many students who are asked to use 'force' scientifically seem only to see two different and mutually exclusive choices: They choose either to follow the linguistic model given by the teacher or to follow their own communicative interest. The first choice is centred on the surface form, the latter relate to the content, or deep structure, of the statement. It can be observed quite frequently that students following the surface form (so trying to use the phrase 'to exert force on') tend to ignore the topic of the discussion or, in some cases, obviously do not understand what they themselves are talking about. The example given by Eva (student no. 13 in table 4, found in their log, illustrates this very clearly. She refers to a videotape showing two students throwing a ball back and forth:

Eva: "One person exerts a force on the ball and throws it to another person. The other person catches the exerted ball. The other person exerts a force on the ball and throws it back. The to exerted balls are thrown back and forth." (163)-(166)

Eva seems to test the new phrase – she uses several fragments of the phrase 'to exert a force on a ball' with different grammatical functions, for example 'exerted' with function of an adjective. One may suppose that Eva tries to detect what function the different fragments of the phrase may have. She seems to be concentrated on following the pattern given by the teacher, the content being unimportant. In the context of the crash test (see figure 1) which was discussed in lesson 6 (see table 4) only a few utterances following the scientific linguistic pattern can be found. Eva says:

Eva: "The man exerts a force on the windshield" (277)

That is obviously correct, but the discussion is on those things effecting the man (crashtest-dummy). The lesson deals not with the destruction of the windshield but with the risk of being hurt. Peter (student no. 15 in table 4) says:

Peter: "The engine exerts a force on the car so it crashes against the wall with high speed." (277)

Similar to above this might be correct in a way but it is clearly off-topic.

Certainly the majority of the utterances in this lesson are not off-topic, but the majority of the students however entirely ignore the fact that they are asked to use 'force' scientifically. This is surprising because the teacher gives a lot of hints, narrows the discussion on only a few aspects, and, in the end, asks explicitly who or what is exerting a force on the man. Salim (student no 14 in table 4) responds:

Salim: "The pressure from the wall when he's going towards the wall [...]." (260)

Within this quite complex context of a crash test students are faced with a particular dilemma: We describe it as a dilemma between surface form and students' communicative interest. This dilemma is characterised by two different and mutually exclusive choices for the students: Either to follow the scientific pattern and ignore the topic of the discussion or to follow their own communicative interest and ignore the necessity of expressing an interaction of two objects. Unfortunately neither the first nor the second choice stands a good chance of winning the teacher's approval, because neither fulfils the requirement to use the term 'force' scientifically.

Strategies: How to avoid an unfamiliar use of the word 'force'

Referring again to the example of a pole jumper (lesson 4 in table 4), the scientific use of the term 'force' can be observed more often than in the lesson concerned with the crash test (note that the example task shown in figure 3 was not within the scope of this lesson but that of lesson 5). As in the case of the crash test lesson the students watched a video of the pole jumper in slow motion and then described the motion in everyday talk. Then, after one student had used the word 'force' spontaneously in his description, the whole class was asked by the teacher to describe the motion using the term 'force' scientifically (at this point categorising the video using categories of type 1 starts). But even within this context there can be observed a frequent change between scientific and everyday uses of the term ‘force’. The following analysis posits that these changes do not happen casually; perhaps this could be interpreted as a process of problem solving: When students are asked to talk scientifically they have to locate appropriate objects interacting with each other. Furthermore they have to trust that these objects have the potential to effect something on another object. In many contexts this percieved ‘active’ role has to be assigned to objects like the ‘ground’ or – in this case – the ‘pole’. Students often do not trust in the capacity to interact. This may be the reason for that they fall back into the everyday way arguing because this allows avoidance of attributing a seemingly ‘active’ role to inanimate objects such as the ground or the pole. Peter (student no. 15 in table 4) says:

Peter	"He exerts a force on the pole and goes, yes, is catapulted up by the pole."	(196)-(197)

This pattern can be found in a variety of utterances, another example is given by Vivien (student no. 6 in table 4) who refers to a person playing with a ball:

Vivien	"A person exerts a force on the ball, the ball drops with much force on the ground."	(167)-(168)

It may be easy to assign an active part to a person because this alignes to common preconcepts. But it is difficult to do the same in the case of the ground because this seems to be far from everyday experience. The ground in this view is nothing more than an inanimate barrier, incapably exerting anything. Thus the speaker argues in scientific terms as long as it is an ‘active’ object exerting a force (a person). In the case that it might be the pole or the ground exerting a force on the ball, the speaker resorts to everyday talk. Everyday uses of the term ‘force’ do not compel students to talk about objects interacting with other objects. The falling back into common parlance everyday ways of talking can be found very frequently within the data.

In addition two more strategies for handling seemingly interacting objects appear: Often students invent to some extent a particular story and attribute it to a given situation, a story which typically provides 'true active partners'. Figure 2 gives an example of a task. Students have to provide a statement to the depicted situation using 'force' scientifically. The vertical arrow points to the earth which is just represented through a horizontal line. The majority of the students do not include the earth in their descriptions. They prefer to talk about the sportsman hitting the ball although it is emphasised specifically in the accompanying text to the task that the statement must not refer to the beginning of the motion (action of the sportsman).

A quite elegant way of solving the problem of handling seemingly active objects which can be observed sometimes within the data is to use a rather impersonal style of talk: 'There is a force exerted on the breaking skater' may serve as an example. The statement expresses the interaction required to be described without stating who or what is exerting the force. So the speaker does not tend to assign an active role to the ground which is exerting the force on the (breaking) skater.

These different strategies may be collectively described as strategies of avoidance. They provide a way to cling onto preconcepts. The way in which the word 'force' is used scientifically obliges students to assign unfamiliar roles to objects. This seems to be a tough challenge. Students normally are aware of mapping their statements to their ideas of a given situation. This means that they do not talk scientifically to fulfill what the teacher asks them to do – they talk scientifically if there is almost no gap between their preconcept and what the scientific phrase 'to exert a force on' may intend. Otherwise if there is an enormous gap between students' preconcepts and what a scientific statement would express they prefer to relapse into everyday talk.

Student's way of participating in the meta-discourse

When students engage in a meta-discourse two patterns of argumentation can be identified: If asked whether a given statement belongs to everyday- or scientific talk students may refer to the surface form (i.e. the presence of particular keywords). The second pattern is that they refer to its deep structure (i.e. the content of the statement). If following exclusively the second pattern they do not make relation to the presence or absence of typical phrases like ‘to exert force on (see table 1, categories of type 2). Figure 3 gives an example of a task. As mentioned above two lessons were characterised by tasks stimulating this meta-discourse. To get an insight into how students argue the group of 20 students was divided into four subgroups following the scheme indicated in table 5. As in the previous case, this division was made for the two lessons (and for the results of the meta-discourse related task during the test half a year later). Table 6 shows the results. Although some data is missing, the table clearly shows that the majority of the students make reference to the surface form as well as to the content: The affiliation to subgroup (i) appears only three times in table 6, twice for student no. 13 and once for student no. 20. This means that there are few examples for utterances belonging to the category *surface form*. Subgroup (ii) appears 13 times, this means that the utterances of these students belong more frequently to *content structure*. Subgroup (iii) appears 19 times. These students argue referring equally to the surface form and to the content of a given statement when they are asked whether it belongs to scientific or every day language.

[Insert table 5 about here] [Insert table 6 about here]

The tasks used to stimulate the meta-discourse always required the students to explain their decisions. Many students argue in the following way: If the given statement belongs to everyday talk, they refer to the content of the statement (and not to the absence of the phrase ‘to exert force on’), for example (see statement of Thomas, figure 3):

> ‘Thomas’ statement belongs to everyday talk. The word ‘force’ means energy.’ (351)

If the given statement belongs to the scientific use of the term ‘force’ they argue with the presence of the phrase ‘to exert force on’ and, in addition, in many cases to its content, for example (see statement of Maria, figure 3):

> ‘Maria’s statement is scientific because two interacting bodies can be found, one which is the person, another which is the force exerted on.’ (343)

In the previous section we showed that students faced with the aforementioned dilemma very frequently decide to follow their communicative interest and ignore scientific aspects – even when asked by the teacher to look for interacting bodies. It is noteworthy that within the meta-discourse the majority of the students make relation to the surface form of a given statement and to it's content – therefore iii appears frequently in table 6. This means that while dealing with scientific phrases within a meta-discourse, interacting bodies (as an essential element of the concept of force) are more likely included in students' utterances in a discussion.

Achievement test and cognitive ability test

As explained in the previous sections, the students passed the verbal part of the cognitive ability test before the teaching sequence started. In the end they passed an achievement test related to the basic ideas of mechanics which had been within the scope of the teaching sequence ('test 2' in figure 4). The results met the level of performance the students had revealed in the previous half of the year and were rated as 'normal' by the teacher (average of 60% correct solutions, $\sigma = 18.4\%$), but there was only a weak correlation formed between this test and the verbal component of the cognitive ability test ($+0.09$). This means that the cognitive ability test is a weak predictor of the success in the achievement test. Although the study did not aim to endorse the appropriateness of the teaching methodology, it is noteworthy that the methodology does not seem to have advantaged those students achieving high scores in the verbal component of the cognitive ability test – notwithstanding the fact that the discussion about language was an essential part of the teaching sequence.

Translation task in the follow-up test

The translation task was designed to obtain more information about the role of the surface form and the intended deep structure (page 14). The students had to translate – if possible – informal sentences into scientific ones. One can expect several conditions under which students translate the given sentences:

1. students translate if triggered by the surface form (assumption 1 explained on page 14),
2. students translate if triggered by the deep structure (content, assumption 2),
3. students translate if the word ‘force’ is mentioned.

The results may be summarised as follows: If, and only if, the deep structure (content) of the given statement triggers a translation, students translate the given sentence into a scientific one, that is into a sentence using the phrase ‘to exert force on’. Thus condition 2 exclusively triggers a translation. This means that even if the surface form follows the pattern subject – (transitive)verb – object (condition 1) they avoid translating it if they cannot associate the given sentence with the scientifically correct concept. They also avoid the translation if the given (informal) sentence contains the word ‘force’ as for example in the sentence ‘the iron ball has much force’ (condition 3). There was only one exception – one student who had probably misunderstood the task tried to translate all sentences. This means that within this type of task students are able to detect everyday uses of the word ‘force’. Furthermore, they are not tempted to translate the sentence into another seemingly scientific form although the given sentence contains the word ‘force’.

There are two sentences in table 2 which may be translated in two different ways – one related to the surface form, another related to the intended deep structure (sentences three and six, marked with an asterisk). The 20 students gave in total 40 translations for these two sentences, but only six solutions can be interpreted as being sustained by the surface form. This means that similar like in the lessons when students are asked to *use* the term force scientifically the (intended) deep structure seems to be much more influential than the surface form.

Discussion and Implications

Tables 4 and 6 give an overview of the ways in which students use the term 'force' and how they comprehend it. At first glance it is remarkable that there are no students whose utterances seem to develop towards a scientific style: Every student changes his or her uses of the word 'force' dependent on the situation. The detailed analysis reveals that the often observed change between scientific and everyday talk does not happen casually but is dependent on the given situation: When students are asked to use the term 'force' scientifically they are faced with what we describe as a dilemma between the surface form and students' communicative interest. This dilemma appears in particular within complex situations, for example the cited crash test. The dilemma is characterised by two different and mutually exclusive choices for the students: Either they follow the scientific pattern and ignore the topic of the discussion or they follow their own communication interest and ignore the necessity of expressing an interaction of two objects. Both choices do not offer any real possibility to consolidate a physical concept of force.

Moreover, the frequent change between scientific and everyday talk can be interpreted as a result of problem solving: Students who are asked to talk scientifically have to locate appropriate objects interacting with each other. They have to accept that these objects effect something on another object. The strategies described can be thought of as strategies for avoiding a discrepancy between students' preconcepts and what a scientific sentence might express. Even they may serve as a way to escape the dilemma between surface form and communicative interest. This leads to a language which is influenced by the preconcepts as well as the linguistic model given by the teacher.

It was reported that within this study the majority of the students follow their communicative interest and often do not regard elements related to the surface form. The translation task in the follow-up test confirms that students' utterances are mainly influenced by the intended deep structure and not by elements from the surface form. The analysis of students' argumentation within the meta-discourse leads to the result that the dominance of content related aspects diminished in favour of formal aspects. By means of regarding aspects of the surface form, students are asked to think about interacting objects. Thus essential parts of the physical concept of force are introduced into students' debate by means of the meta-discourse.

When students are asked to use the term 'force' scientifically very few utterances expressing an interaction between objects using common verbs like 'to pull', 'to push' or 'to hit'can be found. This is surprising because the teaching method emphasises that sentences using such transitive verbs and those using 'to exert force on' are of the same grammatical structure. This observation suggests that developing an adequate concept of force and learning to talk scientifically cannot be disassociated into two consecutive steps, i.e. firstly idiomatically describing interacting bodies, then describing interacting bodies using scientific phraseology. It is more likely that students face two challenges simultaneously: accepting that objects interact and describing the phenomenon scientifically (thus talking of interacting objects). A way of talking in everyday language whilst talking about interacting objects can hardly be observed within the data. Whenever the students use their common day language they talk about force in a sense of momentum, energy, as being the property of one object. This means that everyday language and pre-instructional ideas are so closely associated that the idea of interacting objects is normally not expressed at this language level.

Thereby an interesting new question arises: Brown and Ryoo (2008) report considerable benefits from their 'content-first-approach': The idea of this approach (investigated within biologic contexts) is to treat the content using informal language, then to reutter in scientific terms. This persuasive approach takes account for the dual nature of the challenge faced by the students whilst they are being introduced to new scientific ideas: They have to become familiar with new concepts and with a new language. The content-first-approach therefore disaggregates science instruction into 'explicit conceptual and language components' – not only referring to its logical- but also chronological structure! The data reported in this study however suggest that in case of the term 'force' this chronological disaggregation seems to be impossible due to the close association between everyday language and pre-instructional ideas. In case of the topic 'force' students have to become familiar with new ideas whilst using a new language at the same time. This may account for the difficulties students have in understanding the concept of the term 'force'.

The theoretical framework explained in the opening sections is based on two research fields, namely the field concerned with pre-instructional ideas about mechanics and the field of second language learning. We will now connect our results and the summary related to second language learning.
It was explained that formulaic phrases which are used in a seemingly automated way play an important role for language learners because they tune to some extent their production of sentences: Using such sentences puts learners in the position to communicate in a way which their explicit knowledge of grammatical rules would not allow them to do. During the teaching sequence presented in this paper the phrase 'an object exerts a force on a another object' is emphasised many times by the teacher and the teaching material. Students get to know that this phrase indicates a scientific use of the term force. So it may be expected that students tend to use it very frequently in the case that they are asked to use the word 'force' scientifically. But table 4 shows clearly that only during lesson 4 the scientific phrase is used many times. It is surprising that many students remain on the level of everyday language although they are asked to use the word 'force' in a scientific way. This means that the scientific phrase, although emphasised and marked as *scientific* is not used in an automated way. The formulaic scientific phrase figures not in the way formulaic phrases often do when learning a second language.

In the section about the theoretical framework, a common conflict experienced by language learners was reported: They assign cognitive resources for processing either grammatical rules or contents. van Patten (1996) reports that normally learners decide to process contents and tend to neglect the importance of rules. Learners may regard applying grammatical rules as less important in order to follow their communicative interest. So language learning in classroom is fundamentally characterised by two contradictory aims: On the one hand talking about something (using the new and foreign language) and on the other hand learning to use appropriate vocabulary and generate correct sentences. It is difficult to pay attention to these two aims at the same time unless the given context is very simple. Thus language learners face a dilemma between requirements related to grammatical rules and their communicative interests. It is obvious that this dilemma is analoguous to the dilemma between surface form and communicative interest reported in this paper. In this respect, using scientific phrases in science lessons may be compared to following grammatical rules in language lessons. Table 4 shows that during lesson 4 students succeed many times in using the word ‘force’ in a scientific way, that is to express an interaction between two objects. During this lesson the pole jumper was the object of the study. In contrast, during lesson 6 the majority of the students reverted to everyday speech . The crash test and the risk of a neck fracture was the topic of this lesson. It may be that the students were more affectively engaged discussing this topic in contrast to the topic of the pole jumper so that they faced the described dilemma in a quite unique way.

Furthermore, we can draw a relationship with the interlanguage described by Selinker (1972): The term ‘interlanguage’ denotes a particular language developed and used by language learners. It is influenced by their native language as well as by the foreign one, depending on the context. The frequent change from everyday to scientific use of the term ‘force’ can be viewed as a ‘scientific interlanguage’. The strategies described provide a justification for this comparison: The language used by the students is influenced by their everyday use of ‘force’ (native language) as well as its scientific use (foreign language), depending on the context. They change between these language levels in a seemingly flexible way. The deeper analysis showed that this change depends on pre-instructional ideas and the context of the actual discussion.
It might be that the period of time the teaching sequence lasted was not long enough to observe typical phases or steps such as it is reported by Diehl et al. (2002). Table 4 gives no indication, neither concerning the whole group of students nor a subgroup. So more research is needed to explore this possible relationship between language learning processes and science education.

The results of our study indicate some promising relationships between learning science and learning a foreign language. Thus it is worth looking for suggestions in the field of language learning research to open up new ways for improving science education. But although relationships between second language learning and science education were pointed out in this text, it has to be emphasised that learning science is not the same as learning a foreign language. Some observations within the data are persuasive in suggesting relationships, others seem to be independent from the language learning processes. In addition we must note that whilst language learners are talking about commonplace using a new language, science learners are talking about new and abstract fields of knowledge using a new and foreign language.

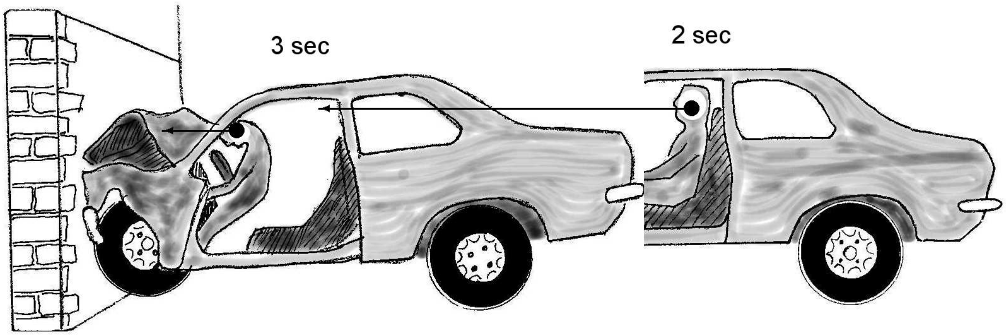

Figure 1: *Example topic (used in lesson 6, see table,4): The picture was presented to the students after having watched a slow-motion video of the crash test. The arrows indicate the velocity of the head of the dummy. The difference of the two arrows ($\Delta\vec{v}$) was also marked in the picture in the course of the lessen. It indicated that there must be a force exerted on the head of the dummy with direction opposite to its motion. The potential risk of neck-fracture in accidents like this comes into the scope of the discussion at this point. The students are asked to describe the movement of the crashtest-dummy using the term 'force' scientifically.*

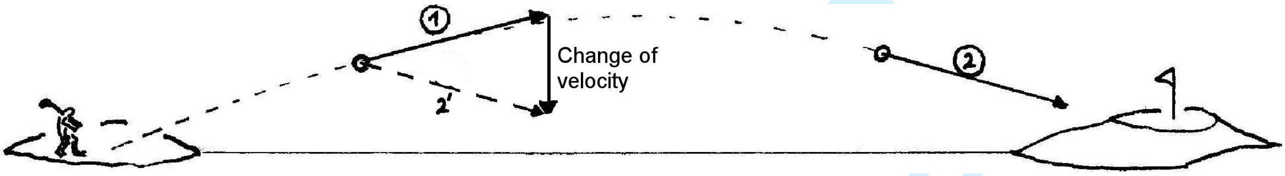

Figure 2: *Students have to write a statement using the term 'force' scientifically referring to the space of time from 1 to 2. It was emphasised that the statement must not refer to the beginning of the motion of the ball. The idea for this task was taken from the Force Concept Inventory (Hestenes, 1992).*

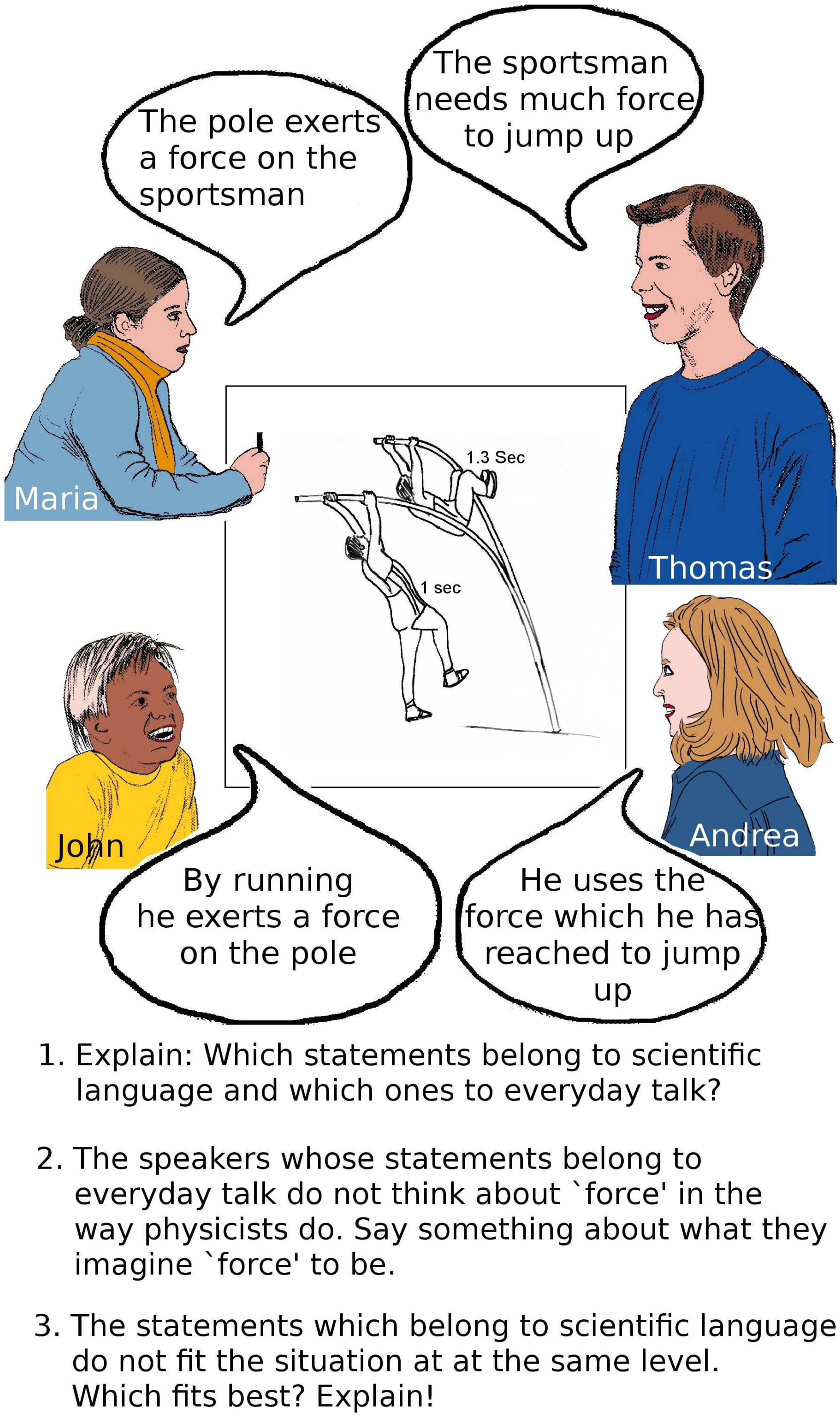

Figure 3: *Example task used in lesson 5 (see table 6): Tasks like this were used to get students engaged into a meta-discourse: They have to explain whether the given statements belong to scientific or everyday use of the term 'force'. Moreover, the students are asked to take over the speaker's point of view (in case of everyday talk) and to explain possible perspectives on the term 'force'. In the end the two statements which seem to be scientific (both Maria and John use 'to exert force on') are not of the same quality. The students are asked to differentiate these statements.*

start	5 weeks	5 weeks	**end**	6 months	
	teaching sequence section 1	teaching sequence section 2		students were taught other topics	
cognitive ability test		videotapes, audiotapes, logs, written tasks	test 2		test 3 (follow-up)

Figure 4: *Data collection over time: The teaching sequence covered a time period of approximately two and a half months. During the second section of the teaching sequence qualitative data via cam-cording, logs and written tasks were collected. In addition, at the beginning of the teaching sequence the students passed the verbal component of the cognitive ability test (for details see page 14). Six months after test 2 they passed another test (test 3).*

Categories Type 1	Example	Description
quantity	'there's a lot of force needed'	the word 'force' may be replaced by another word signifying something such as a quantity, for example 'energy' or 'momentum'
actor	'the force pulls the ball down'	the word 'force' is used in a sense 'acting' on other objects
interaction	'the ground exerts a force on the ball'	the word 'force' is used to denote an interaction between two objects (this was intended by the teaching sequence)
attempt	'he exerts the ball'	the whole sentence gives the impression that the speaker tries to use the correct phrase but does not succeed
others	'the force exerts a force on the ball'	uses of the word 'force' not clearly belonging to one of the categories above
Categories Type 2	**Example**	**Description**
surface form	'this is scientific because the word 'exert' appears in the text'	the speaker assigns a 'scientific' (or everyday) use referring to the *surface form* of a given sentence
content structure	'this is scientific because the description fits well to the given situation'	the speaker assigns a 'scientific' (or everyday) use referring to the *content* of a given sentence

Table 1: *The category system: Categories of type 1 were used when students were asked to use the term 'force' scientifically; categories of type 2 were used when students are asked to participate in a meta-discourse.*

Sentence No	surface form sustains translation	intended deep structure sustains translation	sentence
1	yes	yes	Lars pushes the car
2	yes	no	The iron ball has much force
3*	no	yes	The ball bounces back from the ground
4	no	no	It's favourable to save force
5	yes	no	The engine needs energy
6*	no	yes	The ball is kept by the ballplayer

Table 2: *The translation task in the follow-up test (half a year later): Students are given six sentences using idiomatic language which had to be translated into scientific ones (if possible). The scheme indicates to what extent sustaining the translation either through surface form or intended deep structure is varied. The asterisks indicate that two translations are possible, one referring to the intended deep structure, another possibly related to the surface form. The original test is available online (Rincke, 2007, p. 235).*

subgroup	description: students whose utterances in the lesson
I	belong to categories *interaction* or *attempt* more often than to *quantity*, *actor* or *others*
II	belong in some cases to categories *interaction* or *attempt*, but utterances belonging to *actor*, *quantity* or *others* occur more often or at least equal to *interaction* or *attempt*
III	never belong to categories *interaction* or *attempt*
IV	do not contain the term 'force'
V	no utterance (but student present during lessen)

Table 3: *Scheme indicating the way in which the group of 20 students was divided into further subgroups (analysing their use of the word 'force'). This division refers only to categories of type 1, see table 1 (above).*

No of students	lesson 1	lesson 2	lesson 3	lesson 4	lesson 6	lesson 8
1	I	IV	I	I	V	I
2	I	IV	IV	I	I	IV
3	IV	IV	IV	I	IV	I
4	V	V	IV	I	IV	I
5	V	V	II	I	IV	IV
6	I	I	II	II	V	I
7	IV	IV	I	I	II	I
8	III	III	III	III	III	IV
9	I	I	III	I	III	V
10	I	IV	I	II	-	V
11	I	III	III	II	IV	III
12	I	I	III	II	III	II
13	III	IV	I	II	I	I
14	V	V	IV	II	III	I
15	V	IV	III	II	I	I
16	I	III	III	I	III	III
17	II	I	II	II	III	II
18	IV	I	III	II	III	II
19	V	IV	III	I	IV	III
20	V	II	I	I	III	IV

Table 4: *Students' affiliation to subgroups I-V during those lessons which are characterised by tasks in which students are asked to use the term 'force' scientifically. The shading indicates the categories to which students' utterances belong. See table 3* for details concerning I-V, but roughly one can say 'the darker the gray the more scientific the talk'. (A '-' indicates that the student was absent.) This division refers only to categories of type 1, see table 1 (above).

subgroup	description: students whose utterances in the lesson/test
i	belong more frequently to the category *surface form*
ii	belong more frequently to the category *content structure*
iii	belong equally to the categories *surface form* and *content structure*
iiii	cannot be assigned uniquely (students' utterance too short to categories uniquely)

Table 5: *Scheme indicating the way in which students were divided into further subgroups (analysing their argumentation structure within the meta-discourse). This division refers only to categories of type 2, see table 1 (above).*

No of students	lesson 5	lesson 7	follow-up test
1	iii	-	iiii
2	iii	-	iiii
3	ii	-	ii
4	iii	-	ii
5	iii	-	iii
6	iii	ii	iii
7	iii	-	iiii
8	ii	ii	ii
9	iii	-	iii
10	iii	-	iiii
11	iii	ii	iii
12	iii	ii	iii
13	i	i	iiii
14	iii	-	iiii
15	iii	ii	iii
16	iiii	-	ii
17	iiii	ii	iiii
18	iii	-	iiii
19	ii	-	iiii
20	iiii	-	i

Table 6: *Students' affiliation to subgroups i-iiii. The table shows the results for two lessons which are characterised by students' meta-discourse and for the meta-discourse-related task in the follow-up test. The table indicates the categories to which students' utterances belong. For details concerning i-iii see table 5.* Dark gray (i) indicates that the argumentation refers clearly to the surface form of a given statement. Lighter gray (ii) indicates that the argumentation refers clearly to the content of a given statement. Light gray (iii) indicates that the argumentation refers to the surface form and to the content. (Unfortunately many students were absent in one lesson ('-'). For this reason the results of the follow-up test are included in the table.) This division refers only to categories of type 2, see table 1 (above).

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It's rather like Learning a Language

Development of talk and conceptual understanding in mechanics lessons

Although a broad literature exists concerning the development of conceptual understanding of force and other topics within mechanics, little is known about the role and development of students' talk about the subject. The paper presents an in-depth investigation of students' talk whilst being introduced to the concept of force. The main research goal was to investigate and understand how students develop an understanding of the concept of force and how they use and understand the term 'force'. Therefore we make relation to the research field of students' preconcepts and the field of second language learning. Two classes of N=47 students were video-taped during a time period of nine lessons, each transcribed and analysed using a category system. Additional data was obtained via written tasks, logs kept by the students, and tests. The detailed analysis of the talk and the results of the tests indicate that students are facing difficulties in using the term 'force' scientifically similar to those in a foreign language instruction. Vygotsky (1962) already recognised a relationship between learning in science and learning a language. In this paper important aspects of this relationship are discussed based upon empirical data. We conclude that in some respects it might be useful to make reference to the research related to language learning when thinking about improving science education. In particular, according to Selinker's concept of interlanguage describing language learning processes within language instruction (Selinker, 1972), the language used by the students during physics lessons can be viewed as a 'scientific interlanguage'.

Introduction

In recent years the role of language in science education has been emphasised by many authors. Many investigations concentrate on the flow of discourse within classroom talk (e.g., Bellack, Kliebard, Hyman & Smith, 1966, Lemke, 1990, Mortimer & Scott, 2000, Mortimer & Scott, 2003, Scott, 1998, Sutton, 1998), others make relation to the quality of scientific explanations given to students (e.g., Ogborn, Kress, Martins & McGillicuddy, 1996), finally many more perspectives on classroom talk can be found. The study reported in this paper aims at an investigation of students' understanding and use of a single scientific term which is difficult to learn. The particular term in this study was 'force'. By means of a detailed analysis of students' utterances (i.e. their output) we seek to retrace the process of meaning-making of individuals. Furthermore, the analysis highlights the interdependency between this process of meaning-making and language levels used by the students.

Besides the term 'force', there exist many more scientific terms which are regarded as being difficult to learn (e.g., 'voltage' or 'temperature'). One important reason for these difficulties is their nonspecific use in everyday talk. Often, in everyday talk 'force' acquires the sense of 'energy' or 'momentum'. Sometimes the attribute of 'vitality' is involved. Hence, in order to clarify the scientific concept of force it appears recommendable to contrast the scientific use of the term 'force' with its everyday use. From the students' point of view, learning the scientific concept of force requires to distinguish everyday and scientific usage. Therefore the situation in physics lessons may be experienced as similar to language lessons: In both cases learners have to internalise that words acquire their sense dependent on and in relation to other words making up the whole sentence. For this reason, the results reported in this paper are linked against theory and results within the field of language learning research. The relation to language learning is regarded as one possibility to improve our understanding of learning processes experienced by the students.

In this paper, the underlying teaching method is reported and described, too. Though this method was elaborated and piloted before, the discussion about its applicability is not our primary interest, i.e. the teaching sequence is not the subject of the investigation. The design of the teaching sequence is informed by a vygotskian view on learning as a dialogic process. In this view, new ideas appear firstly on the social plane of talk and interaction. During discussion and working through the ideas every individual has to make sense of the new ideas for her or his own. Our analysis concentrates on this individual process of meaning-making and its interdependency with use of language.

Theoretical background

The aim and purpose of the study requires a theoretical framework for the analysis of students' utterances. Since the study bases upon a teaching method introducing the students to the concept of 'force', a second framework is needed explaining how and why the teaching method was chosen in the way it is reported during the following sections. The framework for the teaching method opens up a broad view on internalising the concept of force as a process which includes both, dialogic structured social interaction and individual meaning-making. After that we introduce a framework for the analysis of individual uterances. Thereby we concentrate on meaning-making and relate the findings to the research field of students' preconcepts and the field of language acquisition.

The teaching method

Discourse analysis of classroom talk represents an important and influential research field concerning the relation between language and science education. It provides an insight into the way meanings are shaped and shared in classroom talk. In order to clarify the background for our teaching sequence, we summarise relevant results for the development of the teaching method.

Sometimes, the classroom talk is regarded as a 'language game' in which every participant highlights a special role defined by permitted moves inside the game (Bellack et al., 1966). Thus, the metaphor of the language game is a vehicle of describing and analysing the flow of discourse. The term 'language game' is essential for the writings of Wittgenstein (Wittgenstein, 1958). Wittgenstein used the term 'language game' as a framework to explain how words acquire their sense: Words do not *have* any sense themselves – they acquire it in the course of a language game. Those language games are activity structures where people act and talk together, and words take on their sense according to their function within this game. In his well known book 'Talking Science' Lemke, 1990 refers to this philosophical framework (p. 185) and extends it to a theory of social semiotics with respect to science education. Lemke claims that the 'triadic dialogue' (p. 217) is a very common form of interaction, also known as I-R-F-pattern ('Initiation - Response - Feedback', Mehan, 1979; Edwards and Mercer (1987)) or as I-R-E pattern ('Initiation - Response - Evaluation', Sinclair & Coulthard, 1975). Lemke identifies other recurring patterns, for example the student-questioning dialogue or the teacher-student debate. Such social 'activity structures' (p. 186) serve as tools for meaning-making. In this view meaning can be thought of as a result of social activities. Learning science therefore includes learning to talk like members of the social community of scientists. In consequence, Lemke asks teachers to 'model scientific language by explaining to students how they themselves are combining terms together in sentences' (p. 170). Thus he recommends that the so called meta-discourse to play an important role in science education. Similar as Lemke, Gee recognises scientific language as an *academic social language*, i.e. a 'way of using language so as to enact a particular socially situated identity and to carry out a particular socially situated activity' (Gee, 2005). He claims that 'one does not know what a social language means in any sense useful for action unless one can situate the meanings of the social language's words and phrases in terms of embodied experiences' (p. 23). So scientific terms and phrases have to be regarded as being part of a social language, used within a social community and embedded in particular activity structures and situations.

In addition to this strand focusing on discourse analysis another strand exists concerning the quality and nature of a teacher's explanations in science education. Ogborn et al. (1996) point out that the 'act and art of explaining to a class is much less discussed than scientific ideas to be explained' (p. 2) and develop a framework for what they call a scientific explanation. This framework is governed by the metaphor of a 'story', although not thought of as a narrative but rather as a set of cooperating protagonists, each of them characterised by special capabilities. Within this framework, terms like 'force' or 'energy' form protagonists which are capable of 'doing' something with other protagonists. In this view a scientific explanation is a 'story' about these protagonists, operating within their cooperation and by this means explaining causal connections (p. 9). Sutton (1998) draws upon the metaphor of 'science as a story', too, also not implying narrative. Sutton recommends emphasising in science education that scientific knowledge is a result of social interactions: 'The word 'story' has many advantages in comparison with 'fact' or 'truth'. It involves learners and invites them to think 'Is it reasonable?"(p. 37).

In the course of the last decade many contributions to the role and practise of language in science education have been influenced by the writings of L. S. Vygotsky. Scott (1998) and Bennett (2003) point out that the increasing impact of Vygotsky's writings could account for the growing interest in the role of language in science education. Vygotsky claimed that 'higher psychological structures' (such as scientific conceptual knowledge) appear, 'first between people as an interpsychological category and then inside the child as an intrapsychological category" (Vygotsky, 1978, p. 128). This means that language plays a key role when students are introduced into new ways of thinking and talking about the world. In this view, the process of internalising new ideas or new languages originates in the social plane. Individuals construct their meaning with respect to the social language which they experience in the given situation.

Within the strand of research projects informed by Vygotsky's writings Mortimer and Scott (2000) characterise content, form and patterns of utterances based upon their 'flow of discourse analytical framework' (Mortimer & Scott, 2000, p. 129). They expand the I-R-F-pattern by differentiating as to whether students' utterances match the intended learning goal or not (content) and attributing it to either a description, explanation or generalisation (form). In addition, the nature of teachers' (and students') interventions is described (pattern). These interventions are divided into three major groups: 'developing scientific knowledge; supporting student meaning-making; and maintaining the teaching narrative' (Mortimer & Scott, 2000, p. 131). Mortimer and Scott distinguish two social languages used in the classroom – the scientific language and the spontaneous, or everyday, language. 'This, of course, can lead to teacher and students talking about the same phenomenon in quite different ways.'

(Mortimer & Scott, p. 128). Mortimer & Scott (2003) refine their analytical framework discussing 'five linked aspects, which focus on the role of the teacher in making the scientific story available, and supporting students in making sense of that story' (p. 25), i.e. teaching purposes, content, communicative approach, patterns of discourse, and teacher interventions. Their framework is based on a sociocultural view of teaching and learning mainly relying on the writings of Vygotsky. They emphasise 'that the analytical framework is offered both as a tool for thinking about and analysing science teaching after the event, and as a model to refer to, *a priori*, in thinking about the planning and development of science teaching' (p. 25). In our case, the framework was used to sustain the planning process of the lessons. This led to the following guidelines:

First, everyday and scientific language were clearly differentiated (cf. Mortimer & Scott, 2003). It was explained to the students that any scientific use of the term 'force' explicitly denotes at least two partners involved in an interaction, e.g. 'the ball exerts a force on the ground'. Thus the students were given an easy-to-use criterion to indicate any scientific use of the term force. In all tasks and texts used during the teaching sequence mixing up the different languages was studiously avoided. Thus a common problem in textbooks was avoided, namely that everyday and scientific use of specific terms appear within the same text without any appropriate explanation to the different language uses, see for example Bennett (2003, p. 169) referring to English textbooks or Rincke (2004) for German ones. The term 'force' was not introduced to the students giving them a short definition, but giving lots of examples illustrating that within scientific uses the term 'force' has other 'capabilities' than within everyday uses (cf. Ogborn et al., 1996).

Second, the meta-discourse suggested by Lemke (1990) played an important role: The aim of the meta-discourse was to engage students in a discussion about language including syntactic and semantic features of informal everyday talk or formal scientific use of the term 'force'. Thus, the simple criterion of differentiating between scientific and everyday language explained above was accompanied by profound discussions about what the meaning of a given description could be or to what extent it describes what was to be described. Students were encouraged to discuss the differences between everyday and scientific use of the term 'force', referring particularly to the different ideas associated with the given statements.

This teaching method is not only influenced by Lemke but also by Noam Chomsky who introduced the deep structure and surface form to model the relationship between language and thought (Chomsky, 1957). Chomsky's idea of the surface form of language is related to the criterion mentioned above: In the first step a scientific use of the term 'force' in this teaching sequence can be identified by searching for (at least) two interacting objects. This interaction normally is described by the phrase 'one object exerts a force on the other object'. Thereby this criterion refers only to the surface form. Chomsky's idea of the deep structure of language is related to the meta-discourse. During this meta-discourse students discuss the ideas related to a given statement. Appropriate descriptions of the motion of a ball or a skater are identified and inadequate uses of the term 'force' are revealed even if two interacting objects seem to appear in the text.

One overarching idea governing both, the design of the teaching sequence and the analytical framework for students' utterances should be emphasised at this point. This idea refers to the relation between *scientific* and *spontaneous* or *everyday language* and it is related to the *content* of Mortimers and Scotts framework. Above all, the relation between these two languages has been discussed by Vygotsky (1962): He compared it with the relationship between the native and a foreign language of a speaker: 'The influence of scientific concepts on the mental development of the child is analogous to the effect of learning a foreign language, a process which is conscious and deliberate from the start. In one's native language, the primitive aspects of speech are acquired before the more complex ones. The latter presupposes of phonetic, grammatical, and syntactic forms. With a foreign language, the higher forms develop before the spontaneous, fluent speech. [...] It is not surprising that an analogy should exist between the interaction between the native and the foreign language and the interaction of scientific and spontaneous concepts, since both processes belong in the sphere of developing verbal thought. However, there are also essential differences between them. In foreign language study, attention centers on the exterior, sonal, physical aspects of verbal thought; in the development of scientific concepts, on its semantic aspect. The developmentmental processes follow separate, though similar paths' (p. 109). For this reason, we chose two different points of departure for the analytical framework explained in the next section: One refers to students' preconcepts (Vygotsky's semantic aspects), the other to language learning processes.

The analysis of utterances: Langage and (scientific) concepts

One conspicuous feature of scientific language may be seen in its special technical vocabulary. But in addition to the subject-specific terminology many morphologic and syntactical features particular to the scientific language can be identified. These features distinguish scientific- from everyday language. At first glance it might seem that the difficulties experienced by students with the scientific language follow from these rare features with which students are not familiar. But Bennett (2003, p. 153) explains 'Whilst the research has confirmed that the language of science can pose difficulties for pupils, other research has suggested that the problem is less to do with the technical vocabulary of science than might be expected.' So it may be assumed that these difficulties do not in the first place emerge from the technical vocabulary but from the fact that scientific conceptualisations are closely connected to scientific language and often far from everyday experience. On the other hand, everyday language is connected to typical and well known pre-instructional conceptions (preconcepts) informed by everyday experience (e.g., Hestenes, Wells & Swackhammer, 1992). Thus, the difference between scientific and everyday language largely reflects the differences between scientific concepts and those ideas used and expressed by the students.

Like it was done by Brown and Ryoo (2008) in their 'content-first-approach' we disaggregate science instruction into 'explicit conceptual and language components' (p. 534), because we assume that students experience at least two developments during science education: They become familiar with scientific concepts and a new language connected to these concepts – not only single new words. Related to this distinction our perspective onto what is happening in the classroom is informed by two perspectives:

Our first point of departure is the research field concerned with students' preconcepts about mechanics (e.g., Jung, Wiesner & Engelhardt, 1981; Wiesner, 1994; Hestenes et al., 1992), which is closely connected to the educational research on conceptual change (e.g., Duit, 2003). The knowledge provided by this research field offers a profound insight into students' pre-instructional ideas about force, energy, momentum, velocity or acceleration. The present study is based on a teaching sequence concerning an introduction into the concept of force, therefore we mainly draw on the knowledge about students' pre-instructional conceptions about force and their difficulties with the scientific concept of force. These pre-instructional conceptions are in large part expressed by common ways to use 'force' in everyday conversation. Dependent upon the context it is used synonymously with energy or momentum in addition to many other uses. It is in this broad range of meanings from informal everyday use to more scientific uses that the problem of polysemy arises which challenges both teaching and learning (Strömdahl, 2007). The pre-instructional conceptions expressed within vernacular often have the distinction of 'force' as a property of a single object, e.g. 'She is a very forceful person'. Teaching the concept of force in mechanics lessons includes stimulating and supporting students not to replace but to complement the informal ideas by a scientific concept of force which expresses an interrelation between at least two objects. More details concerning the various features of pre-instructional conceptions will be discussed later in this text when the system of categories used to analyse transcribed videotapes will be explained.

In addition to pre-instructional conceptions the framework is founded on second language learning. Assuming that students experience a language learning process when they acquire a new scientific concept we need a framework which allows us to map observations made in mechanics lessons to theoretical or empirical results of research in second language learning.

Literature research in the field of (second) language learning bears some remarkable contributions which help us to understand what happens in science lessons. We will summarise the most important topics which we will draw upon in the following sections:

The role of formulaic phrases

As well Language learners as native speakers generate their sentences by far not only by using grammatical rules. Much of what we articulate consists of phrases not formed creatively but retrieved from memory as a whole (Bärenfänger, 2002). These phrases can be regarded to some extent as automated or formulaic. Language learners profit from the use of formulaic phrases: Memorising and using formulaic phrases permits language learners to extend their abilities to communicate. Automated phrases free them, to some extent, from using their limited vocabulary and knowledge of grammatical rules, thus they are able to express complexities which they would not be able to do based on their knowledge of rules and vocabulary. Such formulaic phrases serve to some extent as 'islands of reliability' (p. 126) – as they do not ring false for language learners because they are retrieved wholesale from memory. Native speakers accelerate their production of sentences by using formulaic phrases. Such phrases do not have to be complete sentences – often they consist of only a few words. Consequently, it is recommended that language learners memorise short phrases or at least some words that belong together rather than single words: 'So this (phrase) is another piece of information about a new item which it may be worth teaching. When introducing words like *decision* or *conclusion* we may note that you *take* or *make* the one but usually *come* to the other' (Ur, 1996, p. 61). Similar state Bleyhl and Timm (1998), p. 263: 'A single word is like nothing, it requires a linguistic environment'.[1]

Either following grammatical rules or communicating with somebody – a common conflict

Edmondson (2002) summarises that learning outcomes while learning a new language depend on the quality of cognitive and affective processing achieved by the learner. The deeper the learner engages, cognitively and affectively, the higher the achievement (p. 62). On the other hand, this engagement leads to higher cognitive loads and thus limits the learning outcomes. It can often be observed that learners decide whether to concentrate on following grammatical rules or on communicating a specific content. This decision can be seen as a process of assigning resources either for processing rules or contents. Edmondson concludes that learning grammatical rules or communicating with somebody are in many cases mutual exclusive alternatives. It can be frequently observed that the learner decides to concentrate on the content and neglect grammatical rules (van Patten, 1996).

[1]translated by author

Native language - interlanguage - second language

Novice learners of a new language may use it in quite a simple manner due to their limited knowledge. But simplicity is not the most significant feature of a novice's spoken or written sentences. Novices develop to some extent an individualised language which is influenced not only by the language to be learned but also by their native language. It was Selinker who introduced the term 'interlanguage' to label this specific language used by and depending on the learner (Selinker, 1969, 1972). In order to develop a theory of second-language learning he distinguishes three linguistic systems, the native language of a speaker, his interlanguage and the target language (the language the learner is attempting to learn). A theory of second-language learning should be able to predict behavioral events following from language learning processes. Obviously, not every sentence spoken by a language learner can be undoubtedly related to language learning processes. Investigating such learning processes requires that relevant behavioral events in the performance of a language learner can be separated from common behavioral events not relevant to the theory. 'One set of these behavioral events [...] is the regular reappearance in second-language performance of linguistic phenomena which were thought to be eradicated in the performance of a learner' (Selinker, 1972, p. 211). He points out that the 'well-observed phenomenon of backsliding by second-language learners from a TL [target language] norm is not, as has been generally believed, either random or toward the speaker's NL [native language], but toward an IL [interlanguage] norm' (p. 216). The phenomenon of backsliding is especially observed 'when the learner's attention is focused upon new and difficult intellectual subject matter or when he is in a state of anxiety or other excitement [...]' (p. 215). Five processes are regarded as being central for the learner's interlanguage performance, i.e. (1) language-transfer (rules or structures are derived from the native language), (2) transfer-of-training (unfavourable influence by the training material), (3) strategies of second-language learning (the learner derives rules from the target language), (4) strategies of second-language communication (strategies to communicate in spite of missing linguistic competence), and (5) overgeneralisation (of rules belonging to the target language). Selinker points out that 'beyond the five so-called *central* processes there exist many other processes which account to some degree for the surface form of IL utterances' (p. 220). Other approaches were developed (e.g., 'Approximative Systems', Nemser, 1971) which are similar to Selinker's approach to some extent. Further research was done especially concerning the strategies of second-language learning (e.g., O'Malley & Chamot, 1990) and second-language communication (e.g., Bialystok, 1990) and resulted in refined category systems of strategies.

Diehl, Pistorius and Dietl (2002) observed that language learners essentially have to master fundamentally three steps or phases on their path from beginners to becoming advanced users: During the first phase they tend to memorise short phrases and use them in a formulaic manner. According to Diehl et al. the second phase is triggered by a cognitive overload caused by the increasing amount of formulaic phrases to be remembered. Thus the learners begin to seek for new methods to master their communication needs. They start to work their way through the variety of linguistic forms. Diehl et al. call it the 'turbulent phase', because the learners behave like they have never been taught language, and there is no avoiding this phase. During the third phase, the learners fit their interlanguage to the target language, as long as they are disposed to discard temporary self-made 'rules' which belong to their interlanguage.

Even though it is not possible to describe and compare the overall spectrum of second-language learning theories in this paper we should say something about the relation between the aspects referred here and the overarching field of research concerning second-language learning. Above we summarised the discussion about the role of formulaic phrases, the conflict between following grammatical rules and communicating with somebody, and the concept of interlanguage. This discussion focuses on the language used by the learner, i.e learners' output. There exist further research focusing on learners' output e.g., the research field which concentrates on learners' mistakes and errors and the field which concentrates on differences between the native language of a learner and a certain target language. The former aims at clarifying the reasons of mistakes and thereby fostering the progress of language learning (e.g., Knapp-Potthoff, 1987). The latter bases on the hypothesis that the difficulties experienced by a language learner arise from the differences between his or her native language and a certain target language (e.g., Stockwell & Bowen, 1965; Gass & Selinker, 1983; Kellerman, 1995). Edmondson and House (2000) argue that within the research fields concentrating on learners' output the strand based on Selinker's idea of interlanguage is especially comprehensive and therefore promising (p. 219). It comprises the investigation of the variety of mistakes as well as of interferences between native and target language.

Besides the research field concentrating on learners' output there exist more general theories which include the learner's input (provided by the teacher or other learners) and the student-teacher interaction (for a comprehensive discussion, see e.g., Ellis, 1985; Larsen-Freeman & Long, 1991; Mitchell & Myles, 1998). In this paper we concentrate on learners' output. Therefore we will especially rely on Selinkers concept of interlanguage. A broader perspective including student-teacher interaction with respect to language learning theories may be promising but is not discussed in this paper.

The study

Research question

The main research goal was to investigate and understand the process of students' developing understanding of the concept of force as well as the way students use and understand the term 'force'. Moreover the study asks to what extent results of language learning research can help us to understand the empirical data. This means that the study asks to what extent observations made within students' classroom talk in physics lessons can be linked to language learning processes.

Design: Sample and teaching method

47 students participated in the study. They were on average 14 years old and came from two classes of different public secondary-schools. Both classes were taught by the same teacher. The underlying teaching sequence covered an introduction to the basic ideas of mechanics. The first section (about eight lessons) focused on the description of motions. Thus, an introduction into the dynamic concept

of force was prepared which, at the end of the second section (about nine lessons), resulted in the 'second Newton's law' $\vec{F} \cdot \Delta t = m \cdot \Delta\vec{v}$. A teaching sequence structured in a similar way was already proposed for example by Wiesner (1994) and evaluated with positive results by Wodzinski and Wiesner (1994).[2] The detailed design of every lesson, in particular concerning the method how the students were introduced to the term and concept of force, followed the guidelines explained in the according theoretical framework section. The whole teaching sequence was piloted with 55 students before being used within the study.

Examples

At the beginning of the second part of the teaching sequence the students themselves camcorded several scenarios, for example playing with a ball, riding a bicycle or skating. Afterwards these films were analysed on a personal computer. This analysis aimed at describing the motion at most accuracy. To do so, for example, speeds and directions of the motions were measured. While analysing the filmed motions students realised that a velocity of a person or a ball never changes without the influence of another object, i.e. the ground, a staircase, the air, the earth or something else.

After having filmed and analysed some motions in the described way the phrase 'one object exerts a force on another object' was introduced to the students. This introduction was closely connected to the examples given by the videotapes by 'translating' the interaction of the bodies viewed in the videotape into 'scientific' descriptions: The statement 'the earth pulls the ball down' was translated into the sentence 'the earth exerts a force on the ball downwards'. Then students had to write down some statements about their films using 'force' in the 'scientific' way. Thus, the term 'force' was not introduced by a definition in the way found in several textbooks; it was introduced in the context of students' social activities and by giving examples which showed how the term 'force' interacts with other terms within a given phrase. This way of introduction was brought through Wittgenstein's

[2] A detailed description of the whole material including all texts and tasks can be found in Rincke (2007) or via internet using the persistent identifier urn:nbn:de:hebis:34-2007101519358, for example by typing https://kobra.bibliothek.uni-kassel.de/handle/urn:nbn:de:hebis:34-2007101519358

idea of 'language games' (Wittgenstein, 1958) as activity structures determining the word's sense. Furthermore, it is associated with Gee's idea of scientific terms as being part of a social language (cf. p. 4).

The scene shown in figure 1 fell within the scope of one lesson (note that all lessons discussed in this paper refer to the second section of the teaching sequence – so lesson 1 in figure 1 refers to the first lesson of the second section of the teaching sequence). The overarching question was to understand the risk of a neck fracture in a head-on collision. First, students watched a movie showing a crash test in slow motion. Then the scene was described and discussed using words and expressions without any support from the teacher. After that the students talked informally. Then figure 1 was presented to focus on the motion of the head of the dummy. The vector difference $\Delta\vec{v}$ of the two given arrows (velocities) was marked in the picture, indicating that there must be something exerting a force on the head of the dummy. The students were now asked to refer to the motion of the dummy and to use the term 'force' scientifically.

[Insert figure 1 about here]

Figure 2 refers to a similar task presented in the test at the end of the teaching sequence. Students had to make a statement using the term 'force' scientifically and referring to the motion of the ball during the time period from 1 to 2. The accompanying text emphasised that the statement must not refer to the beginning of the motion (i.e. the action of the sportsman).

[Insert figure 2 about here]

Figure 3 gives examples of tasks involving students in a meta-discourse. They are given four statements and have to explain whether the term 'force' is used scientifically or not. In addition they are asked what else (other) the speakers may talk about if it is not 'force' in a scientific sense. Thus, different understandings of the word 'force' could be discussed. Students were given the chance to talk specially about their preconcept and its possible contrast to the scientific concept of force.

[Insert figure 3 about here]

Design of the study: Data collection

All lessons belonging to the second section of the teaching sequence were audio- and videotaped, then transcribed (approximately nine lessons in each class). In addition, the students kept a log. Here they wrote down their ideas to some of the given tasks, they also had to do some tasks in pairs and to write down their findings. Thus, at the end of the teaching sequence every written or spoken sentence could be assigned to its speaker and was accessible in the following rule-based analysis. Due to the large amount of the text material, a smaller group of students had to be chosen for this analysis. This choice was made according to the number of words uttered by the students with respect to the number of all words spoken. In the first class (19 students in total) those students were selected, whose utterances amounted equal or more than six percent ($\approx 1/19$) of the total number of words spoken in all lessons. This means that the whole group of all students had to be included into the analysis in the hypothetic case that all students had participated in the discussions to the same extent. But in our case a smaller group of seven students was found, each of them contributing equal or more words than $1/19$ of all words spoken. Some students of this smaller group contributed up to $3/19$ of all words spoken. Corresponding to this, among the remaining group of 12 students some where found who had contributed noticeable less than $1/19$ of all words spoken. The group of seven students was chosen for the analysis. The added up amount of all words spoken by these seven students covered about 80 percent of all words spoken by the whole class. In the second class (28 students in total), following the same method 13 students were selected, whose utterances covered equal or more than three percent ($\approx 1/28$) of the words spoken by the whole class. As in the previous case, this smaller group covered approximately 80 percent of all words spoken. The coincidence of approximately 80 percent may be surprising and is not a result of the way the smaller groups were selected. In the end the utterances of a group of 20 students in total were included into the detailed analysis.

The investigation of the text material was done by means of a content analysis following the approach of Philipp Mayring (Mayring, 2000, 2003; Kohlbacher, 2006; Krippendorf, 1980). This approach to content analysis aims at a rule-based, traceable process of unveiling implicit properties of a given text corpus. It is centred on the development and application of categories which fit the research interest. This system of categories has to fulfil quality factors, especially concerning its reliability. For this study the system of categories was developed through a pilot study (55 students) undertaken one year before the main study began. The main goal of this pilot study was to improve and tweak the teaching sequence, especially with respect to the tasks to be used. Nevertheless, also in this pilot study, all lessons of the second section of the teaching sequence were video-taped and transcribed. This was done in order to develop the category system. The result was a draft-version which was further developed in accordance with the following steps:

- About 50 % of the text material was read (according to the recommendation of Mayring, 2003, p. 75).
- A summary of this part of the text material was generated in a rule-based manner: Therefore a set of criteria was established determining which utterances from students should contribute to the summary. The criteria were deduced from the theoretical background explained above whereas it was intended to prevent the investigators from interpreting single utterances in a holistic way, i.e. supposing what the influence on the student under consideration by other utterances could have been. For this reason, at this stadium of the analysis there were no criteria included directly asking for the emergence of an interlanguage. A possible result indicating something similar to interlanguage was regarded as being the subject of a subsequent interpretation.

  The set of criteria concerned utterances in the text indicating to what extent speakers

  1. feel secure while using the phrase 'to exert force on' (see 'island of reliability', page 9)
  2. use the phrase 'to exert force on' in a seemingly automated or formulaic manner (see page 9),

3. seem to suffer from a conflict between the claim to use the word 'force' scientifically and their communication aims (see page 10),
4. apply known pre-instructional ideas about force to a given task (see page 8), and
5. reveal a correct scientific concept when being asked to talk scientifically (see page 8).

The summary extracted by this procedure showed that many utterances referred to the criteria No. 2, 4 and 5. The first and third criterion appeared to be unsuitable, because conflicts or the impression of security emerge from single utterances very seldom. However, later we will show that there are manifesting conflicts when looking deeper into the data. Now it was possible to establish a refined set of criteria which resulted in a new system of categories: No. 4 and 5 (see above) resulted in the categories we will from now on refer to as 'type 1', see table 1. Criterion no. 2 resulted in the categories of 'type 2' (table 1).

[Insert table 1 about here]

Thus, the category system is divided into two parts: Categories of the first part (type 1) concern the use of the term 'force' by students. It is therefore related to situations in which students were explicitly asked to use the term 'force' scientifically (see for example figure 2). The second part of categories (type 2) refers to the way students talk about their own understanding of the term 'force'. It is therefore related to situations in which they were involved in a meta-discourse. During this meta-discourse students were, for example, given a few different short texts describing a motion. In the texts the word 'force' was either used scientifically or as in everyday discourse (see figure 3). Students had to explain how the use differed.

The whole text material (all utterances of 20 selected students in total) was divided into four portions all of which were analysed independently by four pairs of investigators. One part of the text material (about eight percent) was analysed by all pairs of investigators and Cohen's Kappa was computed ($\kappa_1 = 0.81$, $\kappa_2 = 0.64$, $\kappa_3 = 0.86$, $\kappa_1 = 0.72$) to provide security for a sufficient level of reliability. The reached level can be seen as satisfactory, especially with respect to the fact that some categories ask the investigator to interpret to some extent.

Additional data were collected, figure 4 gives an overview: All students were tested with the verbal component of the cognitive ability test (Heller & Perleth, 2000). At the end of the second part of the teaching sequence they had to pass a test related to the contents of the teaching sequence. This test included some basic tasks related to the first part of the teaching sequence (which is not in the scope of this article) and some tasks similar to those which had been discussed during the second part.

[Insert figure 4 about here]

Six months later the students were tested once again. This test (test 3 in figure 4) included a task very similar to the one shown in figure 3. In addition, a new type of task was given. This type was designed to get more information about the way students take into account elements from content or surface form of sentences when reading about 'force'. The main idea of this type of task was that the students had to translate given (common usage) sentences into scientific ones. Firstly they had to decide whether a translation is impossible or possible. Secondly they had to translate if possible. The design of the given sentences, i.e. the design of the task shall be explained in more detail. The sentences were manipulated to relate to two assumptions:

1. The first assumption was that sentences following the pattern, subject – transitive verb – object, encourage students translating it into a scientific one because this pattern is the same as using the phrase 'to exert force on'. This assumption relates to the surface structure of the sentence.
2. The second assumption was that sentences denoting an action effected by one object onto another object stimulates the students to translate also. Note that these actions may not necessarily use transitive verbs. This assumption refers to the deep structure of the sentence. The sentence 'the ball is kept by the ballplayer' for example does not follow the pattern subject – transitive verb – object, thus (accepting the explained assumptions) it may not support a translation due to its surface form. But it may stimulate students to translate it similar to 'the ballplayer exerts a force on the ball' because the given sentence communicates an action effecting the ball

(intended deep structure stimulates a translation). But a translation like 'the ball exerts a force on the ballplayer' would of course be correct, too. The latter translation may be interpreted as being sustained by the surface form in a more general view, i.e. following a pattern like subject – verbs – object.

In the test six sentences were given, systematically varying the two features explained (see table 2). Sentences nos. 2 and 4, the intended deep structure of which do not support a translation, however, mention the word 'force' in an informal sense. These sentences are believed to particularly challenge students' understanding of the concept of force: Those students who are aware of an adequate scientific concept of force are expected to avoid the translation although the word 'force' is explicitly mentioned! The asterisks in the table indicate those sentences which may be translated in two different ways (either sustained by the surface form or the deep structure, similar to the given example above).

[Insert table 2 about here]

Analysis

The category system is divided into two parts as shown in table 1. Categories within the first part are used when students are explicitly asked to use the term 'force' scientifically. Those within the second part are used when students are asked to participate in a meta-discourse. During the teaching sequence six lessons were characterised mainly by tasks asking the students to use the term 'force' scientifically. Thus, the utterances had to be categorised by categories of type 1. In the course of two, nearly whole, lessons the students were employed with a meta-discourse, so categories of type 2 had to be applied. In the following sections the results of these lessons will be discussed.

Students' use of the term 'force'

In order to gain a systematic insight into the way students use the term 'force' the group of 20 selected students was further divided into five additional subgroups I-V. This division was made in each of the six lessons and was related to the assigned categories as it is shown in table 3. Subgroup (I) includes those students who mainly used the scientific phrase (or attempted to do so), i.e. their utterances belonged to *interaction* or *attempt* more often than to *quantity*, *actor* or *others*. Subgroup (II) includes students whose utterances belonged to the categories *actor, quantity, others* equal or more often than to *interaction* or *attempt*. Subgroup (III) denotes those students who never used the term 'force' to express an interaction between different bodies (i.e. no scientific use in the course of the lesson). Table 4 offers an overview over the results: Student nos. 1, 2, 6, 7, 9 and 13 use the scientific phrase or try to use it quite often (three or more times subgroup (I)) Student no. 17 belongs four times to subgroup (II). This means that scientific and everyday use of the term 'force' are quite mixed (see table 3). Students 8 and 16 belong four or five times to subgroup (III). This means that they almost never use the term 'force' in the way the teaching sequence intended to. Overall the table gives the impression that students use the term 'force' in a very heterogeneous way. Surprisingly, there is little, if no evidence that students had progressed towards becoming familiar with scientific use over time. It is therefore reasonable to investigate in more detail under which conditions students imply an interaction while using the term 'force' and under which conditions they tend to fall back into everyday speech. The following examples of students' utterances are translated into English as close to the original as possible. All utterances can be found in the original work of Rincke (2007) (available via internet). In Rincke (2007) each utterance is counted. We will give the original number in parenthesis, thus the interested reader can examine each utterance in its original language.

[Insert table 3 about here] [Insert table 4 about here]

The dilemma between surface form and communicative interest

The following examples show that many students who are asked to use ’force’ scientifically seem only to see two different and mutually exclusive choices: They choose either to follow the linguistic model given by the teacher or to follow their own communicative interest. The first choice is centred on the surface form, the latter relate to the content, or deep structure, of the statement. It can be observed quite frequently that students following the surface form (so trying to use the phrase ‘to exert force on’) tend to ignore the topic of the discussion or, in some cases, obviously do not understand what they themselves are talking about. The example given by Eva (student no. 13 in table 4, found in their log, illustrates this very clearly. She refers to a videotape showing two students throwing a ball back and forth:

> Eva: "One person exerts a force on the ball and throws it to another person. The other person catches the exerted ball. The other person exerts a force on the ball and throws it back. The to exerted balls are thrown back and forth." (163)-(166)

Eva seems to test the new phrase – she uses several fragments of the phrase ‘to exert a force on a ball’ with different grammatical functions, for example ‘exerted’ with function of an adjective. One may suppose that Eva tries to detect what function the different fragments of the phrase may have. She seems to be concentrated on following the pattern given by the teacher, the content being unimportant. In the context of the crash test (see figure 1) which was discussed in lesson 6 (see table 4) only a few utterances following the scientific linguistic pattern can be found. Eva says:

> Eva: "The man exerts a force on the windshield" (277)

That is obviously correct, but the discussion is on those things effecting the man (crashtest-dummy). The lesson deals not with the destruction of the windshield but with the risk of being hurt. Peter (student no. 15 in table 4) says:

Peter: "The engine exerts a force on the car so it crashes against the wall with high speed." (277)

Similar to above this might be correct in a way but it is clearly off-topic.

Certainly the majority of the utterances in this lesson are not off-topic, but the majority of the students however entirely ignore the fact that they are asked to use 'force' scientifically. This is surprising because the teacher gives a lot of hints, narrows the discussion on only a few aspects, and, in the end, asks explicitly who or what is exerting a force on the man. Salim (student no 14 in table 4) responds:

Salim: "The pressure from the wall when he's going towards the wall [...]." (260)

Within this quite complex context of a crash test students are faced with a particular dilemma: We describe it as a dilemma between surface form and students' communicative interest. This dilemma is characterised by two different and mutually exclusive choices for the students: Either to follow the scientific pattern and ignore the topic of the discussion or to follow their own communicative interest and ignore the necessity of expressing an interaction of two objects. Unfortunately neither the first nor the second choice stands a good chance of winning the teacher's approval, because neither fulfils the requirement to use the term 'force' scientifically.

Strategies: How to avoid an unfamiliar use of the word 'force'

Referring again to the example of a pole jumper (lesson 4 in table 4), the scientific use of the term 'force' can be observed more often than in the lesson concerned with the crash test (note that the example task shown in figure 3 was not within the scope of this lesson but that of lesson 5). As in the case of the crash test lesson the students watched a video of the pole jumper in slow motion and then described the motion in everyday talk. Then, after one student had used the word 'force' spontaneously in his description, the whole class was asked by the teacher to describe the motion using the term 'force' scientifically (at this point categorising the video using categories of type 1 starts).

But even within this context a frequent change can be observed between scientific and everyday uses of the term 'force'. The following analysis posits that these changes do not happen casually; perhaps this could be interpreted as a process of problem solving: When students are asked to talk scientifically, they have to locate appropriate objects interacting with each other. Furthermore, they have to trust that these objects have the potential to effect something on another object. In many contexts this percieved 'active' role has to be assigned to objects like the 'ground' or – in this case – the 'pole'. Students often do not trust in the capacity to interact. This may be the reason why they fall back into the everyday way arguing, because this allows avoidance of attributing a seemingly 'active' role to inanimate objects such as the ground or the pole. Peter (student no. 15 in table 4) says:

Peter	"He exerts a force on the pole and goes, yes, is catapulted up by the pole."	(196)-(197)

This pattern can be found in a variety of utterances, another example is given by Vivien (student no. 6 in table 4) who refers to a person playing with a ball:

Vivien	"A person exerts a force on the ball, the ball drops with much force on the ground."	(167)-(168)

It may be easy to assign an active part to a person because this alignes to common preconcepts. But it is difficult to do the same in the case of the ground because this seems to be far from everyday experience. The ground in this view is nothing more than an inanimate barrier, incapably exerting anything. Thus the speaker argues in scientific terms as long as it is an 'active' object exerting a force (a person). In the case that it might be the pole or the ground exerting a force on the ball, the speaker resorts to everyday talk. Everyday uses of the term 'force' do not compel students to talk about objects interacting with other objects. The falling back into common parlance everyday ways of talking can be found very frequently within the data.

In addition, two strategies for handling seemingly interacting objects appear: (1) Often students invent to some extent a particular story and attribute it to a given situation, a story which typically provides 'true active partners'. Figure 2 gives an example of a task. Students have to provide a statement to the depicted situation using 'force' scientifically. The vertical arrow points to the earth which is just represented through a horizontal line. The majority of the students do not include the earth in their descriptions. They prefer to talk about the sportsman hitting the ball although it is emphasised specifically in the accompanying text to the task that the statement must not refer to the beginning of the motion (action of the sportsman). (2) A quite elegant way of solving the problem of handling seemingly active objects which can be observed sometimes within the data is to use a rather impersonal style of talk: 'There is a force exerted on the breaking skater' may serve as an example. The statement expresses the interaction required to be described without stating who or what is exerting the force. So the speaker does not tend to assign an active role to the ground which is exerting the force on the (breaking) skater.

These different strategies may be collectively described as strategies of avoidance. They provide a way to cling onto preconcepts. The way in which the word 'force' is used scientifically obliges students to assign unfamiliar roles to objects. This seems to be a tough challenge. Students normally are aware of mapping their statements to their ideas of a given situation. This means that they do not talk scientifically to fulfill what the teacher asks them to do – they talk scientifically if there is almost no gap between their preconcept and what the scientific phrase 'to exert a force on' may intend. Otherwise, if there is an enormous gap between students' preconcepts and what a scientific statement would express, they prefer to relapse into everyday talk.

Student's way of participating in the meta-discourse

When students engage in a meta-discourse two patterns of argumentation can be identified: If asked whether a given statement belongs to everyday- or scientific talk students may refer to the surface form (i.e. the presence of particular keywords). The second pattern is that they refer to its deep structure (i.e. the content of the statement). If following exclusively the second pattern they do not make relation to the presence or absence of typical phrases like 'to exert force on (see table 1, categories of type 2). Figure 3 gives an example of a task. As mentioned above two lessons were characterised by tasks stimulating this meta-discourse. To get an insight into how students argue the group of 20 students was divided into four subgroups following the scheme indicated in table 5. As in the previous case, this division was made for the two lessons (and for the results of the meta-discourse related task during the test half a year later). Table 6 shows the results. Although some data is missing, the table clearly shows that the majority of the students make reference to the surface form as well as to the content: The affiliation to subgroup (i) appears only three times in table 6, twice for student no. 13 and once for student no. 20. This means that there are few examples for utterances belonging to the category *surface form*. Subgroup (ii) appears 13 times, this means that the utterances of these students belong more frequently to *content structure*. Subgroup (iii) appears 19 times. These students argue referring equally to the surface form and to the content of a given statement when they are asked whether it belongs to scientific or every day language.

[Insert table 5 about here] [Insert table 6 about here]

The tasks used to stimulate the meta-discourse always required the students to explain their decisions. Many students argue in the following way: If the given statement belongs to everyday talk, they refer to the content of the statement (and not to the absence of the phrase 'to exert force on'), for example (see statement of Thomas, figure 3):

> 'Thomas' statement belongs to everyday talk. The word 'force' means energy.' (351)

If the given statement belongs to the scientific use of the term 'force' they argue with the presence of the phrase 'to exert force on' and, in addition, in many cases to its content, for example (see statement of Maria, figure 3):

> 'Maria's statement is scientific because two interacting bodies can be found, one which is the person, another which is the force exerted on.' (343)

In the previous section we showed that students faced with the aforementioned dilemma frequently decide to follow their communicative interest and ignore scientific aspects – even when asked by the teacher to look for interacting bodies. It is noteworthy that within the meta-discourse the majority of the students make relation to the surface form of a given statement and to it's content – therefore iii appears frequently in table 6. This means that while dealing with scientific phrases within a meta-discourse, interacting bodies (as an essential element of the concept of force) are more likely included in students' utterances in a discussion.

Achievement test and cognitive ability test

As explained in the previous sections, the students passed the verbal part of the cognitive ability test before the teaching sequence started. In the end they passed an achievement test related to the basic ideas of mechanics which had been within the scope of the teaching sequence ('test 2' in figure 4). The results met the level of performance the students had revealed in the previous half of the year and were rated as 'normal' by the teacher (average of 60% correct solutions, $\sigma = 18.4\%$), but there was only a weak correlation formed between this test and the verbal component of the cognitive ability test ($+0.09$). This means that the cognitive ability test is a weak predictor of the success in the achievement test. Although the study did not aim to endorse the appropriateness of the teaching methodology, it is noteworthy that the methodology does not seem to have advantaged those students achieving high scores in the verbal component of the cognitive ability test – notwithstanding the fact that the discussion about language was an essential part of the teaching sequence.

Translation task in the follow-up test

The translation task was designed to obtain more information about the role of the surface form and the intended deep structure (page 19). The students had to translate – if possible – informal sentences into scientific ones. One can expect several conditions under which students translate the given sentences:

1. students translate if triggered by the surface form (assumption 1 explained on page 19),
2. students translate if triggered by the deep structure (content, assumption 2),
3. students translate if the word ‘force’ is mentioned.

The results may be summarised as follows: If, and only if, the deep structure (content) of the given statement triggers a translation, students translate the given sentence into a scientific one, that is into a sentence using the phrase ‘to exert force on’. Thus condition 2 exclusively triggers a translation. This means that even if the surface form follows the pattern subject – (transitive)verb – object (condition 1) they avoid translating it if they cannot associate the given sentence with the scientifically correct concept. They also avoid the translation if the given (informal) sentence contains the word ‘force’ as for example in the sentence ‘the iron ball has much force’ (condition 3). There was only one exception – one student who had probably misunderstood the task tried to translate all sentences. This means that within this type of task students are able to detect everyday uses of the word ‘force’. Furthermore, they are not tempted to translate the sentence into another seemingly scientific form although the given sentence contains the word ‘force’.

There are two sentences in table 2 which may be translated in two different ways – one related to the surface form, another related to the intended deep structure (sentences three and six, marked with an asterisk). The 20 students gave in total 40 translations for these two sentences, but only six solutions can be interpreted as being sustained by the surface form. This means that similar to in the lessons when students are asked to *use* the term force scientifically the (intended) deep structure seems to be much more influential than the surface form.

Discussion and Implications

Tables 4 and 6 give an overview of the ways in which students use the term ‘force’ and how they comprehend it. At first glance it is remarkable that there are no students whose utterances seem to develop towards a scientific style: Every student changes his or her uses of the word ‘force’ depending on the situation. The detailed analysis reveals that the often observed change between scientific and everyday talk does not happen casually but depends on the given situation: When students are asked to use the term ’force’ scientifically they are faced with what we describe as a dilemma between the surface form and students’ communicative interest. This dilemma appears in particular within complex situations, for example the cited crash test. The dilemma is characterised by two different and mutually exclusive choices for the students: Either they follow the scientific pattern and ignore the topic of the discussion or they follow their own communication interest and ignore the necessity of expressing an interaction of two objects. Both choices do not offer any real possibility to consolidate a physical concept of force.

Moreover, the frequent change between scientific and everyday talk can be interpreted as a result of problem solving: Students who are asked to talk scientifically have to locate appropriate objects interacting with each other. They have to accept that these objects effect something on another object. The strategies described can be thought of as strategies for avoiding a discrepancy between students’ preconcepts and what a scientific sentence might express. Even they may serve as a way to escape the dilemma between surface form and communicative interest. This leads to a language which is influenced by the preconcepts as well as the linguistic model given by the teacher.

It was reported that within this study the majority of the students follow their communicative interest and often do not regard elements related to the surface form. The translation task in the follow-up test confirms that students’ utterances are mainly influenced by the intended deep structure and not by elements from the surface form. The analysis of students’ argumentation within the meta-discourse leads to the result that the dominance of content related aspects diminished in favour of formal aspects. By means of regarding aspects of the surface form, students are asked to think about interacting objects. Thus, essential parts of the physical concept of force are introduced into students' debate by means of the meta-discourse.

When students are asked to use the term 'force' scientifically very few utterances expressing an interaction between objects using common verbs like 'to pull', 'to push' or 'to hit'can be found. This is surprising because the teaching method emphasises that sentences using such transitive verbs and those using 'to exert force on' are of the same grammatical structure. This observation suggests that developing an adequate concept of force and learning to talk scientifically cannot be disassociated into two consecutive steps, i.e. first idiomatically describing interacting bodies, then describing interacting bodies using scientific phraseology. It is more likely that students face two challenges simultaneously: accepting that objects interact and describing the phenomenon scientifically (thus talking of interacting objects). A way of talking in everyday language whilst talking about interacting objects can hardly be observed within the data. Whenever the students use their everyday language they talk about force in a sense of momentum, energy, as being the property of one object. This means that everyday language and pre-instructional ideas are so closely associated that the idea of interacting objects is normally not expressed at this language level.

Thereby an interesting new question arises: Brown and Ryoo (2008) report considerable benefits from their 'content-first-approach': The idea of this approach (investigated within biologic contexts) is to treat the content using informal language, then to reutter in scientific terms. This persuasive approach accounts for the dual nature of the challenge faced by the students whilst they are being introduced to new scientific ideas: They have to become familiar with new concepts and with a new language. The content-first-approach therefore disaggregates science instruction into 'explicit conceptual and language components' – not only referring to its logical – but also chronological structure! The data reported in this study, however, suggest that in case of the term 'force' this chronological disaggregation seems to be impossible due to the close association between everyday language and pre-instructional ideas. In case of the topic 'force' students have to become familiar with new ideas whilst using a new language at the same time. This may account for the difficulties students have in understanding the concept of the term 'force'. This observation can be directly related to a claim made by Gee

(2005): 'Lifeworld language is problematic for science' (p. 30). He argues 'I believe there are good reasons to encourage children, even clearly on, to marry scientific activities with scientific ways with words, and not lifeworld languages, though lifeworld languages are obviously the starting point for the acquisition of any later social language, as Vygotsky pointed out.'

The theoretical framework for the analysis of students' utterances explained in the opening sections is based on two research fields, namely the field concerned with pre-instructional ideas about mechanics and the field of second language learning. We will now connect our results and the summary related to second language learning.

It was explained that formulaic phrases which are used in a seemingly automated way play an important role for language learners because they tune to some extent their production of sentences: Using such sentences puts learners in the position to communicate in a way which their explicit knowledge of grammatical rules would not allow them to do. During the teaching sequence presented in this paper the phrase 'an object exerts a force on a another object' is emphasised many times by the teacher and the teaching material. Students get to know that this phrase indicates a scientific use of the term force. So it may be expected that students tend to use it very frequently in the case that they are asked to use the word 'force' scientifically. But table 4 shows clearly that only during lesson 4 the scientific phrase is used many times. It is surprising that many students remain on the level of everyday language although they are asked to use the word 'force' in a scientific way. This means that the scientific phrase, although emphasised and marked as *scientific* is not used in an automated way. The formulaic scientific phrase figures not in the way formulaic phrases often do when learning a second language.

In the section about the theoretical framework, a common conflict experienced by language learners was reported: They assign cognitive resources for processing either grammatical rules or contents. van Patten (1996) reports that normally learners decide to process contents and tend to neglect the importance of rules. Learners may regard applying grammatical rules as less important in order to follow their communicative interest. So language learning in classroom is fundamentally characterised by two contradictory aims: On the one hand talking about something (using the new and foreign language) and on the other hand learning to use appropriate vocabulary and generate correct sentences. It is difficult to pay attention to these two aims at the same time unless the given context is very simple. Thus language learners face a dilemma between requirements related to grammatical rules and their communicative interests. It is obvious that this dilemma is analoguous to the dilemma between surface form and communicative interest reported in this paper. In this respect, using scientific phrases in science lessons may be compared to following grammatical rules in language lessons. Table 4 shows that during lesson 4 students succeed many times in using the word 'force' in a scientific way, that is to express an interaction between two objects. During this lesson the pole jumper was the object of the study. In contrast, during lesson 6 the majority of the students reverted to everyday speech . The crash test and the risk of a neck fracture was the topic of this lesson. It may be that the students were more affectively engaged discussing this topic in contrast to the topic of the pole jumper so that they faced the described dilemma in a quite unique way. This encourages us to draw a relationship with the concept of interlanguage described by Selinker (1972). Whereas almost all students during lesson 4 are suggestive of having understood the concept of force and being able to use the term 'force' appropriately, they slide back into their everyday use of 'force' during lesson 6. This reappearance of linguistic phenomena which were thought to be eradicated is what Selinker interprets as behavioral events following from language learning. From this point of view the language the students revert to can be seen as a form of 'scientific interlanguage'. The frequent change from everyday to scientific use of the term 'force' which can be observed during the teaching sequence for almost every student can be viewed as this 'scientific interlanguage'. The strategies described provide a justification for this comparison because of their similarities to the central processes explained by Selinker: The language used by the students is influenced by their everyday use of 'force' (language-transfer from the 'native language') as well as its scientific use (second-language learning), depending on the context. The example provided by Eva (163)-(166) may be interpreted as the result of a process of overgeneralisation or transfer-of-training. The deeper analysis showed that the change between different language levels is not random but depends on pre-instructional ideas and the context of the actual discussion.

Fortunately the period of time the teaching sequence lasted was long enough to see that after lesson 4 the students did *not* accomplish their learning of the concept of force. If the teaching sequence had ended accidently with lesson 4, its result would entice to praise the underlying teaching method as being appropriate to teach the concept of force and the use of the term 'force' within some lessons. But table 4 shows that learning is going on. This is not surprising if we accept that we are dealing with language learning processes to some extent. So the period of time was long enough to observe what was reported in this paper. But it might be that it was not long enough to observe typical phases or steps such as it is reported by Diehl et al. (2002). Table 4 gives no indication, neither concerning the whole group of students nor a subgroup. Hence, more research is needed to explore this possible relationship between language learning processes and science education.

The results of our study indicate some promising relationships between learning science and learning a foreign language. Thus, it is worth looking for suggestions in the field of language learning research to open up new ways for improving science education. But although relationships between second language learning and science education were pointed out in this text, it has to be emphasised that learning science is not the same as learning a foreign language. Some observations within the data are persuasive in suggesting relationships, others seem to be independent from the language learning processes. In addition we must note that whilst language learners are talking about commonplace using a new language, science learners are talking about new and abstract fields of knowledge using a new and foreign language.

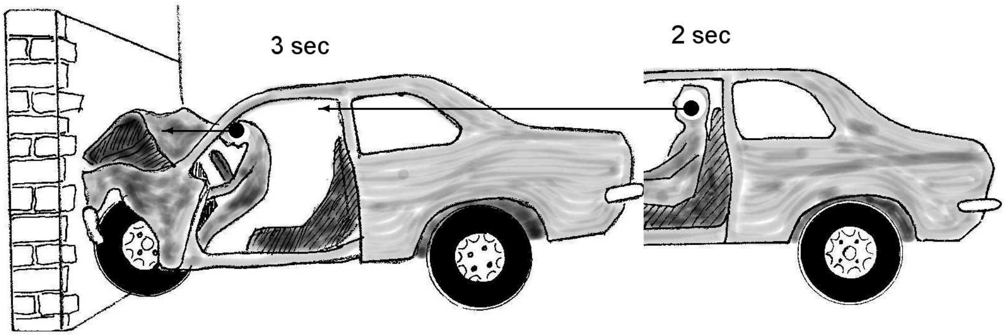

Figure 1: *Example topic (used in lesson 6, see table,4): The picture was presented to the students after having watched a slow-motion video of the crash test. The arrows indicate the velocity of the head of the dummy. The difference of the two arrows ($\Delta\vec{v}$) was also marked in the picture in the course of the lessen. It indicated that there must be a force exerted on the head of the dummy with direction opposite to its motion. The potential risk of neck-fracture in accidents like this comes into the scope of the discussion at this point. The students are asked to describe the movement of the crashtest-dummy using the term 'force' scientifically.*

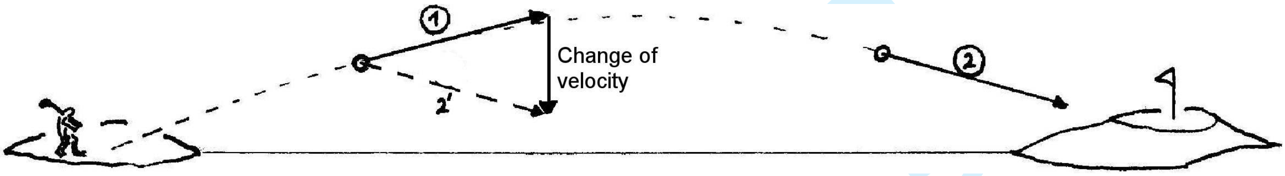

Figure 2: *Students have to write a statement using the term 'force' scientifically referring to the space of time from 1 to 2. It was emphasised that the statement must not refer to the beginning of the motion of the ball. The idea for this task was taken from the Force Concept Inventory (Hestenes, 1992).*

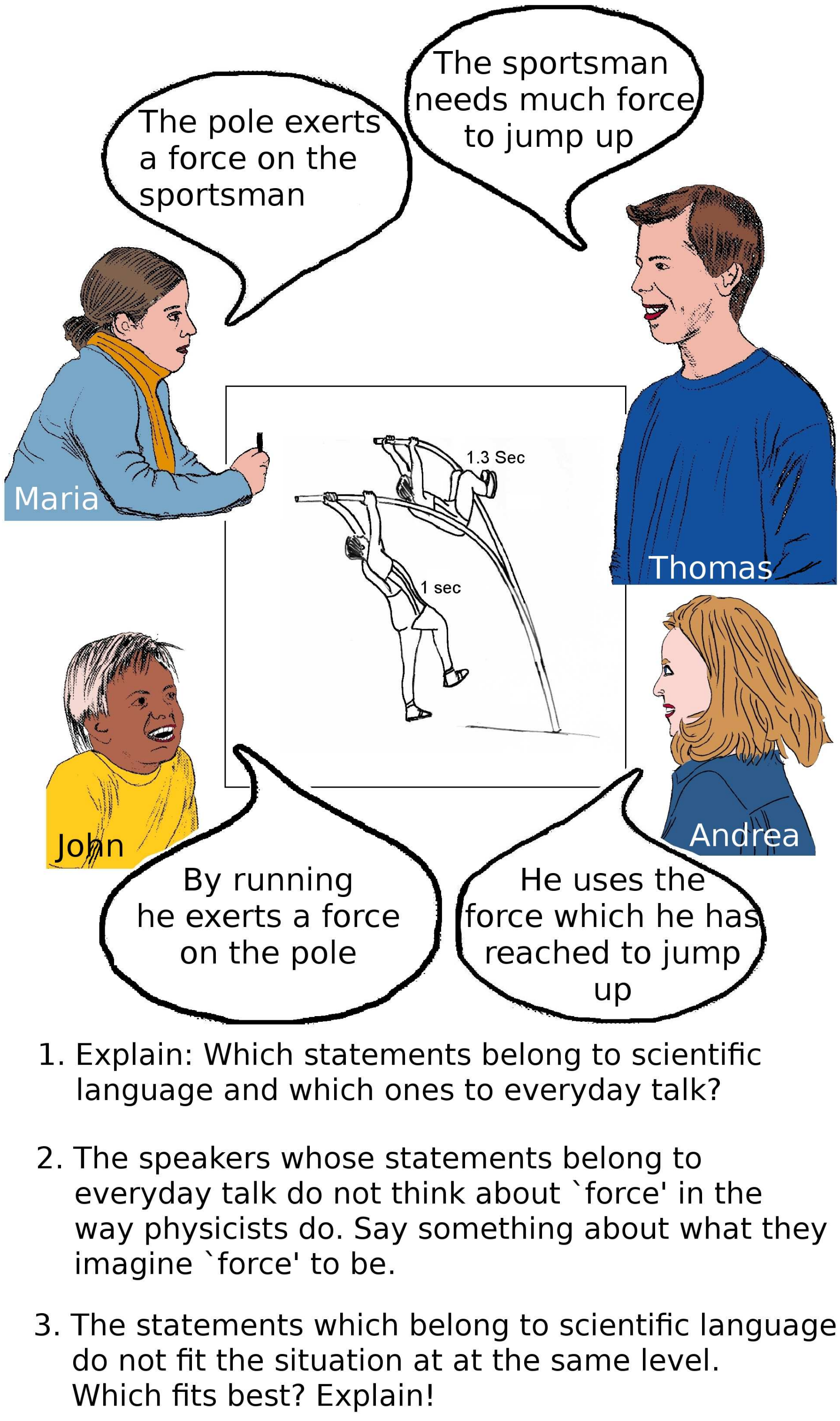

Figure 3: *Example task used in lesson 5 (see table 6): Tasks like this were used to get students engaged into a meta-discourse: They have to explain whether the given statements belong to scientific or everyday use of the term 'force'. Moreover, the students are asked to take over the speaker's point of view (in case of everyday talk) and to explain possible perspectives on the term 'force'. In the end the two statements which seem to be scientific (both Maria and John use 'to exert force on') are not of the same quality. The students are asked to differentiate these statements.*

start	5 weeks	5 weeks	**end**	6 months	
	teaching sequence section 1	teaching sequence section 2		students were taught other topics	
cognitive ability test		videotapes, audiotapes, logs, written tasks	test 2		test 3 (follow-up)

Figure 4: *Data collection over time: The teaching sequence covered a time period of approximately two and a half months. During the second section of the teaching sequence qualitative data via camcording, logs and written tasks were collected. In addition, at the beginning of the teaching sequence the students passed the verbal component of the cognitive ability test (for details see page 19). Six months after test 2 they passed another test (test 3).*

Categories Type 1	Example	Description
quantity	'there's a lot of force needed'	the word 'force' may be replaced by another word signifying something such as a quantity, for example 'energy' or 'momentum'
actor	'the force pulls the ball down'	the word 'force' is used in a sense 'acting' on other objects
interaction	'the ground exerts a force on the ball'	the word 'force' is used to denote an interaction between two objects (this was intended by the teaching sequence)
attempt	'he exerts the ball'	the whole sentence gives the impression that the speaker tries to use the correct phrase but does not succeed
others	'the force exerts a force on the ball'	uses of the word 'force' not clearly belonging to one of the categories above
Categories Type 2	**Example**	**Description**
surface form	'this is scientific because the word 'exert' appears in the text'	the speaker assigns a 'scientific' (or everyday) use referring to the *surface form* of a given sentence
content structure	'this is scientific because the description fits well to the given situation'	the speaker assigns a 'scientific' (or everyday) use referring to the *content* of a given sentence

Table 1: *The category system: Categories of type 1 were used when students were asked to use the term 'force' scientifically; categories of type 2 were used when students are asked to participate in a meta-discourse.*

Sentence No	surface form sustains translation	intended deep structure sustains translation	sentence
1	yes	yes	Lars pushes the car
2	yes	no	The iron ball has much force
3*	no	yes	The ball bounces back from the ground
4	no	no	It's favourable to save force
5	yes	no	The engine needs energy
6*	no	yes	The ball is kept by the ballplayer

Table 2: *The translation task in the follow-up test (half a year later): Students are given six sentences using idiomatic language which had to be translated into scientific ones (if possible). The scheme indicates to what extent sustaining the translation either through surface form or intended deep structure is varied. The asterisks indicate that two translations are possible, one referring to the intended deep structure, another possibly related to the surface form. The original test is available online (Rincke, 2007, p. 235).*

subgroup	description: students whose utterances in the lesson
I	belong to categories *interaction* or *attempt* more often than to *quantity*, *actor* or *others*
II	belong in some cases to categories *interaction* or *attempt*, but utterances belonging to *actor*, *quantity* or *others* occur more often or at least equal to *interaction* or *attempt*
III	never belong to categories *interaction* or *attempt*
IV	do not contain the term 'force'
V	no utterance (but student present during lesson)

Table 3: *Scheme indicating the way in which the group of 20 students was divided into further subgroups (analysing their use of the word 'force'). This division refers only to categories of type 1, see table 1 (above).*

No of students	lesson 1	lesson 2	lesson 3	lesson 4	lesson 6	lesson 8
1	I	IV	I	I	V	I
2	I	IV	IV	I	I	IV
3	IV	IV	IV	I	IV	I
4	V	V	IV	I	IV	I
5	V	V	II	I	IV	IV
6	I	I	II	II	V	I
7	IV	IV	I	I	II	I
8	III	III	III	III	III	IV
9	I	I	III	I	III	V
10	I	IV	I	II	-	V
11	I	III	III	II	IV	III
12	I	I	III	II	III	II
13	III	IV	I	II	I	I
14	V	V	IV	II	III	I
15	V	IV	III	II	I	I
16	I	III	III	I	III	III
17	II	I	II	II	III	II
18	IV	I	III	II	III	II
19	V	IV	III	I	IV	III
20	V	II	I	I	III	IV

Table 4: *Students' affiliation to subgroups I-V during those lessons which are characterised by tasks in which students are asked to use the term 'force' scientifically. The shading indicates the categories to which students' utterances belong. See table 3* for details concerning I-V, but roughly one can say 'the darker the gray the more scientific the talk'. (A '-' indicates that the student was absent.) This division refers only to categories of type 1, see table 1 (above).

subgroup	description: students whose utterances in the lesson/test
i	belong more frequently to the category *surface form*
ii	belong more frequently to the category *content structure*
iii	belong equally to the categories *surface form* and *content structure*
iiii	cannot be assigned uniquely (students' utterance too short to categories uniquely)

Table 5: *Scheme indicating the way in which students were divided into further subgroups (analysing their argumentation structure within the meta-discourse). This division refers only to categories of type 2, see table 1 (above).*

No of students	lesson 5	lesson 7	follow-up test
1	iii	-	iiii
2	iii	-	iiii
3	ii	-	ii
4	iii	-	ii
5	iii	-	iii
6	iii	ii	iii
7	iii	-	iiii
8	ii	ii	ii
9	iii	-	iii
10	iii	-	iiii
11	iii	ii	iii
12	iii	ii	iii
13	i	i	iiii
14	iii	-	iiii
15	iii	ii	iii
16	iiii	-	ii
17	iiii	ii	iiii
18	iii	-	iiii
19	ii	-	iiii
20	iiii	-	i

Table 6: *Students' affiliation to subgroups i-iiii. The table shows the results for two lessons which are characterised by students' meta-discourse and for the meta-discourse-related task in the follow-up test. The table indicates the categories to which students' utterances belong. For details concerning i-iii see table 5.* Dark gray (i) indicates that the argumentation refers clearly to the surface form of a given statement. Lighter gray (ii) indicates that the argumentation refers clearly to the content of a given statement. Light gray (iii) indicates that the argumentation refers to the surface form and to the content. (Unfortunately many students were absent in one lesson ('-'). For this reason the results of the follow-up test are included in the table.) This division refers only to categories of type 2, see table 1 (above).

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It's rather like Learning a Language

Development of talk and conceptual understanding in mechanics lessons

Although a broad literature exists concerning the development of conceptual understanding of force and other topics within mechanics, ~~there is little~~ little is known about the role and development of students' talk about the subject. ~~This~~ The paper presents an in-depth investigation of students' talk whilst being introduced to the concept of force. The main research goal was to investigate and understand ~~the process of students ' developing~~ how students develop an understanding of the concept of force ~~as well as the way students~~ and how they use and understand the term 'force'. Therefore we make relation to the research field of students' preconcepts and the field of second language learning. Two classes of N=47 students were ~~camcorded~~ video-taped during a time period of nine lessons, each transcribed and analysed using a category system. Additional data was obtained via written tasks, logs kept by the students, and tests. The detailed analysis of the talk and the ~~result~~ results of the tests indicate that students are facing difficulties ~~similar to those when being asked to use a foreign language in language lessons when they are asked to use~~ in using the term 'force' scientifically ~~. It was Vygotsky who~~ similar to those in a foreign language instruction. Vygotsky (1962) already recognised a relationship between learning in science and learning a language. In this paper important aspects of this relationship are discussed based upon empirical data. We conclude that in some respects it might be useful to make reference to the research related to language learning when thinking about improving science education. In particular, according to Selinker's concept of interlanguage describing language learning processes within language instruction (Selinker, 1972), the language used by the students during physics lessons can be viewed as a 'scientific interlanguage'.

Introduction

In recent years the role of language in science education has been emphasised by many authors~~(~~. Many investigations concentrate on the flow of discourse within classroom talk (e.g., Bellack, Kliebard, Hyman & Smith, 1966, ~~, , ,~~ Lemke, 1990, Mortimer & Scott, 2000, ~~, ,~~ Mortimer & Scott, 2003, Scott, 1998, Sutton, 1998)~~. In particular , the research field of discourse~~ , others make relation to the quality of scientific explanations given to students (e.g., Ogborn, Kress, Martins & McGillicuddy, 1996), finally many more perspectives on classroom talk can be found. The study reported in this paper aims at an investigation of students' understanding and use of a single scientific term which is difficult to learn. The particular term in this study was 'force'. By means of a detailed analysis of students' utterances (i.e. their output) we seek to retrace the process of meaning-making of individuals. Furthermore, the analysis highlights the interdependency between this process of meaning-making and language levels used by the students.

Besides the term 'force', there exist many more scientific terms which are regarded as being difficult to learn (e.g., 'voltage' or 'temperature'). One important reason for these difficulties is their nonspecific use in everyday talk. Often, in everyday talk 'force' acquires the sense of 'energy' or 'momentum'. Sometimes the attribute of 'vitality' is involved. Hence, in order to clarify the scientific concept of force it appears recommendable to contrast the scientific use of the term 'force' with its everyday use. From the students' point of view, learning the scientific concept of force requires to distinguish everyday and scientific usage. Therefore the situation in physics lessons may be experienced as similar to language lessons: In both cases learners have to internalise that words acquire their sense dependent on and in relation to other words making up the whole sentence. For this reason, the results reported in this paper are linked against theory and results within the field of language learning research. The relation to language learning is regarded as one possibility to improve our understanding of learning processes experienced by the students.

In this paper, the underlying teaching method is reported and described, too. Though this method was elaborated and piloted before, the discussion about its applicability is not our primary interest, i.e. the teaching sequence is not the subject of the investigation. The design of the teaching sequence is informed by a vygotskian view on learning as a dialogic process. In this view, new ideas appear firstly on the social plane of talk and interaction. During discussion and working through the ideas every individual has to make sense of the new ideas for her or his own. Our analysis concentrates on this individual process of meaning-making and its interdependency with use of language.

Theoretical background

The aim and purpose of the study requires a theoretical framework for the analysis of students' utterances. Since the study bases upon a teaching method introducing the students to the concept of 'force', a second framework is needed explaining how and why the teaching method was chosen in the way it is reported during the following sections. The framework for the teaching method opens up a broad view on internalising the concept of force as a process which includes both, dialogic structured social interaction and individual meaning-making. After that we introduce a framework for the analysis of individual uterances. Thereby we concentrate on meaning-making and relate the findings to the research field of students' preconcepts and the field of language acquisition.

The teaching method

Discourse analysis of classroom talk ~~provides an interesting~~ represents an important and influential research field concerning the relation between language and science education. It provides an insight into the way meanings are shaped and shared in classroom talk. ~~Some earlier contributions refer to classroom talk~~ In order to clarify the background for our teaching sequence, we summarise relevant results for the development of the teaching method.

Sometimes, the classroom talk is regarded as a 'language game' in which every participant highlights a special role defined by permitted moves inside the game (Bellack et al., 1966). Thus, the metaphor of the language game is a vehicle of describing and analysing the flow of discourse. The term 'language game' is essential for the writings of Wittgenstein (Wittgenstein, 1958). Wittgenstein used the term 'language game' as a framework to explain how words acquire their sense: Words do not *have* any sense themselves – they acquire it in the course of a language game. Those language games are activity structures where people act and talk together, and words take on their sense according to their function within this game. ~~The~~ In his well known book ~~of J. Lemke~~ 'Talking Science' Lemke, 1990 refers to this philosophical framework (p. 185) and extends it to a theory of social semiotics with respect to science education. Lemke claims that the 'triadic dialogue' (p. 217) is a very common form of interaction, also known as I-R-F-pattern ('Initiation - Response - Feedback', Mehan, 1979~~,~~ ; Edwards and Mercer (1987)) or as I-R-E pattern ('Initiation - Response - Evaluation', Sinclair & Coulthard, 1975). ~~He~~ Lemke identifies other recurring patterns, for example the student-questioning dialogue or the teacher-student debate. Such social 'activity structures' (p. 186) serve as tools for meaning-making. In this view meaning can be thought of as a result of social activities. Learning science therefore includes learning to ~~speak~~ talk like members of the social community of scientists. In consequence, Lemke asks teachers to 'model scientific language by explaining to students how they themselves are combining terms together in sentences' (p. 170). Thus ~~Lemke~~ he recommends that the so called meta-discourse to play an important role in science education. ~~With reference to Lemke, explains that the 'dominance of low-level IRF activities often presents science to students as if it is objective ...and not the study of what people have ...said about nature'~~Similar as Lemke, Gee recognises scientific language as an *academic social language*, i.e. a 'way of using language so as to enact a particular socially situated identity and to carry out a particular socially situated activity' (Gee, 2005). He claims that 'one does not know what a social language means in any sense useful for action unless one can situate the meanings of the social language's words and phrases in terms of embodied experiences' (p. ~~94). recommends teaching science as a way of 'inducting someone into new ways of seeing and new ways of talking' about nature.~~ 23). So scientific terms and phrases have to be regarded as being part of a social language, used within a social community and embedded in particular activity structures and situations.

In addition to this strand focusing on discourse analysis another strand exists concerning the quality and nature of a teacher's explanations in science education~~:~~. Ogborn et al. (1996) point out that the 'act and art of explaining to a class is much less discussed than scientific ideas to be explained' (p. 2) and develop a framework for what they call a scientific explanation. This framework is governed by the metaphor of a 'story', although not thought of as a ~~narration~~ narrative but rather as a set of cooperating protagonists, each of them characterised by special capabilities. Within this framework, terms like 'force' or 'energy' form protagonists which are capable of 'doing' something with other protagonists. In this view a scientific explanation is a 'story' about these protagonists, operating within their cooperation and by this means explaining causal connections (p. 9). Sutton (1998) draws upon the metaphor of 'science as a story', too, also not implying ~~narration~~narrative. Sutton recommends emphasising in science education that scientific knowledge is a result of social interactions: 'The word 'story' has many advantages in comparison with 'fact' or 'truth'. It involves learners and invites them to think 'Is it reasonable?"(p. 37).

In the course of the last decade many contributions to the role and practise of language in science education have been influenced by the writings of L. S. Vygotsky~~:~~. Scott (1998) and Bennett (2003) point out that the increasing impact of Vygotsky's writings could account for the growing interest in the role of language in science education. Vygotsky claimed that 'higher psychological structures' (such as scientific conceptual knowledge) appear, 'first between people as an interpsychological category and then inside the child as an intrapsychological category" (Vygotsky, 1978, p. 128). This means that language plays a key role when students are introduced into new ways of thinking and talking about the world. In this view, the process of internalising new ideas or new languages originates in the social plane. Individuals construct their meaning with respect to the social language which they experience in the given situation.

Within the strand of research projects informed by Vygotsky's writings Mortimer and Scott (2000) characterise content, form and patterns of utterances based upon their 'flow of discourse analytical framework' (Mortimer & Scott, 2000, p. 129). They expand the I-R-F-pattern by differentiating as to whether students' utterances match the intended learning goal or not (content) and attributing it to either a description, explanation or generalisation (form). In addition, the nature of teachers' (and students') interventions is described (pattern). These interventions are divided into three major groups: 'developing scientific knowledge; supporting student meaning-making; and maintaining the teaching narrative' (Mortimer & Scott, 2000, p. 131). Mortimer and Scott distinguish two social languages used in the classroom – the scientific language and the spontaneous, or everyday, language. 'This, of course, can lead to teacher and students talking about the same phenomenon in quite different ways.' (Mortimer & Scott, p. 128). ~~These two languages have been discussed already by : He compared the relationship between these languages~~ Mortimer & Scott (2003) refine their analytical framework discussing 'five linked aspects, which focus on the role of the teacher in making the scientific story available, and supporting students in making sense of that story' (p. 25), i.e. teaching purposes, content, communicative approach, patterns of discourse, and teacher interventions. Their framework is based on a sociocultural view of teaching and learning mainly relying on the writings of Vygotsky. They emphasise 'that the analytical framework is offered both as a tool for thinking about and analysing science teaching after the event, and as a model to refer to, *a priori*, in thinking about the planning and development of science teaching' (p. 25). In our case, the framework was used to sustain the planning process of the lessons. This led to the following guidelines:

First, everyday and scientific language were clearly differentiated (cf. Mortimer & Scott, 2003). It was explained to the students that any scientific use of the term 'force' explicitly denotes at least two partners involved in an interaction, e.g. 'the ball exerts a force on the ground'. Thus the students were given an easy-to-use criterion to indicate any scientific use of the term force. In all tasks and texts used during the teaching sequence mixing up the different languages was studiously avoided. Thus a common problem in textbooks was avoided, namely that everyday and scientific use of specific terms appear within the same text without any appropriate explanation to the different language uses, see for example Bennett (2003, p. 169) referring to English textbooks or Rincke (2004) for German ones. The term 'force' was not introduced to the students giving them a short definition, but giving lots of examples illustrating that within scientific uses the term 'force' has other 'capabilities' than within everyday uses (cf. Ogborn et al., 1996).

Second, the meta-discourse suggested by Lemke (1990) played an important role: The aim of the meta-discourse was to engage students in a discussion about language including syntactic and semantic features of informal everyday talk or formal scientific use of the term 'force'. Thus, the simple criterion of differentiating between scientific and everyday language explained above was accompanied by profound discussions about what the meaning of a given description could be or to what extent it describes what was to be described. Students were encouraged to discuss the differences between everyday and scientific use of the term 'force', referring particularly to the different ideas associated with the given statements.

This teaching method is not only influenced by Lemke but also by Noam Chomsky who introduced the deep structure and surface form to model the relationship between language and thought (Chomsky, 1957). Chomsky's idea of the surface form of language is related to the criterion mentioned above: In the first step a scientific use of the term 'force' in this teaching sequence can be identified by searching for (at least) two interacting objects. This interaction normally is described by the phrase 'one object exerts a force on the other object'. Thereby this criterion refers only to the surface form. Chomsky's idea of the deep structure of language is related to the meta-discourse. During this meta-discourse students discuss the ideas related to a given statement. Appropriate descriptions of the motion of a ball or a skater are identified and inadequate uses of the term 'force' are revealed even if two interacting objects seem to appear in the text.

One overarching idea governing both, the design of the teaching sequence and the analytical framework for students' utterances should be emphasised at this point. This idea refers to the relation between *scientific* and *spontaneous* or *everyday language* and it is related to the *content* of Mortimers and Scotts framework. Above all, the relation between these two languages has been discussed by Vygotsky (1962): He compared it with the relationship between the native and a foreign language of a speaker~~. Primarily we will draw on this comparison in this text. Furthermore, we will discuss to what extent learning science can be compared with learning a new language .~~ : 'The influence of scientific concepts on the mental development of the child is analogous to the effect of learning a foreign language, a process which is conscious and deliberate from the start. In one's native language, the primitive aspects of speech are acquired before the more complex ones. The latter presupposes of phonetic, grammatical, and syntactic forms. With a foreign language, the higher forms develop before the spontaneous, fluent speech. [...] It is not surprising that an analogy should exist between the interaction between the native and the foreign language and the interaction of scientific and spontaneous concepts, since both processes belong in the sphere of developing verbal thought. However, there are also essential differences between them. In foreign language study, attention centers on the exterior, sonal, physical aspects of verbal thought; in the development of scientific concepts, on its semantic aspect. The developmentmental processes follow separate, though similar paths' (p. 109). For this reason, we chose two different points of departure for the analytical framework explained in the next section: One refers to students' preconcepts (Vygotsky's semantic aspects), the other to language learning processes.

~~Theoretical framework~~

~~In~~

The analysis of utterances: Langage and (scientific) concepts

One conspicuous feature of scientific language may be seen in its special technical vocabulary. But in addition to the subject-specific terminology many morphologic and syntactical features particular to the scientific language can be identified. These features distinguish scientific- from everyday language. At first glance it might seem that the difficulties experienced by students with the scientific language follow from these rare features with which students are not familiar. But Bennett (2003, p. 153) explains 'Whilst the research has confirmed that the language of science can pose difficulties for pupils, other research has suggested that the problem is less to do with the technical vocabulary of science than might be expected.' So it may be assumed that these difficulties ~~emerge~~ do not in the first place emerge from the technical vocabulary but from the fact that scientific conceptualisations ~~(in many cases so far from everyday experience)~~ are closely connected to scientific language and often far from everyday experience. On the other hand, everyday language is connected to typical and well known pre-instructional conceptions (preconcepts) informed by everyday experience (e.g., Hestenes, Wells & Swackhammer, 1992). Thus, the difference between scientific and everyday language ~~reflects in large part~~ largely reflects the differences between scientific concepts and those ideas used and expressed by the students.

~~Langage and (scientific) concepts~~

~~Similar to~~

Like it was done by Brown and Ryoo (2008) in their ‘content-first-approach’ we disaggregate science instruction into ‘explicit conceptual and language components’ (p. 534), because we assume that students experience at least two developments ~~whilst being taught science~~ during science education: They become familiar with scientific concepts and a new language connected to these concepts – not only single new words. Related to this distinction our perspective onto what is happening in the classroom is informed by two perspectives:

Our first point of departure is the research field concerned with students’ preconcepts about mechanics (e.g., Jung, Wiesner & Engelhardt, 1981; Wiesner, 1994; Hestenes et al., 1992), which is closely connected to the educational research on conceptual change (e.g., Duit, 2003). The knowledge provided by this research field offers a profound insight into students’ pre-instructional ideas about force, energy, momentum, velocity or acceleration. The present study is based on a teaching sequence concerning an introduction into the concept of force, therefore we mainly draw on the knowledge about students’ pre-instructional conceptions about force and their difficulties with the scientific concept of force. These pre-instructional conceptions are in large part expressed by common ways to use ‘force’ in everyday conversation. Dependent upon the context it is used synonymously with energy or momentum in addition to many other uses. It ~~’s~~ is in this broad range of meanings from informal everyday use to more scientific uses that the problem of polysemy arises which challenges both teaching and learning (Strömdahl, 2007). The pre-instructional conceptions expressed within vernacular often have the distinction of ‘force’ as a property of a single object~~: –~~, e.g. ‘She is a very forceful person’~~could serve as an example~~. Teaching the concept of force in mechanics lessons includes stimulating and supporting students not to replace but to complement the informal ideas by a scientific concept of force which expresses an interrelation between at least two objects. More details concerning the various features of pre-instructional conceptions will be discussed later in this text when the system of categories used to analyse transcribed videotapes will be explained.

In addition to ~~the research of~~ pre-instructional conceptions the framework is founded on ~~the research field of~~ second language learning. ~~If we start from the assumption~~ Assuming that students experience a language learning process when they acquire a new scientific concept we need a framework which allows us to map observations made in mechanics lessons to theoretical or empirical results ~~in the research field of~~ of research in second language learning.

~~An extensive literature~~ Literature research in the field of (second) language learning bears some remarkable contributions which help us to understand what happens in science lessons. We will summarise the most important topics which we will draw upon in the following sections:

The role of formulaic phrases

~~Language learners such~~ As well Language learners as native speakers generate their sentences by far not only by using grammatical rules. Much of ~~everything we say~~ what we articulate consists of phrases not formed creatively but retrieved ~~wholesale from memory~~ from memory as a whole (Bärenfänger, 2002). These phrases can be regarded to some extent as automated or formulaic. Language learners ~~such as native speakers~~ profit from the use of formulaic phrases: Memorising and using formulaic phrases permits language learners to extend their abilities to communicate. ~~These formulaic or automated~~ Automated phrases free them, to some extent, from using their limited vocabulary and knowledge of grammatical rules, thus they are able to express complexities which they would not be able to do based on their knowledge of rules and vocabulary. Such formulaic phrases serve to some extent as 'islands of reliability' (p. 126) – as they do not ring false for language learners because they are retrieved wholesale from memory. Native speakers accelerate their production of sentences by using formulaic phrases. ~~They~~ Such phrases do not have to be complete sentences – often they consist of only a few words. Consequently, it is recommended that language learners memorise short phrases or at least some words that belong together rather than single words: 'So this (phrase) is another piece of information about a new item which it may be worth teaching. When introducing words like *decision* or *conclusion* we may note that you *take* or *make* the one but usually *come* to the other' (Ur, 1996, p. 61). Similar state Bleyhl and Timm (1998), p. 263: 'A single word is like nothing, it requires a linguistic environment'.[1]

Either following grammatical rules or communicating with somebody – a common conflict

Edmondson (2002) ~~p. 62~~ summarises that learning outcomes while learning a new language depend on the quality of cognitive and affective processing achieved by the learner. The deeper the learner engages, cognitively and affectively, the higher the achievement ~~.~~ (p. 62). On the other hand, this engagement ~~effects~~ leads to higher cognitive loads and thus limits the learning outcomes. ~~So it~~ It can often be observed that learners decide whether to concentrate on following grammatical rules or on communicating a specific content. This decision can be seen as a process of assigning resources either for processing rules or contents. Edmondson concludes that learning grammatical rules or communicating with somebody ~~,~~ are in many cases mutual exclusive alternatives~~whereas it~~. It can be frequently observed that the learner decides to concentrate on the content and neglect grammatical rules (van Patten, 1996).

Native language - interlanguage - second language

~~Novices (in terms~~ Novice learners of a new language ~~) may use their language~~ may use it in quite a simple manner due to ~~the limitations in their~~ their limited knowledge. But simplicity is not the most significant feature of a novice's spoken or written sentences. Novices develop to some extent

[1] translated by author

an individualised language which is influenced not only by the language to be learned but also by their native language. It was Selinker who introduced the term ‘interlanguage’ to label this specific language used by and depending on the learner ~~. He described it as variable, flexible and to some extent self-reliant and systematic. Later in this text we will make reference to the interlanguage while analysing the language used by the students in science lessons.~~ (Selinker, 1969, 1972). In order to develop a theory of second-language learning he distinguishes three linguistic systems, the native language of a speaker, his interlanguage and the target language (the language the learner is attempting to learn). A theory of second-language learning should be able to predict behavioral events following from language learning processes. Obviously, not every sentence spoken by a language learner can be undoubtedly related to language learning processes. Investigating such learning processes requires that relevant behavioral events in the performance of a language learner can be separated from common behavioral events not relevant to the theory. ‘One set of these behavioral events [...] is the regular reappearance in second-language performance of linguistic phenomena which were thought to be eradicated in the performance of a learner’ (Selinker, 1972, p. 211). He points out that the ‘well-observed phenomenon of backsliding by second-language learners from a TL [target language] norm is not, as has been generally believed, either random or toward the speaker’s NL [native language], but toward an IL [interlanguage] norm’ (p. 216). The phenomenon of backsliding is especially observed ‘when the learner’s attention is focused upon new and difficult intellectual subject matter or when he is in a state of anxiety or other excitement [...]’ (p. 215). Five processes are regarded as being central for the learner’s interlanguage performance, i.e. (1) language-transfer (rules or structures are derived from the native language), (2) transfer-of-training (unfavourable influence by the training material), (3) strategies of second-language learning (the learner derives rules from the target language), (4) strategies of second-language communication (strategies to communicate in spite of missing linguistic competence), and (5) overgeneralisation (of rules belonging to the target language). Selinker points out that ‘beyond the five so-called *central* processes there exist many other processes which account to some degree for the surface form of IL utterances’ (p. 220). Other approaches were developed (e.g., ‘Approximative Systems’, Nemser, 1971) which are similar to Selinker's approach to some extent. Further research was done especially concerning the strategies of second-language learning (e.g., O'Malley & Chamot, 1990) and second-language communication (e.g., Bialystok, 1990) and resulted in refined category systems of strategies.

Diehl, Pistorius and Dietl (2002) observed that language learners essentially have to master fundamentally three steps or phases on their path from beginners to becoming advanced users: During the first phase they tend to memorise short phrases and use them in a formulaic manner. According to Diehl et al. the second phase is triggered by a cognitive overload caused by the increasing amount of formulaic phrases to be remembered. Thus the learners begin to seek for new methods to master their communication needs. They start to work their way through the variety of linguistic forms. Diehl et al. call it the 'turbulent phase', because the learners behave like they have never been taught language, and there is no avoiding this phase. During the third phase, the learners fit their interlanguage to the target language, as long as they are disposed to discard temporary self-made 'rules' which belong to their interlanguage.

Even though it is not possible to describe and compare the overall spectrum of second-language learning theories in this paper we should say something about the relation between the aspects referred here and the overarching field of research concerning second-language learning. Above we summarised the discussion about the role of formulaic phrases, the conflict between following grammatical rules and communicating with somebody, and the concept of interlanguage. This discussion focuses on the language used by the learner, i.e learners' output. There exist further research focusing on learners' output e.g., the research field which concentrates on learners' mistakes and errors and the field which concentrates on differences between the native language of a learner and a certain target language. The former aims at clarifying the reasons of mistakes and thereby fostering the progress of language learning (e.g., Knapp-Potthoff, 1987). The latter bases on the hypothesis that the difficulties experienced by a language learner arise from the differences between his or her native language and a certain target language (e.g., Stockwell & Bowen, 1965; Gass & Selinker, 1983; Kellerman, 1995). Edmondson and House (2000) argue that within the research fields concentrating on learners' output the strand based on Selinker's idea of interlanguage is especially comprehensive and therefore promising (p. 219). It comprises the investigation of the variety of mistakes as well as of interferences between native and target language.

Besides the research field concentrating on learners' output there exist more general theories which include the learner's input (provided by the teacher or other learners) and the student-teacher interaction (for a comprehensive discussion, see e.g., Ellis, 1985; Larsen-Freeman & Long, 1991; Mitchell & Myles, 1998). In this paper we concentrate on learners' output. Therefore we will especially rely on Selinkers concept of interlanguage. A broader perspective including student-teacher interaction with respect to language learning theories may be promising but is not discussed in this paper.

The study

Research question

The main research goal was to investigate and understand the process of students' developing understanding of the concept of force as well as the way students use and understand the term 'force'. Moreover the study asks to what extent results of language learning research can help us to understand the empirical data. This means that the study asks to what extent observations made within students' classroom talk in physics lessons can be linked to language learning processes.

Design: Sample and teaching method

47 students participated in the study. They were on average 14 years old and came from two classes of ~~two~~ different public secondary-schools. Both classes were taught by the same teacher. The underlying teaching sequence covered an introduction to the basic ideas of mechanics. The first section (about eight lessons) focused on the description of motions. Thus, an introduction into the dynamic concept of force was prepared which, at the end of the second section (about nine lessons), resulted in the

'second Newton's law' $\vec{F} \cdot \Delta t = m \cdot \Delta \vec{v}$. A teaching sequence structured in a similar way was already proposed for example by Wiesner (1994) and evaluated with positive results by Wodzinski and Wiesner (1994).[2] ~~In addition to the suggestions of Wiesner and Wodzinski two further features were applied to the teaching sequence presented here whereas the whole teaching sequence was piloted with 55 students before being used within the study:~~

~~Firstly, everyday and scientific language were clearly differentiated. It was explained to the students that any scientific use of the term 'force' explicitly denotes at least two partners involved in an interaction, for example 'the ball exerts a force on the ground'. Thus the students were given an easy-to-use criterion to indicate any scientific use of the term force. In all tasks and texts used during the teaching sequence mixing up the different languages was studiously avoided. Thus a well known problem common in textbooks was avoided, namely that everyday and scientific use of specific terms appear within the same text without any appropriate explanation to the different language uses, see for example referring to English textbooks or for German ones.~~

~~Secondly, the meta-discourse suggested by played an important role: The aim of the meta-discourse was to engage students in a discussion about language including syntactic and semantic features of informal everyday talk or formal scientific use of the term 'force'. Thus the simple criterion of differentiating between scientific and everyday language explained above was accompanied by profound discussions about what the meaning of a given description could be or to what extent it describes what was to be described. Students were encouraged to discuss the differences between everyday and scientific use of the term 'force', referring particularly to the different ideas associated with the the given statements.~~

~~This teaching method is not only influenced by Lemke but also by Noam Chomsky who introduced the deep structure and surface form to model the relationship between language and thought . Chomsky's idea of the surface form of language is related to the criterion mentioned above: In the first step a~~

[2] A detailed description of the whole material including all texts and tasks can be found in Rincke (2007) or via internet using the persistent identifier urn:nbn:de:hebis:34-2007101519358, for example by typing https://kobra.bibliothek.uni-kassel.de/handle/urn:nbn:de:hebis:34-2007101519358

~~scientific use of the term 'force' in this teaching sequence can be identified by searching for (at least) two interacting objects. This interaction normally is described by the phrase 'one object exerts a force on the other object'. Thereby this criterion refers only to the surface form. Chomsky's idea of the deep structure of language is related to the meta-discourse. During this meta-discourse students discuss the ideas related to a given statement. Appropriate descriptions of the motion of a ball or a skater are identified and inadequate uses of the term 'force' are revealed even if two interacting objects seem to appear in the text.~~

The detailed design of every lesson, in particular concerning the method how the students were introduced to the term and concept of force, followed the guidelines explained in the according theoretical framework section. The whole teaching sequence was piloted with 55 students before being used within the study.

Examples

At the beginning of the second part of the teaching sequence the students themselves camcorded several scenarios, for example playing with a ball, riding a bicycle or skating. Afterwards these films were analysed ~~using~~ on a personal computer. This analysis aimed at ~~the best accuracy in~~ describing the motion ~~. Therefore~~at most accuracy. To do so, for example, speeds and directions of the motions were measured. While analysing the filmed motions students realised that a velocity of a person or a ball never changes without the influence of another object, i.e. the ground, a staircase, the air, the earth or ~~anything~~ something else.

After having filmed and analysed some motions in the described way the phrase 'one object exerts a force on another object' was introduced to the students. This introduction was closely connected to the examples given by the videotapes by 'translating' the interaction of the bodies viewed in the videotape into 'scientific' descriptions: The statement 'the earth pulls the ball down' was translated into the sentence 'the earth exerts a force on the ball downwards'. Then students had to write down some statements about their films using 'force' in the 'scientific' way. Thus, the term 'force' was not introduced by a definition in the way found in several textbooks; it was introduced in the context of students' social activities and by giving examples which showed how the term 'force' interacts with other terms within a given phrase. This way of introduction was brought through Wittgenstein's idea of 'language games' (Wittgenstein, 1958) as activity structures determining the word's sense. Furthermore, it is associated with Gee's idea of scientific terms as being part of a social language (cf. p. 4).

The scene shown in figure 1 fell within the scope of one lesson (note that all lessons discussed in this paper refer to the second section of the teaching sequence – so lesson 1 in figure 1 refers to the first lesson of the second section of the teaching sequence). The overarching question was to understand the risk of a neck fracture in a head-on collision. ~~Firstly~~ First, students watched a movie showing a crash test in slow motion. Then the scene was described and discussed using words and expressions without any support from the teacher. ~~Firstly~~ After that the students talked informally. Then figure 1 was presented to focus on the motion of the head of the dummy. The vector difference $\Delta\vec{v}$ of the two given arrows (velocities) was marked in the picture, indicating that there must be something exerting a force on the head of the dummy. The students were now asked to refer to the motion of the dummy and to use the term 'force' scientifically.

[Insert figure 1 about here]

Figure 2 refers to a similar task presented in the test at the end of the teaching sequence. Students had to make a statement using the term 'force' scientifically and referring to the motion of the ball during the time period from 1 to 2. The accompanying text emphasised that the statement must not refer to the beginning of the motion (i.e. the action of the sportsman).

[Insert figure 2 about here]

Figure 3 gives examples of tasks involving students in a meta-discourse. They are given four statements and have to explain whether the term 'force' is used scientifically or not. In addition they are asked what else (other) the speakers may talk about if it is not ‘force’ in a scientific sense. Thus, different understandings of the word ‘force’ could be discussed. Students were given the chance to talk specially about their preconcept and its possible contrast to the scientific concept of force.

[Insert figure 3 about here]

Design of the study: Data collection

All lessons belonging to the second section of the teaching sequence were audio- and videotaped, then transcribed (approximately nine lessons in each ~~group~~class). In addition, the students kept a log. Here they wrote down their ideas to some of the given tasks, they also had to do some tasks in pairs and to write down their findings. Thus, at the end of the teaching sequence every written or spoken sentence could be assigned to its speaker and was accessible in the following rule-based analysis. ~~Owing~~ Due to the large amount of the text material, a smaller group of students had to be chosen for this analysis. This choice was made according to the number of words uttered by the students with respect to the number of all words spoken. In the first class (19 students in total) ~~seven~~ those students were selected, whose utterances amounted equal or more than six percent ($\approx 1/19$) of the total number of words spoken in all lessons. This means that the whole group of all students had to be included into the analysis in the hypothetic case that all students had participated in the discussions to the same extent. But in our case a smaller group of seven students was found, each of them contributing equal or more words than $1/19$ of all words spoken. Some students of this smaller group contributed up to $3/19$ of all words spoken. Corresponding to this, among the remaining group of 12 students some where found who had contributed noticeable less than $1/19$ of all words spoken. The group of seven students was chosen for the analysis. The added up amount of all words spoken by these seven students covered about 80 percent of all words spoken by the whole class. In the second class (28 students in total), following the same method 13 students were selected, whose utterances covered equal or more than three percent ($\approx 1/28$) of ~~all words spoken , thus~~ the words spoken by the whole class. As in the previous case, this smaller group covered approximately 80 percent of all words spoken~~, also. So the~~. The coincidence of approximately 80 percent may be surprising and is not a result of the way the smaller groups were selected. In the end the utterances of a group of 20 students in total were included into the detailed analysis.

The investigation of the text material was done by means of a content analysis following the approach of Philipp Mayring (Mayring, 2000, 2003; Kohlbacher, 2006; Krippendorf, 1980). This approach to content analysis aims at a rule-based, traceable process of unveiling implicit properties of a given text corpus. It is centred on the development and application of categories which fit the research interest. This system of categories has to fulfil quality factors, ~~expecially~~ especially concerning its reliability. For this study the system of categories was developed through a ~~long lasting process beginning with a~~ pilot study (55 students) undertaken one year before the main study began. The main goal of this pilot study was to improve and tweak the teaching sequence, especially ~~in respect~~ with respect to the tasks to be used. ~~However, as in the main~~ Nevertheless, also in this pilot study, all lessons of the second section of the teaching sequence were ~~camcorded and transcribedduring this pilot study also~~video-taped and transcribed. This was ~~necessary to be able to begin with the development of the~~ done in order to develop the category system. The result was a draft-version which was further developed in accordance with the following steps:

- About 50 % of the text material was read (according to the recommendation of Mayring, 2003, p. 75).

- A summary of this part of the text material was generated in a rule-based manner: Therefore a set of criteria was established determining which utterances from students should contribute to the summary. The criteria were deduced from the theoretical background explained above ~~. These criteria~~ whereas it was intended to prevent the investigators from interpreting single utterances in a holistic way, i.e. supposing what the influence on the student under consideration by other utterances could have been. For this reason, at this stadium of the analysis there were no criteria included directly asking for the emergence of an interlanguage. A possible result indicating something similar to interlanguage was regarded as being the subject of a subsequent interpretation.

The set of criteria concerned utterances in the text indicating to what extent speakers

1. feel secure while using the phrase 'to exert force on' (see 'island of reliability'), , page 10)

2. use the phrase 'to exert force on' in a seemingly automated or formulaic manner (see page 10),

3. seem to suffer from a conflict between the claim to use the word 'force' scientifically and their communication aims (see page 11),

4. apply known pre-instructional ideas about force to a given task , (see page 9), and

5. reveal a correct scientific concept when being asked to talk scientifically (see page 9).

The summary extracted by this procedure showed that many utterances referred to the criteria No. 2, 4 and 5. The first and third criterion appeared to be unsuitable, because conflicts or the impression of security emerge from single utterances very seldom. However, later we will show that there are manifesting conflicts when looking deeper into the data. Now it was possible to establish a refined set of criteria which resulted in a new system of categories: No. 4 and 5 (see above) resulted in the categories we will from now on refer to as 'type 1', see table 1. Criterion no. 2 resulted in the categories of 'type 2' (table 1).

[Insert table 1 about here]

Thus, the category system is divided into two parts: Categories of the first part (type 1) concern the use of the term 'force' by students. It is therefore related to situations in which students were explicitly asked to use the term 'force' scientifically , (see for example figure 2). The second part of categories (type 2) refers to the way students talk about their own understanding of the term 'force'. It is therefore related to situations in which they were involved in a meta-discourse. During this meta-discourse students were, for example, given a few different short texts describing a motion. In the texts the word 'force' was either used scientifically or as in everyday discourse ~~,~~ (see figure 3). Students had to explain how the use ~~differentiated~~differed.

The whole text material (all utterances of 20 selected students in total) was divided into four portions all of which were analysed independently by four pairs of investigators. One part of the text material (about eight percent) was analysed by all pairs of investigators and Cohen's Kappa was computed ($\kappa_1 = 0.81$, $\kappa_2 = 0.64$, $\kappa_3 = 0.86$, $\kappa_1 = 0.72$) to provide security for a sufficient level of reliability. The reached level can be seen as satisfactory, especially with respect to the fact that some categories ask the investigator to interpret to some extent.

Additional data were collected, figure 4 gives an overview: All students were tested with the verbal component of the cognitive ability test (Heller & Perleth, 2000). At the end of the second part of the teaching sequence they had to pass a test related to the contents of the teaching sequence. This test included some basic tasks related to the first part of the teaching sequence (which is not in the scope of this article) and some tasks similar to those which had been discussed during the second part.

[Insert figure 4 about here]

Six months later the students were tested once again. This test (test 3 in figure 4) included a task very similar to the one shown in figure 3. In addition, a new type of task was given. This type was designed to get more information about the way students take into account elements from content or surface form of sentences when reading about 'force'. The main idea of this type of task was that the students had to translate given (common usage) sentences into scientific ones. Firstly they had to decide whether a translation is ~~possible or impossible .~~ impossible or possible. Secondly they had to translate if possible. The design of the given sentences, i.e. the design of the task shall be explained in more detail. The sentences were manipulated to relate to two assumptions:

1. The first assumption was that sentences following the pattern, subject – transitive verb – object, encourage students translating it into a scientific one because this pattern is the same as using the phrase 'to exert force on'. This assumption relates to the surface structure of the sentence.

2. The second assumption was that sentences denoting an action effected by one object onto another object stimulates the students to translate also. Note that these actions may not necessarily use transitive verbs. This assumption refers to the deep structure of the sentence. The sentence 'the ball is kept by the ballplayer' for example does not follow the pattern subject – transitive verb – object, thus (accepting the explained assumptions) it may not support a translation due to its surface form. But it may stimulate students to translate it similar to 'the ballplayer exerts a force on the ball' because the given sentence communicates an action effecting the ball (intended deep structure stimulates a translation). But a translation like 'the ball exerts a force on the ballplayer' would of course be correct, too. The latter translation may be interpreted as being sustained by the surface form in a more general view, i.e. following a pattern like subject – verbs – object.

In the test six sentences were given, systematically varying the two features explained ~~,~~(see table 2). Sentences nos. 2 and 4, the intended deep structure of which do not support a translation, however, mention the word 'force' in an informal sense. These sentences are believed to particularly challenge students' understanding of the concept of force: Those students who are aware of an adequate scientific concept of force are expected to avoid the translation although the word 'force' is explicitly mentioned! The asterisks in the table indicate those sentences which may be translated in two different ways (either sustained by the surface form or the deep structure, similar to the given example above).

[Insert table 2 about here]

Analysis

The category system is divided into two parts as shown in table 1. Categories within the first part are used when students are explicitly asked to use the term 'force' scientifically. Those within the second part are used when students are asked to participate in a meta-discourse. During the teaching sequence six lessons were characterised mainly by tasks asking the students to use the term 'force' scientifically. Thus, the utterances had to be categorised by categories of type 1. In the course of two, nearly whole, lessons the students were employed with a meta-discourse, so categories of type 2 had to be applied. In the following sections the results of these lessons will be discussed.

Students' use of the term 'force'

~~To~~ In order to gain a systematic insight into the way students use the term 'force' the group of 20 selected students was further divided into five additional subgroups I-V. This division was made in each of the six lessons and was related to the assigned categories as it is shown in table 3. Subgroup (I) includes those students who mainly used the scientific phrase (or attempted to do so), i.e. their utterances belonged to *interaction* or *attempt* more often than to *quantity*, *actor* or *others*. Subgroup (II) includes students whose utterances belonged to the categories *actor*, *quantity*, *others* equal or more often than to *interaction* or *attempt*. Subgroup (III) denotes those students who never used the term 'force' to express an interaction between different bodies (i.e. no scientific use in the course of the lesson). Table 4 offers an overview over the results: Student nos. 1, 2, 6, 7, 9 and 13 use the scientific phrase or try to use it quite often (three or more times subgroup (I)) Student no. 17 belongs four times to subgroup (II). This means that scientific and everyday use of the term 'force' are quite mixed (see table 3). Students 8 and 16 belong four or five times to subgroup (III). This means that they almost never use the term 'force' in the way the teaching sequence intended to. Overall the table gives the impression that students use the term 'force' in a very heterogeneous way. Surprisingly, there is little, if no evidence that students had progressed towards becoming familiar with scientific use over time. It is therefore reasonable to investigate in more detail under which conditions students imply an interaction while using the term 'force' and under which conditions they tend to fall back into everyday speech. The following examples of students' utterances are translated into English as close to the original as possible. All utterances can be found in the original work of Rincke (2007) (available via internet). In Rincke (2007) each utterance is counted. We will give the original number in parenthesis, thus the interested reader can examine each utterance in its original language.

[Insert table 3 about here] [Insert table 4 about here]

The dilemma between surface form and communicative interest

The following examples show that many students who are asked to use ’force’ scientifically seem only to see two different and mutually exclusive choices: They choose either to follow the linguistic model given by the teacher or to follow their own communicative interest. The first choice is centred on the surface form, the latter relate to the content, or deep structure, of the statement. It can be observed quite frequently that students following the surface form (so trying to use the phrase ‘to exert force on’) tend to ignore the topic of the discussion or, in some cases, obviously do not understand what they themselves are talking about. The example given by Eva (student no. 13 in table 4, found in their log, illustrates this very clearly. She refers to a videotape showing two students throwing a ball back and forth:

> Eva: "One person exerts a force on the ball and throws it to another person. The other person catches the exerted ball. The other person exerts a force on the ball and throws it back. The to exerted balls are thrown back and forth." (163)-(166)

Eva seems to test the new phrase – she uses several fragments of the phrase ‘to exert a force on a ball’ with different grammatical functions, for example ‘exerted’ with function of an adjective. One may suppose that Eva tries to detect what function the different fragments of the phrase may have. She seems to be concentrated on following the pattern given by the teacher, the content being unimportant. In the context of the crash test (see figure 1) which was discussed in lesson 6 (see table 4) only a few utterances following the scientific linguistic pattern can be found. Eva says:

Eva: "The man exerts a force on the windshield" (277)

That is obviously correct, but the discussion is on those things effecting the man (crashtest-dummy). The lesson deals not with the destruction of the windshield but with the risk of being hurt. Peter (student no. 15 in table 4) says:

Peter: "The engine exerts a force on the car so it crashes against the wall with high speed." (277)

Similar to above this might be correct in a way but it is clearly off-topic.
Certainly the majority of the utterances in this lesson are not off-topic, but the majority of the students however entirely ignore the fact that they are asked to use 'force' scientifically. This is surprising because the teacher gives a lot of hints, narrows the discussion on only a few aspects, and, in the end, asks explicitly who or what is exerting a force on the man. Salim (student no 14 in table 4) responds:

Salim: "The pressure from the wall when he's going towards the wall [...]." (260)

Within this quite complex context of a crash test students are faced with a particular dilemma: We describe it as a dilemma between surface form and students' communicative interest. This dilemma is characterised by two different and mutually exclusive choices for the students: Either to follow the scientific pattern and ignore the topic of the discussion or to follow their own communicative interest and ignore the necessity of expressing an interaction of two objects. Unfortunately neither the first nor the second choice stands a good chance of winning the teacher's approval, because neither fulfils the requirement to use the term 'force' scientifically.

Strategies: How to avoid an unfamiliar use of the word 'force'

Referring again to the example of a pole jumper (lesson 4 in table 4), the scientific use of the term 'force' can be observed more often than in the lesson concerned with the crash test (note that the example task shown in figure 3 was not within the scope of this lesson but that of lesson 5). As in the case of the crash test lesson the students watched a video of the pole jumper in slow motion and then described the motion in everyday talk. Then, after one student had used the word 'force' spontaneously in his description, the whole class was asked by the teacher to describe the motion using the term 'force' scientifically (at this point categorising the video using categories of type 1 starts). But even within this context ~~there can be observed~~ a frequent change can be observed between scientific and everyday uses of the term 'force'. The following analysis posits that these changes do not happen casually; perhaps this could be interpreted as a process of problem solving: When students are asked to talk scientifically, they have to locate appropriate objects interacting with each other. Furthermore, they have to trust that these objects have the potential to effect something on another object. In many contexts this percieved 'active' role has to be assigned to objects like the 'ground' or – in this case – the 'pole'. Students often do not trust in the capacity to interact. This may be the reason ~~for that~~ why they fall back into the everyday way arguing, because this allows avoidance of attributing a seemingly 'active' role to inanimate objects such as the ground or the pole. Peter (student no. 15 in table 4) says:

Peter	"He exerts a force on the pole and goes, yes, is catapulted up by the pole."	(196)-(197)

This pattern can be found in a variety of utterances, another example is given by Vivien (student no. 6 in table 4) who refers to a person playing with a ball:

Vivien	"A person exerts a force on the ball, the ball drops with much force on the ground."	(167)-(168)

It may be easy to assign an active part to a person because this alignes to common preconcepts. But it is difficult to do the same in the case of the ground because this seems to be far from everyday experience. The ground in this view is nothing more than an inanimate barrier, incapably exerting anything. Thus the speaker argues in scientific terms as long as it is an 'active' object exerting a force (a person). In the case that it might be the pole or the ground exerting a force on the ball, the speaker resorts to everyday talk. Everyday uses of the term 'force' do not compel students to talk about objects interacting with other objects. The falling back into common parlance everyday ways of talking can be found very frequently within the data.

In addition~~two more~~ , two strategies for handling seemingly interacting objects appear: (1) Often students invent to some extent a particular story and attribute it to a given situation, a story which typically provides 'true active partners'. Figure 2 gives an example of a task. Students have to provide a statement to the depicted situation using 'force' scientifically. The vertical arrow points to the earth which is just represented through a horizontal line. The majority of the students do not include the earth in their descriptions. They prefer to talk about the sportsman hitting the ball although it is emphasised specifically in the accompanying text to the task that the statement must not refer to the beginning of the motion (action of the sportsman).

(2) A quite elegant way of solving the problem of handling seemingly active objects which can be observed sometimes within the data is to use a rather impersonal style of talk: 'There is a force exerted on the breaking skater' may serve as an example. The statement expresses the interaction required to be described without stating who or what is exerting the force. So the speaker does not tend to assign an active role to the ground which is exerting the force on the (breaking) skater.

These different strategies may be collectively described as strategies of avoidance. They provide a way to cling onto preconcepts. The way in which the word 'force' is used scientifically obliges students to assign unfamiliar roles to objects. This seems to be a tough challenge. Students normally are aware of mapping their statements to their ideas of a given situation. This means that they do not talk scientifically to fulfill what the teacher asks them to do – they talk scientifically if there is almost no gap between their preconcept and what the scientific phrase 'to exert a force on' may intend. Otherwise, if there is an enormous gap between students' preconcepts and what a scientific statement would express, they prefer to relapse into everyday talk.

Student's way of participating in the meta-discourse

When students engage in a meta-discourse two patterns of argumentation can be identified: If asked whether a given statement belongs to everyday- or scientific talk students may refer to the surface form (i.e. the presence of particular keywords). The second pattern is that they refer to its deep structure (i.e. the content of the statement). If following exclusively the second pattern they do not make relation to the presence or absence of typical phrases like 'to exert force on (see table 1, categories of type 2). Figure 3 gives an example of a task. As mentioned above two lessons were characterised by tasks stimulating this meta-discourse. To get an insight into how students argue the group of 20 students was divided into four subgroups following the scheme indicated in table 5. As in the previous case, this division was made for the two lessons (and for the results of the meta-discourse related task during the test half a year later). Table 6 shows the results. Although some data is missing, the table clearly shows that the majority of the students make reference to the surface form as well as to the content: The affiliation to subgroup (i) appears only three times in table 6, twice for student no. 13 and once for student no. 20. This means that there are few examples for utterances belonging to the category *surface form*. Subgroup (ii) appears 13 times, this means that the utterances of these students belong more frequently to *content structure*. Subgroup (iii) appears 19 times. These students argue referring equally to the surface form and to the content of a given statement when they are asked whether it belongs to scientific or every day language.

[Insert table 5 about here] [Insert table 6 about here]

The tasks used to stimulate the meta-discourse always required the students to explain their decisions. Many students argue in the following way: If the given statement belongs to everyday talk, they refer to the content of the statement (and not to the absence of the phrase 'to exert force on'), for example (see statement of Thomas, figure 3):

> 'Thomas' statement belongs to everyday talk. The word 'force' means energy.' (351)

If the given statement belongs to the scientific use of the term 'force' they argue with the presence of the phrase 'to exert force on' and, in addition, in many cases to its content, for example (see statement of Maria, figure 3):

> 'Maria's statement is scientific because two interacting bodies can be found, one which is the person, another which is the force exerted on.' (343)

In the previous section we showed that students faced with the aforementioned dilemma ~~very~~ frequently decide to follow their communicative interest and ignore scientific aspects – even when asked by the teacher to look for interacting bodies. It is noteworthy that within the meta-discourse the majority of the students make relation to the surface form of a given statement and to it's content – therefore iii appears frequently in table 6. This means that while dealing with scientific phrases within a meta-discourse, interacting bodies (as an essential element of the concept of force) are more likely included in students' utterances in a discussion.

Achievement test and cognitive ability test

As explained in the previous sections, the students passed the verbal part of the cognitive ability test before the teaching sequence started. In the end they passed an achievement test related to the basic ideas of mechanics which had been within the scope of the teaching sequence ('test 2' in figure 4). The results met the level of performance the students had revealed in the previous half of the year and were rated as 'normal' by the teacher (average of 60% correct solutions, $\sigma = 18.4\%$), but there was only a weak correlation formed between this test and the verbal component of the cognitive ability test ($+0.09$). This means that the cognitive ability test is a weak predictor of the success in the achievement test. Although the study did not aim to endorse the appropriateness of the teaching methodology, it is noteworthy that the methodology does not seem to have advantaged those students achieving high scores in the verbal component of the cognitive ability test – notwithstanding the fact that the discussion about language was an essential part of the teaching sequence.

Translation task in the follow-up test

The translation task was designed to obtain more information about the role of the surface form and the intended deep structure (page 21). The students had to translate – if possible – informal sentences into scientific ones. One can expect several conditions under which students translate the given sentences:

1. students translate if triggered by the surface form (assumption 1 explained on page 21),
2. students translate if triggered by the deep structure (content, assumption 2),
3. students translate if the word 'force' is mentioned.

The results may be summarised as follows: If, and only if, the deep structure (content) of the given statement triggers a translation, students translate the given sentence into a scientific one, that is into a sentence using the phrase 'to exert force on'. Thus condition 2 exclusively triggers a translation. This means that even if the surface form follows the pattern subject – (transitive)verb – object (condition 1) they avoid translating it if they cannot associate the given sentence with the scientifically correct concept. They also avoid the translation if the given (informal) sentence contains the word 'force' as for example in the sentence 'the iron ball has much force' (condition 3). There was only one exception – one student who had probably misunderstood the task tried to translate all sentences. This means that within this type of task students are able to detect everyday uses of the word 'force'. Furthermore, they are not tempted to translate the sentence into another seemingly scientific form although the given sentence contains the word 'force'.

There are two sentences in table 2 which may be translated in two different ways – one related to the surface form, another related to the intended deep structure (sentences three and six, marked with an asterisk). The 20 students gave in total 40 translations for these two sentences, but only six solutions can be interpreted as being sustained by the surface form. This means that similar ~~like~~ to in the lessons when students are asked to *use* the term force scientifically the (intended) deep structure seems to be much more influential than the surface form.

Discussion and Implications

Tables 4 and 6 give an overview of the ways in which students use the term ‘force’ and how they comprehend it. At first glance it is remarkable that there are no students whose utterances seem to develop towards a scientific style: Every student changes his or her uses of the word ‘force’ ~~dependent~~ depending on the situation. The detailed analysis reveals that the often observed change between scientific and everyday talk does not happen casually but ~~is dependent~~ depends on the given situation: When students are asked to use the term ’force’ scientifically they are faced with what we describe as a dilemma between the surface form and students’ communicative interest. This dilemma appears in particular within complex situations, for example the cited crash test. The dilemma is characterised by two different and mutually exclusive choices for the students: Either they follow the scientific pattern and ignore the topic of the discussion or they follow their own communication interest and ignore the necessity of expressing an interaction of two objects. Both choices do not offer any real possibility to consolidate a physical concept of force.

Moreover, the frequent change between scientific and everyday talk can be interpreted as a result of problem solving: Students who are asked to talk scientifically have to locate appropriate objects interacting with each other. They have to accept that these objects effect something on another object. The strategies described can be thought of as strategies for avoiding a discrepancy between students’ preconcepts and what a scientific sentence might express. Even they may serve as a way to escape the dilemma between surface form and communicative interest. This leads to a language which is influenced by the preconcepts as well as the linguistic model given by the teacher.

It was reported that within this study the majority of the students follow their communicative interest and often do not regard elements related to the surface form. The translation task in the follow-up test confirms that students' utterances are mainly influenced by the intended deep structure and not by elements from the surface form. The analysis of students' argumentation within the meta-discourse leads to the result that the dominance of content related aspects diminished in favour of formal aspects. By means of regarding aspects of the surface form, students are asked to think about interacting objects. Thus, essential parts of the physical concept of force are introduced into students' debate by means of the meta-discourse.

When students are asked to use the term 'force' scientifically very few utterances expressing an interaction between objects using common verbs like 'to pull', 'to push' or 'to hit'can be found. This is surprising because the teaching method emphasises that sentences using such transitive verbs and those using 'to exert force on' are of the same grammatical structure. This observation suggests that developing an adequate concept of force and learning to talk scientifically cannot be disassociated into two consecutive steps, i.e. ~~firstly~~ first idiomatically describing interacting bodies, then describing interacting bodies using scientific phraseology. It is more likely that students face two challenges simultaneously: accepting that objects interact and describing the phenomenon scientifically (thus talking of interacting objects). A way of talking in everyday language whilst talking about interacting objects can hardly be observed within the data. Whenever the students use their ~~common day~~ everyday language they talk about force in a sense of momentum, energy, as being the property of one object. This means that everyday language and pre-instructional ideas are so closely associated that the idea of interacting objects is normally not expressed at this language level.

Thereby an interesting new question arises: Brown and Ryoo (2008) report considerable benefits from their 'content-first-approach': The idea of this approach (investigated within biologic contexts) is to treat the content using informal language, then to reutter in scientific terms. This persuasive approach ~~takes account~~ accounts for the dual nature of the challenge faced by the students whilst they are being introduced to new scientific ideas: They have to become familiar with new concepts and with a new language. The content-first-approach therefore disaggregates science instruction into 'explicit conceptual and language components' – not only referring to its ~~logical~~ logical – but also chronological structure! The data reported in this study~~however~~ , however, suggest that in case of the term 'force' this chronological disaggregation seems to be impossible due to the close association between everyday language and pre-instructional ideas. In case of the topic 'force' students have to become familiar with new ideas whilst using a new language at the same time. This may account for the difficulties students have in understanding the concept of the term 'force'. This observation can be directly related to a claim made by Gee (2005): 'Lifeworld language is problematic for science' (p. 30). He argues 'I believe there are good reasons to encourage children, even clearly on, to marry scientific activities with scientific ways with words, and not lifeworld languages, though lifeworld languages are obviously the starting point for the acquisition of any later social language, as Vygotsky pointed out.'

The theoretical framework for the analysis of students' utterances explained in the opening sections is based on two research fields, namely the field concerned with pre-instructional ideas about mechanics and the field of second language learning. We will now connect our results and the summary related to second language learning.

It was explained that formulaic phrases which are used in a seemingly automated way play an important role for language learners because they tune to some extent their production of sentences: Using such sentences puts learners in the position to communicate in a way which their explicit knowledge of grammatical rules would not allow them to do. During the teaching sequence presented in this paper the phrase 'an object exerts a force on a another object' is emphasised many times by the teacher and the teaching material. Students get to know that this phrase indicates a scientific use of the term force. So it may be expected that students tend to use it very frequently in the case that they are asked to use the word 'force' scientifically. But table 4 shows clearly that only during lesson 4 the scientific phrase is used many times. It is surprising that many students remain on the level of everyday language although they are asked to use the word 'force' in a scientific way. This means that the scientific phrase, although emphasised and marked as *scientific* is not used in an automated way. The formulaic scientific phrase figures not in the way formulaic phrases often do when learning a second language.

In the section about the theoretical framework, a common conflict experienced by language learners was reported: They assign cognitive resources for processing either grammatical rules or contents. van Patten (1996) reports that normally learners decide to process contents and tend to neglect the importance of rules. Learners may regard applying grammatical rules as less important in order to follow their communicative interest. So language learning in classroom is fundamentally characterised by two contradictory aims: On the one hand talking about something (using the new and foreign language) and on the other hand learning to use appropriate vocabulary and generate correct sentences. It is difficult to pay attention to these two aims at the same time unless the given context is very simple. Thus language learners face a dilemma between requirements related to grammatical rules and their communicative interests. It is obvious that this dilemma is analoguous to the dilemma between surface form and communicative interest reported in this paper. In this respect, using scientific phrases in science lessons may be compared to following grammatical rules in language lessons. Table 4 shows that during lesson 4 students succeed many times in using the word ‘force’ in a scientific way, that is to express an interaction between two objects. During this lesson the pole jumper was the object of the study. In contrast, during lesson 6 the majority of the students reverted to everyday speech . The crash test and the risk of a neck fracture was the topic of this lesson. It may be that the students were more affectively engaged discussing this topic in contrast to the topic of the pole jumper so that they faced the described dilemma in a quite unique way.

~~Furthermore, we can~~ This encourages us to draw a relationship with the concept of interlanguage described by Selinker (1972)~~: The term ‘interlanguage’ denotes a particular language developed and used by language learners. It is influenced by their native language as well as by the foreign one, depending on the context~~. Whereas almost all students during lesson 4 are suggestive of having understood the concept of force and being able to use the term ‘force’ appropriately, they slide back into their everyday use of ‘force’ during lesson 6. This reappearance of linguistic phenomena which were thought to be eradicated is what Selinker interprets as behavioral events following from language learning. From this point of view the language the students revert to can be seen as a form of ‘scientific interlanguage’. The frequent change from everyday to scientific use of the term ‘force’ ~~can be viewed~~

~~as a~~ which can be observed during the teaching sequence for almost every student can be viewed as this 'scientific interlanguage'. The strategies described provide a justification for this comparison because of their similarities to the central processes explained by Selinker: The language used by the students is influenced by their everyday use of 'force' (~~native language~~language-transfer from the 'native language') as well as its scientific use (~~foreign language~~second-language learning), depending on the context. ~~They change between these language levels in a seemingly flexible way~~The example provided by Eva (163)-(166) may be interpreted as the result of a process of overgeneralisation or transfer-of-training. The deeper analysis showed that ~~this change~~ the change between different language levels is not random but depends on pre-instructional ideas and the context of the actual discussion.

~~It might be that~~ Fortunately the period of time the teaching sequence lasted was ~~not~~ long enough to see that after lesson 4 the students did *not* accomplish their learning of the concept of force. If the teaching sequence had ended accidently with lesson 4, its result would entice to praise the underlying teaching method as being appropriate to teach the concept of force and the use of the term 'force' within some lessons. But table 4 shows that learning is going on. This is not surprising if we accept that we are dealing with language learning processes to some extent. So the period of time was long enough to observe what was reported in this paper. But it might be that it was not long enough to observe typical phases or steps such as it is reported by Diehl et al. (2002). Table 4 gives no indication, neither concerning the whole group of students nor a subgroup. ~~So~~ Hence, more research is needed to explore this possible relationship between language learning processes and science education.

The results of our study indicate some promising relationships between learning science and learning a foreign language. Thus, it is worth looking for suggestions in the field of language learning research to open up new ways for improving science education. But although relationships between second language learning and science education were pointed out in this text, it has to be emphasised that learning science is not the same as learning a foreign language. Some observations within the data are persuasive in suggesting relationships, others seem to be independent from the language learning processes. In addition we must note that whilst language learners are talking about commonplace using a new language, science learners are talking about new and abstract fields of knowledge using a new and foreign language.

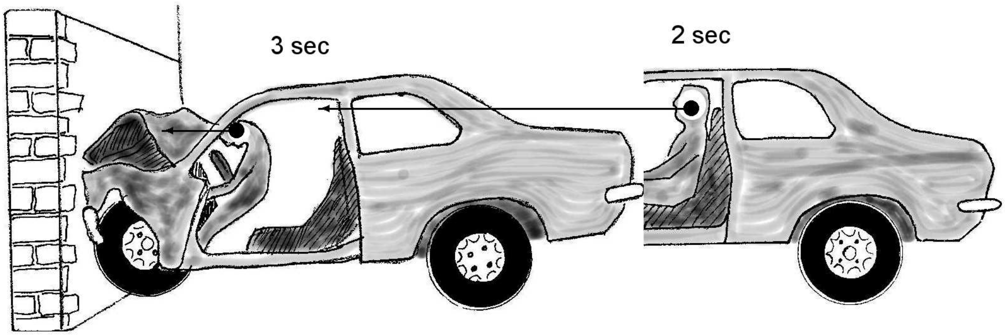


Figure 1: *Example topic (used in lesson 6, see table,4): The picture was presented to the students after having watched a slow-motion video of the crash test. The arrows indicate the velocity of the head of the dummy. The difference of the two arrows ($\Delta\vec{v}$) was also marked in the picture in the course of the lessen. It indicated that there must be a force exerted on the head of the dummy with direction opposite to its motion. The potential risk of neck-fracture in accidents like this comes into the scope of the discussion at this point. The students are asked to describe the movement of the crashtest-dummy using the term 'force' scientifically.*

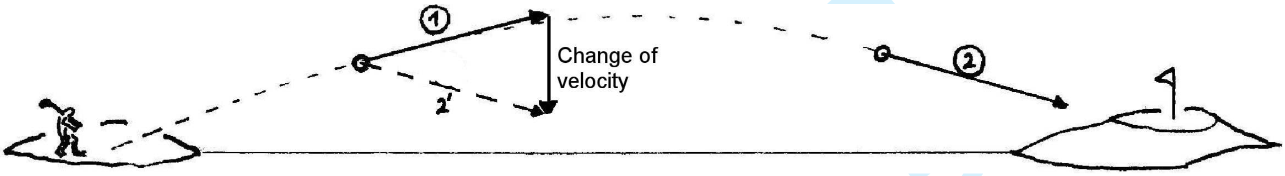
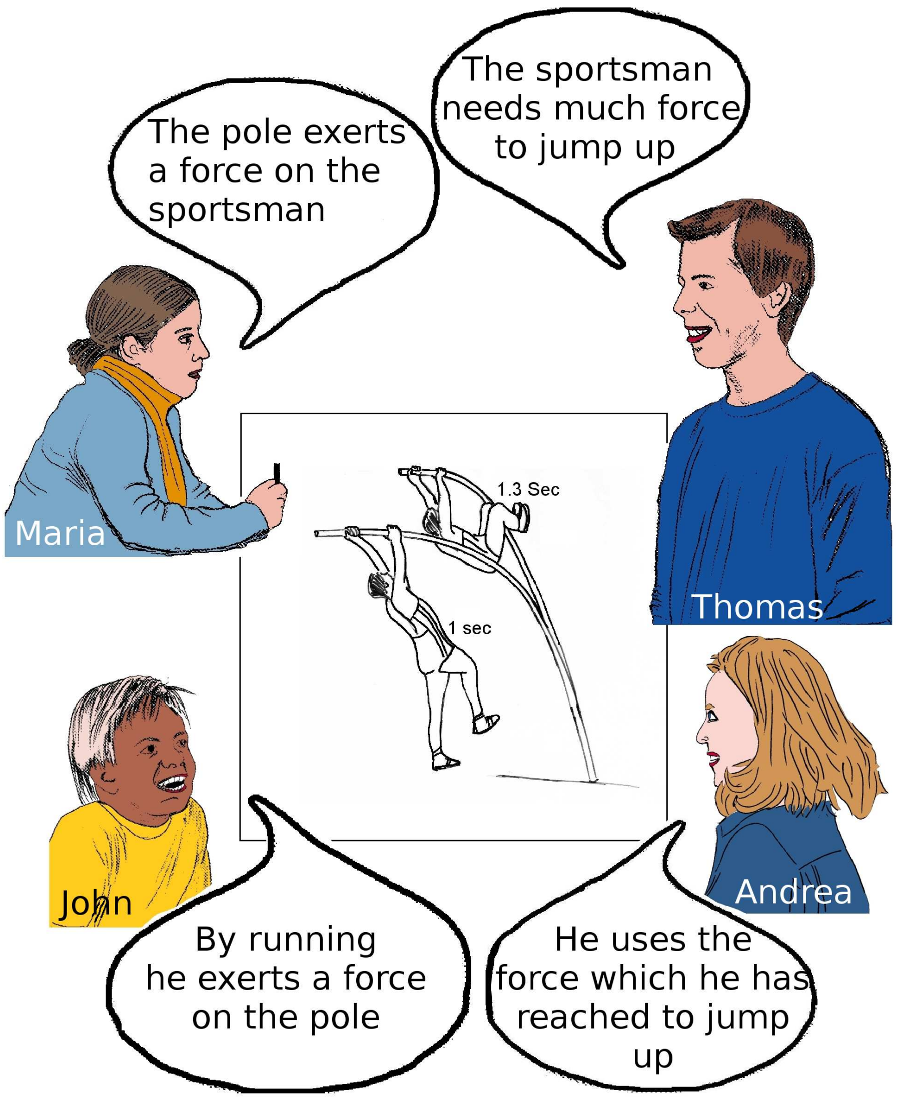


Figure 2: *Students have to write a statement using the term 'force' scientifically referring to the space of time from 1 to 2. It was emphasised that the statement must not refer to the beginning of the motion of the ball. The idea for this task was taken from the Force Concept Inventory (Hestenes, 1992).*



1. Explain: Which statements belong to scientific language and which ones to everyday talk?

2. The speakers whose statements belong to everyday talk do not think about `force' in the way physicists do. Say something about what they imagine `force' to be.

3. The statements which belong to scientific language do not fit the situation at at the same level. Which fits best? Explain!

Figure 3: *Example task used in lesson 5 (see table 6): Tasks like this were used to get students engaged into a meta-discourse: They have to explain whether the given statements belong to scientific or everyday use of the term 'force'. Moreover, the students are asked to take over the speaker's point of view (in case of everyday talk) and to explain possible perspectives on the term 'force'. In the end the two statements which seem to be scientific (both Maria and John use 'to exert force on') are not of the same quality. The students are asked to differentiate these statements.*

start	5 weeks	5 weeks	**end**	6 months	
	teaching sequence section 1	teaching sequence section 2		students were taught other topics	
cognitive ability test		videotapes, audiotapes, logs, written tasks	test 2		test 3 (follow-up)

Figure 4: *Data collection over time: The teaching sequence covered a time period of approximately two and a half months. During the second section of the teaching sequence qualitative data via camcording, logs and written tasks were collected. In addition, at the beginning of the teaching sequence the students passed the verbal component of the cognitive ability test (for details see page 21). Six months after test 2 they passed another test (test 3).*

Categories Type 1	Example	Description
quantity	'there's a lot of force needed'	the word 'force' may be replaced by another word signifying something such as a quantity, for example 'energy' or 'momentum'
actor	'the force pulls the ball down'	the word 'force' is used in a sense 'acting' on other objects
interaction	'the ground exerts a force on the ball'	the word 'force' is used to denote an interaction between two objects (this was intended by the teaching sequence)
attempt	'he exerts the ball'	the whole sentence gives the impression that the speaker tries to use the correct phrase but does not succeed
others	'the force exerts a force on the ball'	uses of the word 'force' not clearly belonging to one of the categories above
Categories Type 2	**Example**	**Description**
surface form	'this is scientific because the word 'exert' appears in the text'	the speaker assigns a 'scientific' (or everyday) use referring to the *surface form* of a given sentence
content structure	'this is scientific because the description fits well to the given situation'	the speaker assigns a 'scientific' (or everyday) use referring to the *content* of a given sentence

Table 1: *The category system: Categories of type 1 were used when students were asked to use the term 'force' scientifically; categories of type 2 were used when students are asked to participate in a meta-discourse.*

Sentence No	surface form sustains translation	intended deep structure sustains translation	sentence
1	yes	yes	Lars pushes the car
2	yes	no	The iron ball has much force
3*	no	yes	The ball bounces back from the ground
4	no	no	It's favourable to save force
5	yes	no	The engine needs energy
6*	no	yes	The ball is kept by the ballplayer

Table 2: *The translation task in the follow-up test (half a year later): Students are given six sentences using idiomatic language which had to be translated into scientific ones (if possible). The scheme indicates to what extent sustaining the translation either through surface form or intended deep structure is varied. The asterisks indicate that two translations are possible, one referring to the intended deep structure, another possibly related to the surface form. The original test is available online (Rincke, 2007, p. 235).*

subgroup	description: students whose utterances in the lesson
I	belong to categories *interaction* or *attempt* more often than to *quantity*, *actor* or *others*
II	belong in some cases to categories *interaction* or *attempt*, but utterances belonging to *actor*, *quantity* or *others* occur more often or at least equal to *interaction* or *attempt*
III	never belong to categories *interaction* or *attempt*
IV	do not contain the term 'force'
V	no utterance (but student present during ~~lessen~~lesson)

Table 3: *Scheme indicating the way in which the group of 20 students was divided into further subgroups (analysing their use of the word 'force'). This division refers only to categories of type 1, see table 1 (above).*

No of students	lesson 1	lesson 2	lesson 3	lesson 4	lesson 6	lesson 8
1	I	IV	I	I	V	I
2	I	IV	IV	I	I	IV
3	IV	IV	IV	I	IV	I
4	V	V	IV	I	IV	I
5	V	V	II	I	IV	IV
6	I	I	II	II	V	I
7	IV	IV	I	I	II	I
8	III	III	III	III	III	IV
9	I	I	III	I	III	V
10	I	IV	I	II	-	V
11	I	III	III	II	IV	III
12	I	I	III	II	III	II
13	III	IV	I	II	I	I
14	V	V	IV	II	III	I
15	V	IV	III	II	I	I
16	I	III	III	I	III	III
17	II	I	II	II	III	II
18	IV	I	III	II	III	II
19	V	IV	III	I	IV	III
20	V	II	I	I	III	IV

Table 4: *Students' affiliation to subgroups I-V during those lessons which are characterised by tasks in which students are asked to use the term 'force' scientifically. The shading indicates the categories to which students' utterances belong. See table 3* for details concerning I-V, but roughly one can say 'the darker the gray the more scientific the talk'. (A '-' indicates that the student was absent.) This division refers only to categories of type 1, see table 1 (above).

subgroup	description: students whose utterances in the lesson/test
i	belong more frequently to the category *surface form*
ii	belong more frequently to the category *content structure*
iii	belong equally to the categories *surface form* and *content structure*
iiii	cannot be assigned uniquely (students' utterance too short to categories uniquely)

Table 5: *Scheme indicating the way in which students were divided into further subgroups (analysing their argumentation structure within the meta-discourse). This division refers only to categories of type 2, see table 1 (above).*

No of students	lesson 5	lesson 7	follow-up test
1	iii	-	iiii
2	iii	-	iiii
3	ii	-	ii
4	iii	-	ii
5	iii	-	iii
6	iii	ii	iii
7	iii	-	iiii
8	ii	ii	ii
9	iii	-	iii
10	iii	-	iiii
11	iii	ii	iii
12	iii	ii	iii
13	i	i	iiii
14	iii	-	iiii
15	iii	ii	iii
16	iiii	-	ii
17	iiii	ii	iiii
18	iii	-	iiii
19	ii	-	iiii
20	iiii	-	i

Table 6: *Students' affiliation to subgroups i-iiii. The table shows the results for two lessons which are characterised by students' meta-discourse and for the meta-discourse-related task in the follow-up test. The table indicates the categories to which students' utterances belong. For details concerning i-iii see table 5.* Dark gray (i) indicates that the argumentation refers clearly to the surface form of a given statement. Lighter gray (ii) indicates that the argumentation refers clearly to the content of a given statement. Light gray (iii) indicates that the argumentation refers to the surface form and to the content. (Unfortunately many students were absent in one lesson ('-'). For this reason the results of the follow-up test are included in the table.) This division refers only to categories of type 2, see table 1 (above).

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It's rather like Learning a Language

Development of talk and conceptual understanding in mechanics lessons

Although a broad literature exists concerning the development of conceptual understanding of force and other topics within mechanics, little is known about the role and development of students' talk about the subject. The paper presents an in-depth investigation of students' talk whilst being introduced to the concept of force. The main research goal was to investigate and understand how students develop an understanding of the concept of force and how they use and understand the term 'force'. Therefore we make relation to the research field of students' preconceptions and the field of second language learning. Two classes of N=47 students were video-taped during a time period of nine lessons, each transcribed and analysed using a category system. Additional data was obtained via written tasks, logs kept by the students, and tests. The detailed analysis of the talk and the results of the tests indicate that students are facing difficulties in using the term 'force' scientifically similar to those in a foreign language instruction. Vygotsky (1962) already recognised a relationship between learning in science and learning a language. In this paper important aspects of this relationship are discussed based upon empirical data. We conclude that in some respects it might be useful to make reference to the research related to language learning when thinking about improving science education. In particular, according to Selinker's concept of interlanguage describing language learning processes within language instruction (Selinker, 1972), the language used by the students during physics lessons can be viewed as a 'scientific interlanguage'.

Introduction

In recent years the role of language in science education has been emphasised by many authors. Many investigations concentrate on the flow of discourse within classroom talk (e.g., Bellack, Kliebard, Hyman & Smith, 1966, Lemke, 1990, Mortimer & Scott, 2000, Mortimer & Scott, 2003, Scott, 1998, Sutton, 1998), and others make relation to the quality of scientific explanations given to students (e.g., Ogborn, Kress, Martins & McGillicuddy, 1996). Many more perspectives on classroom talk can also be found. The study reported in this paper is an investigation of students' understanding and use of a single scientific term which is difficult to learn, the term 'force'. In this study, 'force' serves as an example. By means of a detailed analysis of students' utterances (i.e. their output) we seek to retrace the process of meaning-making of individuals. Furthermore, the analysis illuminates the interdependency of the process of meaning-making and the language levels used by the students.

Besides the term 'force', there are many more scientific terms which are regarded as similarly difficult to learn (e.g., 'voltage' and 'temperature'). One important reason for these difficulties is their nonspecific use in everyday talk. Often, in everyday talk 'force' carries the sense of 'energy' or 'momentum'. Sometimes the attribute of 'vitality' is involved. Hence, in order to clarify the scientific concept of force, teachers are recommended to contrast the scientific use of the term 'force' with its everyday use. From the students' point of view, learning the scientific concept of force requires them to distinguish everyday and scientific usage. So the situation in physics lessons may be experienced as similar to language lessons: In both cases learners have to appreciate that words acquire their sense in a way that is dependent on, and in relation to, other words making up the whole sentence. For this reason, the results reported in this paper are linked to theory and results in the field of language learning research. This relation to language learning offers one possible way to improve our understanding of learning processes experienced by the students.

In this paper, not only methods and results of the analysis of students' output is reported, but also the applied teaching method. This method has been elaborated and piloted before, so its applicability is not our primary interest, i.e. the teaching sequence is not the subject of the investigation. The design of the teaching sequence is informed by a Vygotskian view of learning as a dialogic process. In this view, new ideas appear firstly on the social plane of talk and interaction. During discussion and working through the ideas every individual has to make sense of the new ideas for her- or himself. Our analysis concentrates on this individual process of meaning-making and its interdependency with use of language.

Theoretical background

The aim and purpose of the study requires a theoretical framework for the analysis of students' utterances. Since the study is based upon a teaching method for introducing the students to the concept of 'force', a second framework is needed to explain how and why the teaching method was chosen in the way it is reported in the sections that follow. The framework for the teaching method takes a broad view on internalising the concept of force as a process which includes both dialogic structured social interaction and individual meaning-making. After that we introduce the framework on which the analysis of utterances is based on. In this we concentrate on individual meaning-making and link the findings to the research fields of students' preconceptions and language acquisition.

The teaching method

Discourse analysis of classroom talk is an important and influential strand of research on the relation between language and science education. It provides an insight into the way meanings are shaped and shared in classroom talk. In order to clarify the background for our teaching sequence, we summarise research results that are relevant to the development of the teaching method.

Sometimes, classroom talk is regarded as a 'language game' in which every participant highlights a special role defined by permitted moves inside the game (Bellack et al., 1966). Thus the metaphor of the language game is a vehicle for describing and analysing the flow of discourse. The term 'language game' is central for the writings of Wittgenstein (Wittgenstein, 1958). Wittgenstein used the term 'language game' as a way to explain how words acquire their sense: Words do not *have* any sense themselves – they acquire it in the course of a language game. These language games are activity structures where people act and talk together, and words take on their sense according to their function within the game. In the well known book 'Talking Science', Lemke (1990) refers to this philosophical framework (p. 185) and extends it to a theory of social semiotics with respect to science education. He claims that the 'triadic dialogue' (p. 217), also known as I-R-F-pattern ('Initiation - Response - Feedback', Mehan, 1979; Edwards & Mercer, 1987) or as I-R-E pattern ('Initiation - Response - Evaluation', Sinclair & Coulthard, 1975), is a very common form of interaction. Lemke identifies other recurring patterns, for example the student-questioning dialogue and the teacher-student debate. Such social 'activity structures' (p. 186) serve as tools for meaning-making. In this view meaning can be thought of as a result of social activities. Learning science therefore includes learning to talk like members of the social community of scientists. In consequence, Lemke asks teachers to 'model scientific language by explaining to students how they themselves are combining terms together in sentences' (p. 170). Thus he recommends that so-called meta-discourse should play an important role in science education. Like Lemke, Gee treats scientific language as an *academic social language*, i.e. a 'way of using language so as to enact a particular socially situated identity and to carry out a particular socially situated activity' (Gee, 2005). He claims that 'one does not know what a social language means in any sense useful for action unless one can situate the meanings of the social language's words and phrases in terms of embodied experiences' (p. 23). So scientific terms and phrases have to be regarded as being part of a social language, used within a social community and embedded in particular activity structures and situations.

Another research strand concerns the quality and nature of teachers' explanations in science education. Ogborn et al. (1996) point out that the 'act and art of explaining to a class is much less discussed than scientific ideas to be explained' (p. 2) and develop a framework for what they call a scientific explanation. This framework is governed by the metaphor of a 'story', although not thought of as a narrative but rather as a set of cooperating protagonists, each of them characterised by special capabilities. Within this framework, terms like 'force' or 'energy' identify protagonists capable of 'doing' something with or to other protagonists. In this view a scientific explanation is a 'story' about these protagonists, interacting with each other and hence explaining causal connections (p. 9). Sutton (1998) also draws upon the metaphor of 'science as a story', again not implying narrative. Sutton recommends emphasising in science education that scientific knowledge is a result of social interactions: 'The word 'story' has many advantages in comparison with 'fact' or 'truth'. It involves learners and invites them to think 'Is it reasonable?"(p. 37).

In the course of the last decade many contributions to the role and use of language in science education have been influenced by the writings of L. S. Vygotsky. Vygotsky claimed that 'higher psychological structures' (such as scientific conceptual knowledge) appear 'first between people as an interpsychological category and then inside the child as an intrapsychological category' (Vygotsky, 1978, p. 128). This means that language plays a key role when students are introduced into new ways of thinking and talking about the world. In this view, the process of internalising new ideas or new languages originates in the social plane. Individuals construct their meaning with respect to the social language which they experience in the given situation.

Within the strand of research informed by Vygotsky's writings Mortimer and Scott (2000) characterise content, form and patterns of utterances using a 'flow of discourse analytical framework' (Mortimer & Scott, 2000, p. 129). They expand the I-R-F-pattern by differentiating students' utterances which match the intended learning goal and do not (content) and classifying utterances either as a description, explanation or generalisation (form). In addition, the nature of teachers' (and students') interventions is described (pattern). These interventions are divided into three major groups: 'developing scientific knowledge; supporting student meaning-making; and maintaining the teaching narrative' (Mortimer & Scott, 2000, p. 131). Mortimer and Scott distinguish two social languages used in the classroom – the scientific and the spontaneous or everyday, language. 'This, of course, can lead to teacher and students talking about the same phenomenon in quite different ways.' (Mortimer & Scott, p. 128). Mortimer & Scott (2003) refine their analytical framework by discussing 'five linked aspects, which focus on the role of the teacher in making the scientific story available, and supporting students in making sense of that story' (p. 25). There are teaching purposes, content, communicative approach, patterns of discourse, and teacher interventions. Their framework is based on a sociocultural view of teaching and learning which mainly relies on the writings of Vygotsky. They emphasise 'that the analytical framework is offered both as a tool for thinking about and analysing science teaching after the event, and as a model to refer to, *a priori*, in thinking about the planning and development of science teaching' (p. 25). In our case, the framework was used to inform the planning process of the lessons. This led to the following guidelines:

First, everyday and scientific language were clearly differentiated (cf. Mortimer & Scott, 2003). It was explained to the students that any scientific use of the term 'force' explicitly denotes at least two partners involved in an interaction, e.g. 'the ball exerts a force on the ground'. Thus the students were given an easy-to-use criterion to indicate any scientific use of the term force. In all tasks and texts used during the teaching sequence mixing up the different languages was studiously avoided. Thus a common problem in textbooks was avoided, namely that everyday and scientific use of specific terms appear within the same text without any appropriate explanation of the different language uage (see for example Bennett (2003, p. 169) referring to English textbooks or Rincke (2004) to German ones). The term 'force' was not introduced to the students by giving them a short definition, but by giving many examples illustrating that, within scientific usage, the term 'force' has other 'capabilities' than it has in everyday use (cf. Ogborn et al., 1996).

Second, the meta-discourse suggested by Lemke (1990) played an important role: The aim of the meta-discourse was to engage students in a discussion about language including syntactic and semantic features of informal everyday talk and of formal scientific use of the term 'force'. Thus, the simple criterion for differentiating between scientific and everyday language explained above was accompanied by profound discussions about what the meaning of a given description could be, or about the extent to which it describes what was to be described. Students were encouraged to discuss the differences between everyday and scientific use of the term 'force', referring particularly to the different ideas associated with the given statements.

This teaching method is not only influenced by Lemke but also by Noam Chomsky who introduced the ideas of deep structure and surface form to model the relationship between language and thought (Chomsky, 1957). Chomsky's idea of the surface form of language is related to the criterion mentioned above: In the first step a scientific use of the term 'force' in this teaching sequence can be identified by the students by searching for (at least) two interacting objects. This interaction is normally described by the phrase 'one object exerts a force on the other object'. Hence this criterion refers only to the surface form. Chomsky's idea of the deep structure of language is related to the meta-discourse. During this meta-discourse students discuss the ideas related to a given statement. Appropriate descriptions of the motion of a ball or a skater are identified and inadequate uses of the term 'force' are revealed even if two interacting objects seem to appear in the text.

One overarching idea governing both the design of the teaching sequence and the analytical framework for students' utterances should be emphasised at this point. This idea refers to the relation between *scientific* and the *spontaneous* or *everyday language* and it is related to the *content* of Mortimers and Scotts framework. The relation between these two languages has been discussed by Vygotsky (1962), who compared it with the relationship between the native and a foreign language of a speaker: 'The influence of scientific concepts on the mental development of the child is analogous to the effect of learning a foreign language, a process which is conscious and deliberate from the start. In one's native language, the primitive aspects of speech are acquired before the more complex ones. The latter presupposes some awareness of phonetic, grammatical, and syntactic forms. With a foreign language, the higher forms develop before spontaneous, fluent speech. [...] It is not surprising that an analogy should exist between the interaction between the native and the foreign language and the interaction of scientific and spontaneous concepts, since both processes belong in the sphere of developing verbal thought. However, there are also essential differences between them. In foreign language study, attention centers on the exterior, sonal, physical aspects of verbal thought; in the development of scientific concepts, on its semantic aspect. The two developmental processes follow separate, though similar paths' (p. 109). For this reason, we chose two different points of departure for the analytical framework explained in the next section: One refers to students' preconceptions (Vygotsky's semantic aspects), the other to language learning processes.

The analysis of utterances: Langage and (scientific) concepts

One conspicuous feature of scientific language is its special technical vocabulary. In addition to subject-specific terminology, many morphologic and syntactical features particular to scientific language can be identified. These features distinguish scientific- from everyday language. At first glance it might seem that the difficulties experienced by students with scientific language follow from these distinctive features with which students are not familiar. But Bennett (2003, p. 153) explains ‘Whilst the research has confirmed that the language of science can pose difficulties for pupils, other research has suggested that the problem is less to do with the technical vocabulary of science than might be expected.’ In fact these difficulties appear to emerge not in the first place from the technical vocabulary but from the fact that scientific conceptualisations (in many cases very far removed from every day experience) are closely connected to scientific language. On the other hand, everyday language is connected to typical and well known pre-instructional conceptions informed by everyday experience (e.g., Hestenes, Wells & Swackhammer, 1992). Thus, the difference between scientific and everyday language largely reflects the differences between scientific concepts and the ideas used and expressed by the students.

As Brown and Ryoo (2008) did in their ‘content-first-approach’, we disaggregate science instruction into ‘explicit conceptual and language components’ (p. 534), because we assume that students experience at least two kinds of development whilst being taught science: They become familiar with scientific concepts and with a new language connected to these concepts – not only single new words. Related to this distinction our perspective on what is happening in the classroom is informed by two perspectives:

Our first point of departure is the research field concerned with students’ preconceptions about mechanics (e.g., Jung, Wiesner & Engelhardt, 1981; Wiesner, 1994; Hestenes et al., 1992), which is closely connected to educational research on conceptual change (e.g., Duit, 2003). The knowledge provided by this research field offers a profound insight into students’ pre-instructional ideas about force, energy, momentum, velocity or acceleration. The present study is based on a teaching sequence to introduce the concept of force, so we draw mainly on the knowledge of students' pre-instructional conceptions of force and their difficulties with the scientific concept of force. These pre-instructional conceptions are in large part expressed through common ways of using 'force' in everyday conversation. Dependent upon the context, it is used synonymously with energy or momentum, in addition to many other uses. It's in this broad range of meanings from informal everyday uses to more scientific uses that the problem of polysemy arises which challenges both teaching and learning (Strömdahl, 2007). The pre-instructional conceptions expressed in vernacular language often treat 'force' as a property of a single object, e.g. 'She is a very forceful person'. Teaching the concept of force in mechanics lessons includes stimulating and supporting students not to replace but to complement the informal ideas by a scientific concept of force which expresses an interrelation between at least two objects. More details of the various features of pre-instructional conceptions will be discussed later in this article when the system of categories used to analyse transcribed videotapes will be explained.

In addition to pre-instructional conceptions, the framework is based on second language learning. Assuming that students experience a language learning process when they acquire a new scientific concept, we need a framework which allows us to map observations made in mechanics lessons to theoretical or empirical results of research in second language learning.

The extensive research literature in the field of (second) language learning includes some remarkable contributions which help us to understand what happens in science lessons. We will summarise the most important aspects which we will draw upon in the following sections:

The role of formulaic phrases

Language learners as native speakers do not generate their sentences only by using grammatical rules. Much of what we articulate consists of phrases not formed creatively but retrieved from memory as a whole (Bärenfänger, 2002). These phrases can be regarded to some extent as automated or formulaic. Language learners profit from the use of formulaic phrases, memorising and using formulaic phrases permits language learners to extend their abilities to communicate. Automated phrases free them, to some extent, from using their limited vocabulary and knowledge of grammatical rules, thus they are able to express complexities which they would not be able to do based on their knowledge of rules and vocabulary. These formulaic phrases serve to some extent as 'islands of reliability' (p. 126) – as they do not ring false for language learners because they are retrieved wholesale from memory. Native speakers accelerate their production of sentences by using formulaic phrases. Such phrases do not have to be complete sentences – often they consist of only a few words. Consequently, it is recommended that language learners memorise short phrases or at least some words that belong together rather than single words: 'So this (phrase) is another piece of information about a new item which it may be worth teaching. When introducing words like *decision* or *conclusion* we may note that you *take* or *make* the one but usually *come* to the other' (Ur, 1996, p. 61). Similarly state Bleyhl and Timm (1998): 'A single word is like nothing, it requires a linguistic environment' (p. 263).[1]

Either following grammatical rules or communicating with somebody – a common conflict

Edmondson (2002) notes that learning outcomes while learning a new language depend on the quality of cognitive and affective processing achieved by the learner. The deeper the learner engages, cognitively and affectively, the higher the achievement (p. 62). On the other hand, this engagement leads to higher cognitive loads and thus limits the learning outcomes. It can often be observed that learners decide whether to concentrate on following grammatical rules or on communicating a specific content. This decision can be seen as a process of assigning resources either for processing rules or contents. Edmondson concludes that learning grammatical rules or communicating with somebody are in many cases mutually exclusive alternatives. Learners can frequently be observed to concentrate on the content and neglect grammatical rules (van Patten, 1996).

Native language - interlanguage - second language

Novice learners of a new language may use it in quite a simple manner due to their limited knowledge. But simplicity is not the most significant feature of a novice's spoken or written sentences. Novices develop to some extent an individualised language which is influenced not only by the language to be

[1] translated by author

learned but also by their native language. Selinker introduced the term 'interlanguage' to label this specific language used by and depending on the learner (Selinker, 1969, 1972). In order to develop a theory of second-language learning, he distinguishes three linguistic systems, the native language of a speaker, his interlanguage and the target language (the language the learner is attempting to learn). A theory of second-language learning should be able to predict behavioral events following from language learning processes. Obviously, not every sentence spoken by a language learner can be related unequivocally to language learning processes. Investigating such learning processes requires that relevant behavioral events in the performance of a language learner can be separated from common behavioral events that are not relevant to the theory. Selinker (1972) claims that 'One set of these behavioral events [...] is the regular reappearance in second-language performance of linguistic phenomena which were thought to be eradicated in the performance of a learner' (p. 211). He points out that the 'well-observed phenomenon of backsliding by second-language learners from a TL [target language] norm is not, as has been generally believed, either random or toward the speaker's NL [native language], but toward an IL [interlanguage] norm' (p. 216). The phenomenon of backsliding is particularly noticeable 'when the learner's attention is focused upon new and difficult intellectual subject matter or when he is in a state of anxiety or other excitement [...]' (p. 215). Five processes are regarded as being central for the learner's interlanguage performance, i.e. (1) language-transfer (rules or structures are derived from the native language), (2) transfer-of-training (unfavourable influence by the training material), (3) strategies of second-language learning (the learner derives rules from the target language), (4) strategies of second-language communication (strategies to communicate in spite of missing linguistic competence), and (5) overgeneralisation (of rules belonging to the target language). Selinker points out that 'beyond the five so-called *central* processes there exist many other processes which account to some degree for the surface form of IL utterances' (p. 220). Other approaches have been developed (e.g., 'Approximative Systems', Nemser, 1971) which are similar to Selinker's approach to some extent. Further research has been carried out especially concerning the strategies of second-language learning (e.g., O'Malley & Chamot, 1990) and second-language communication (e.g., Bialystok, 1990) and has resulted in refined category systems of strategies.

Diehl, Pistorius and Dietl (2002) observed that language learners essentially have to master fundamentally three steps or phases on their path from beginners to becoming advanced users: During the first phase they tend to memorise short phrases and use them in a formulaic manner. According to Diehl et al. the second phase is triggered by cognitive overload caused by the increasing number of formulaic phrases to be remembered. Thus the learners begin to seek new methods to master their communication needs. They start to work their way through the variety of linguistic forms. Diehl et al. call this the 'turbulent phase', because learners behave as though they have never been taught language, and there is no avoiding this phase. During the third phase, the learners fit their interlanguage to the target language, as long as they are disposed to discard temporary self-made 'rules' which belong to their interlanguage.

Even though it is not possible to describe and compare the overall spectrum of second-language learning theories in this paper, we should say something about the relation between the aspects referred to here and the overarching field of research on second-language learning. Above we summarised the discussion about the role of formulaic phrases, the conflict between following grammatical rules and communicating with somebody, and the concept of interlanguage. This discussion focuses on the language used by the learners, i.e the learners' output. There exist further research focusing on the learners' output e.g., the research field which concentrates on learners' mistakes and errors and the field which concentrates on differences between the native language of a learner and a certain target language. The former aims at clarifying the reasons for mistakes, thereby fostering the progress of language learning (e.g., Knapp-Potthoff, 1987). The latter is based on the hypothesis that the difficulties experienced by a language learner arise from the differences between his or her native language and a certain target language (e.g., Stockwell & Bowen, 1965; Gass & Selinker, 1983; Kellerman, 1995). Edmondson and House (2000) argue that within the research fields concentrating on learners' output, the strand based on Selinker's idea of interlanguage is especially comprehensive and therefore promising (p. 219). It comprises the investigation of the variety of mistakes as well as of interferences between native and target language.

In addition to the research field concentrating on learners' output, there are also more general theories which include the learner's input (provided by the teacher or other learners) and the student-teacher interaction (for a comprehensive discussion, see, for example, Ellis, 1985; Larsen-Freeman & Long, 1991; Mitchell & Myles, 1998). In this paper we concentrate on learners' output. Therefore we will especially rely on Selinkers concept of interlanguage. A broader perspective including student-teacher interaction with respect to language learning theories may be promising but is not discussed in this paper.

The study

Research question

The main research goal was to investigate and understand the process by which students develop an understanding of the concept of force, and the way students use and understand the term 'force'. Moreover the study asks to what extent results from language learning research can help us to understand the empirical data. This means that the study asks to what extent observations made within students' classroom talk in physics lessons can be linked to language learning processes.

Design: Sample and teaching method

Forty-seven students participated in the study. They were on average 14 years old and came from two classes in different public secondary schools. Both classes were taught by the same teacher. The underlying teaching sequence included an introduction to the basic ideas of mechanics. The first section (about eight lessons) focused on the description of motions. This prepared the way for an introduction to the dynamic concept of force which, at the end of the second section (about nine lessons), led to Newton's 'second law' $\vec{F} \cdot \Delta t = m \cdot \Delta \vec{v}$. A teaching sequence structured in a similar way has previously been proposed, for example by Wiesner (1994), and evaluated with positive results by Wodzinski and Wiesner (1994).[2] The detailed design of every lesson, in particular concerning the method by which the students were introduced to the term and concept of force, followed the guidelines explained in the theoretical background section. The whole teaching sequence was piloted with 55 students before being used within the study.

Examples

At the beginning of the second part of the teaching sequence, the students themselves camcorded several scenarios, for example playing with a ball, riding a bicycle or skating. Afterwards these films were analysed on a personal computer. This analysis aimed at describing the motion as accurately as possible. To do so, for example, speeds and directions of the motions were measured. While analysing the filmed motions, students realised that the velocity of a person or a ball never changes without the influence of another object, e.g. the ground, a staircase, the air, the Earth or something else.

After having filmed and analysed some motions in the manner described the phrase 'one object exerts a force on another object' was introduced to the students. This introduction was closely connected to the examples given in the videotapes by 'translating' the interaction of the bodies viewed in the videotape into 'scientific' descriptions: for example, the statement 'the earth pulls the ball down' was translated into the sentence 'the earth exerts a force on the ball downwards'. Students then had to write down some statements about their films using 'force' in the 'scientific' way. Thus, the term 'force' was not introduced by a definition as is done in several textbooks, but by giving examples which showed how the term 'force' interacts with other terms within a given phrase. This way of introducting 'force' was informed by Wittgenstein's idea of 'language games' (Wittgenstein, 1958) as activity structures determining the word's sense. Furthermore, it is associated with Gee's idea of scientific terms as being part of a social language (cf. p. 4).

[2] A detailed description of the whole material including all texts and tasks can be found in Rincke (2007) or via internet using the persistent identifier urn:nbn:de:hebis:34-2007101519358, for example by typing https://kobra.bibliothek.uni-kassel.de/handle/urn:nbn:de:hebis:34-2007101519358

The scene shown in Figure 1 fell within the scope of one lesson (note that all lessons discussed in this paper refer to the second section of the teaching sequence – so lesson 1 in Figure 1 refers to the first lesson of the second section of the teaching sequence). The overarching question was to understand the risk of a neck fracture in a head-on collision. First, students watched a movie showing a crash test in slow motion. Then the scene was described and discussed using words and expressions without any support from the teacher. After that the students talked informally. Then Figure 1 was presented to focus on the motion of the head of the dummy. The vector difference $\Delta\vec{v}$ of the two given arrows (velocities) was marked in the picture, indicating that there must be something exerting a force on the head of the dummy. The students were now asked to refer to the motion of the dummy and to use the term 'force' scientifically.

[Insert figure 1 about here]

Figure 2 refers to a similar task presented in the test at the end of the teaching sequence. Students had to make a statement using the term 'force' scientifically and referring to the motion of the ball during the time period from 1 to 2. The accompanying text emphasised that the statement must not refer to the beginning of the motion (i.e. the action of the sportsman).

[Insert figure 2 about here]

Figure 3 gives examples of tasks involving students in a meta-discourse. Students are given four statements and have to explain whether the term 'force' is being used scientifically or not. In addition they are asked what else the speakers may be talking about if it is not 'force' in a scientific sense. Thus, different understandings of the word 'force' can be discussed. Students were given the chance to talk specifically about their preconception and its possible contrast to the scientific concept of force.

[Insert figure 3 about here]

Design of the study: Data collection

All lessons in the second section of the teaching sequence were audio- and videotaped, then transcribed (approximately nine lessons in each class). In addition, the students kept a log. In this they wrote down their ideas about some of the given tasks. They also had to do some tasks in pairs and to write down their findings. Thus, at the end of the teaching sequence every written or spoken sentence could be assigned to its speaker and was accessible for the subsequent rule-based analysis. Due to the large amount of the text material, a smaller group of students had to be chosen for this analysis. This choice was made according to the number of words uttered by the students relative to the total number of words spoken. In the first class (19 students in total) those students were selected whose utterances amounted to six percent ($\approx 1/19$) or more of the total number of words spoken in all lessons. This means that the whole group of students would have to be included in the analysis in the hypothetical case that all students had participated in the discussions to the same extent. But in our case a smaller group of seven students was identified, each of them contributing $1/19$ or more of all words spoken. Some students in this smaller group contributed up to $3/19$ of all words spoken. Consequently, among the remaining group of 12 students, there were some who had contributed noticeably less than $1/19$ of all words spoken. The group of seven students was chosen for the analysis. The sum of all words spoken by these seven students amounted to 80 percent of all words spoken by the whole class. In the second class (28 students in total), following the same method 13 students were selected, whose utterances represented three percent ($\approx 1/28$) or more of the words spoken by the whole class. As in the previous case, this smaller group contributed approximately 80 percent of all words spoken. The coincidence of approximately 80 percent may be surprising but is not a result of the way the smaller groups were selected. In the end the utterances of a sample of 20 students was included in the detailed analysis.

The investigation of the text material was done by means of a content analysis following the approach of Philipp Mayring (Mayring, 2000, 2003; Kohlbacher, 2006; Krippendorf, 1980). This aims at a rule-based, traceable process for unveiling implicit properties of a given text corpus. It is centred on the development and application of categories which fit the research interest. This system of categories has to fulfil certain quality factors, especially concerning its reliability. For this study the system of categories was developed through a pilot study (55 students) undertaken one year before the main study began. The main goal of this pilot study was to improve and adjust the teaching sequence, especially in respect of the tasks used. Nevertheless, as in the main study, all lessons in the second section of the teaching sequence were video-taped and transcribed. This was done in order to develop the category system which was further developed as follows:

- About 50 % of the text material was read (according to the recommendation of Mayring, 2003, p. 75).
- A summary of this part of the text material was generated in a rule-based manner: a set of criteria was established determining which utterances from students should contribute to the summary. The criteria were deduced from the theoretical background explained above by a method intended to prevent the investigators from interpreting single utterances in a holistic way, i.e. inferring what the influence on the student under consideration by other utterances might have been. For this reason, at this stage of the analysis there were no criteria directly focusing in the emergence of an interlanguage. A possible result indicating something similar to interlanguage was regarded as a subject for a subsequent interpretation.

  The set of criteria concerned utterances in the text indicating the extent to which speakers

  1. feel secure while using the phrase ‘to exert force on’ (see ‘island of reliability’, page 9)
  2. use the phrase ‘to exert force on’ in a seemingly automated or formulaic manner (see page 9),
  3. seem to suffer from a conflict between the requirement to use the word ‘force’ scientifically and their communication aims (see page 10),
  4. apply known pre-instructional ideas about force to a given task (see page 8), and
  5. reveal a correct scientific concept when being asked to talk scientifically (see page 8).

The summary produced by this procedure showed that many utterances corresponded to the criteria 2, 4 and 5. The first and third criteria appeared to be unsuitable, because conflicts or the impression of security very seldom emerged from single utterances. However, later we will show that conflicts ermerge when we look deeper into the data. Now it was possible to establish a refined set of criteria which resulted in a new system of categories: numbers 4 and 5 (above) became the categories we will from now on refer to as 'type 1', see Table 1. Criterion no. 2 became the categories 'type 2' (Table 1).

[Insert table 1 about here]

Thus, the category system is divided into two parts: Categories of the first group (type 1) concern the use of the term 'force' by students. These are therefore related to situations in which students were explicitly asked to use the term 'force' scientifically (see for example Figure 2). The second group of categories (type 2) refers to the way students talk about their own understanding of the term 'force'. These are therefore related to situations in which students were involved in a meta-discourse. During this meta-discourse students were, for example, given a few different short texts describing an example of motion. In the texts, the word 'force' was used either scientifically or as in everyday discourse (see Figure 3). Students had to explain how the use differed.

The whole text material (all utterances of 20 selected students in total) was divided into four portions, all of which were analysed independently by four pairs of investigators. One part of the text material (about eight percent) was analysed by all pairs of investigators and Cohen's Kappa was computed ($\kappa_1 = 0.81$, $\kappa_2 = 0.64$, $\kappa_3 = 0.86$, $\kappa_1 = 0.72$) to provide evidence of a sufficient level of reliability. The level reached can be seen as satisfactory, especially in the light of the fact that some categories require the investigator to interpret the utterance to some extent.

Additional data were collected, as shown in Figure 4: All students were tested using the verbal component of a cognitive ability test (Heller & Perleth, 2000). At the end of the second part of the teaching sequence students had to pass a test related to the contents of the teaching sequence. This test included some basic tasks related to the first part of the teaching sequence (which is not within the scope of this article) and some tasks similar to those which had been discussed during the second part.

[Insert figure 4 about here]

Six months later the students were tested once again. This test (test 3 in Figure 4) included a task very similar to the one shown in Figure 3. In addition, a new type of task was given. This was designed to collect more information about the way in which students take into account elements from content or from surface form of sentences when reading about 'force'. The main idea of this type of task was that the students had to translate given (common usage) sentences into scientific ones. Firstly they had to decide whether a translation is impossible or possible. Secondly they had to translate if possible. The design of the given sentences (and hence the design of the task) will be explained in more detail. The sentences were manipulated in the light of two assumptions:

1. The first assumption was that sentences following the pattern, subject – transitive verb – object, encourage students translating it into a scientific one because this pattern is the same as using the phrase 'to exert force on'. This assumption relates to the surface structure of the sentence.

2. The second assumption was that sentences denoting an action effected by one object on another stimulates the students to translate also. Note that these actions may not necessarily use transitive verbs. This assumption refers to the deep structure of the sentence. The sentence 'the ball is kept by the ballplayer', for example, does not follow the pattern subject – transitive verb – object. Thus (accepting assumptions explained above) it may not support a translation due to its surface form. But it may stimulate students to translate it in a manner similar to 'the ballplayer exerts a force on the ball' because the given sentence communicates an action effected on the ball (intended deep structure stimulates a translation). But a translation like 'the ball exerts a force on the ballplayer' would of course also be correct. The latter translation may be interpreted as being sustained by the surface form in a more general way, i.e. following a pattern like subject – verb – object.

In the test six sentences were given, systematically varying the two features explained (see Table 2). Sentences 2 and 4, the intended deep structure of which do not support a translation, however, mention the word ‘force’ in an informal sense. These sentences are believed to pose a particular challenge to students’ understanding of the concept of force: Those students who are aware of an adequate scientific concept of force are expected to avoid the translation even though the word ‘force’ is explicitly mentioned. The asterisks in the table indicate those sentences which may be translated in two different ways (either sustained by the surface form or the deep structure, similar to the example given above).

[Insert table 2 about here]

Analysis

The category system is divided into two parts as shown in Table 1. Categories in the first part are used when students are explicitly asked to use the term ‘force’ scientifically. Those in the second part are used when students are asked to participate in a meta-discourse. During the teaching sequence, six lessons were characterised mainly by tasks asking the students to use the term ‘force’ scientifically. Thus, the utterances had to be categorised using categories of type 1. In the course of two, nearly whole, lessons the students were engaged in a meta-discourse, so categories of type 2 had to be applied. In the following sections the results from these lessons will be discussed.

Students’ use of the term ‘force’

In order to gain a systematic insight into the way students used the term ‘force’, the group of 20 selected students was further divided into five subgroups I-V. This division was made in each of the six lessons and was related to the assigned categories shown in Table 3. Subgroup (I) included those students who mainly used scientific phrases (or attempted to do so), i.e. their utterances belonged to *interaction* or *attempt*, more often than to *quantity, actor* or *others.* Subgroup (II) includes students whose utterances belonged to the categories *actor, quantity, others* as often as or more often than to *interaction* or *attempt.* Subgroup (III) included those students who never used the term 'force' to express an interaction between different bodies (i.e. no scientific use in the course of the lesson). Table 4 offers an overview over the results: Students 1, 2, 6, 7, 9 and 13 used 'force' scientifically quite often (during three or more lessons, they belong to subgroup (I)). In the course of four lessons, student no. 17 belongs to subgroup (II). This means that scientific and everyday use of the term 'force' are quite mixed (see Table 3). Students 8 and 16 belong to subgroup (III) in the course of four or five lessons. This means that they almost never use the term 'force' in the way the teaching sequence intended them to. Overall Table 4 gives the impression that students use the term 'force' in a very heterogeneous way. Surprisingly, there is little, or no evidence that students had progressed towards becoming familiar with scientific usage over time. It is therefore reasonable to investigate in more detail the conditions under which students imply an interaction when using the term 'force' and the conditions under which they tend to fall back into everyday speech. The following examples of students' utterances are translated into English as close to the original as possible. All utterances can be found in the original work of Rincke (2007) (available via the Internet). In Rincke (2007), each utterance is numbered. We will give the original number in parenthesis, so that an interested reader can examine each utterance in its original language.

[Insert table 3 about here] [Insert table 4 about here]

The dilemma between surface form and communicative interest

The following examples show that many students who are asked to use 'force' scientifically seem only to see two different and mutually exclusive choices. They choose either to follow the linguistic model given by the teacher or to follow their own communicative interest. The first choice is centred on the surface form, the latter relates to the content, or deep structure, of the statement. It can be observed quite frequently that students following the surface form (so trying to use the phrase 'to exert force on') tend to ignore the topic of the discussion or, in some cases, obviously do not understand what they themselves are talking about. The example given by Eva (student 13 in Table 4) in her log, illustrates this very clearly. She refers to a videotape showing two students throwing a ball back and forth:

> Eva: 'One person exerts a force on the ball and throws it to another person. The other person catches the exerted ball. The other person exerts a force on the ball and throws it back. The exerted balls are thrown back and forth.' (163)-(166)

Eva seems to test the new phrase – she uses several fragments of the phrase 'to exert a force on a ball' with different grammatical functions, for example 'exerted' with the function of an adjective. One might suppose that Eva is trying to detect the function of the different fragments of the phrase. She seems to concentrate on following the pattern given by the teacher and to regard the content as unimportant. In the context of the crash test (see Figure 1) which was discussed in lesson 6 (see Table 4) only a few utterances following the scientific linguistic pattern can be found. For example, Eva says:

> Eva: 'The man exerts a force on the windshield' (277)

This is obviously correct, but the discussion is about the things which affect the man (crashtest-dummy). The lesson deals not with the destruction of the windshield but with the risk of being hurt. Peter (student 15 in Table 4) says:

> Peter: 'The engine exerts a force on the car so it crashes against the wall with high speed.' (277)

Like the utterance discussed above, this might be correct in a way but is clearly off-topic.

The majority of the utterances in this lesson were not off-topic, but a majority of the students entirely ignored the fact that they were asked to use 'force' scientifically. This is surprising because the teacher gave a lot of hints, narrowed the discussion to only a few aspects, and, in the end, asked explicitly who or what is exerting a force on the man. Salim (student 14 in Table 4) responded:

Salim: 'The pressure from the wall when he's going towards the wall [...].' (260)

Within this quite complex context of a crash test students are faced with a particular dilemma: We would describe it as a dilemma between surface form and students' communicative interest. This dilemma is characterised by two different and mutually exclusive choices for the students: either to follow the scientific pattern and ignore the topic of the discussion or to follow their own communicative interest and ignore the necessity to express an interaction of two objects. Unfortunately neither the first nor the second choice stands a good chance of winning the teacher's approval, because neither fulfils the requirement to use the term 'force' scientifically.

Strategies: How to avoid an unfamiliar use of the word 'force'

Referring again to the example of a pole jumper (lesson 4 in Table 4), the scientific use of the term 'force' can be observed more often than in the lesson concerned with the crash test (note that the example task shown in Figure 3 was not within the scope of this lesson but that of lesson 5). As in the crash test lesson, the students watched a video of a pole jumper in slow motion and then described the motion in everyday language. Then, after one student had used the word 'force' spontaneously in his description, the whole class was asked by the teacher to describe the motion using the term 'force' scientifically (at this point categorising the utterances using categories of type 1 starts). But even within this context a frequent change between scientific and everyday uses of the term 'force' can be observed. The following analysis posits that these changes do not happen casually; perhaps this could be interpreted as a process of problem solving: When students are asked to talk scientifically, they have to locate appropriate objects interacting with each other. Furthermore, they have to trust that these objects have the potential to affect another object. In many contexts, this 'active' role has to be assigned to objects like the 'ground' or – in this case – the 'pole'. Students often do not have any trust in the capacity of these objects to interact. This may be the reason why they fall back into the everyday way of arguing, because this allows them to avoid attributing a seemingly 'active' role to inanimate objects such as the ground or the pole. Peter (student 15 in Table 4), for example, says:

Peter	'He exerts a force on the pole and goes, yes, is catapulted up by the pole.'	(196)-(197)

This pattern can be found in a variety of utterances. Another example is given by Vivien (student in Table 4) who refers to a person playing with a ball:

Vivien	'A person exerts a force on the ball, the ball drops with much force on the ground.'	(167)-(168)

It may be easy to assign an active role to a person because this aligns with common preconceptions. But it is difficult to do the same in the case of the ground because this seems to be far from everyday experience. The ground in this view is nothing more than an inanimate barrier, incapable of exerting anything. Thus the speaker argues in scientific terms as long as it is an 'active' object exerting a force (a person). In case where it might be the pole or the ground exerting a force on the ball, the speaker resorts to everyday talk. Everyday uses of the term 'force' do not compel students to talk about objects interacting with other objects. This kind of falling back into everyday ways of talking can be found very frequently within the data.

In addition, two more strategies for handling seemingly interacting objects appear. (1) Often students invent a story and attribute it to a given situation, a story which typically provides 'true active partners'. Figure 2 gives an example of a task. Students have to provide a statement about the situation depicted using the word 'force' scientifically. The vertical arrow points to the Earth which is just represented by a horizontal line. The majority of the students do not include the Earth in their descriptions. They prefer to talk about the sportsman hitting the ball although it is emphasised specifically in the text accompanying the task that the statement must not refer to the beginning of the motion (the action of the sportsman). (2) A quite elegant way of solving the problem of handling seemingly active objects, which can sometimes be observed in the data, is to use a rather impersonal style of talk: 'There is a force exerted on the braking skater' is an example. This statement identifies the interaction being discussed without stating who or what is exerting the force. So the speaker does not need to assign an active role to the ground which is exerting the force on the (braking) skater.

These different strategies may be collectively described as strategies of avoidance. They provide a way to cling on to preconceptions. The way in which the word 'force' is used scientifically obliges students to assign unfamiliar roles to objects. This seems to be a tough challenge. Students are normally aware of mapping their statements to their ideas about a given situation. This means that they do not talk scientifically to fulfil what the teacher asks them to do – they talk scientifically if there is almost no gap between their preconception and what the scientific phrase 'to exert a force on' intends. Otherwise, if there is an enormous gap between students' preconceptions and what a scientific statement expresses, they prefer to relapse into everyday talk.

Student's way of participating in the meta-discourse

When students engage in a meta-discourse, two patterns of argumentation can be identified. If asked whether a given statement belongs to everyday- or scientific talk, students may refer to the surface form of the statement (i.e. the presence of particular keywords). The second pattern is referring to the deep structure of the statement (i.e. its content). If following exclusively the second pattern, students do not argue on the basis of the presence or of the absence of certain words or phrases like 'to exert force on (see Table 1, categories of type 2). Figure 3 gives an example of a task. As mentioned above, two lessons were characterised by tasks stimulating this meta-discourse. To get an insight into how students argue, the group of 20 students was divided into four subgroups, using the scheme shown in Table 5. As in the previous case, this division was made for the two lessons (and for the results of the meta-discourse related task during the test half a year later). Table 6 shows the results. Although some data is missing, the table clearly shows that the majority of the students make reference to the surface form as well as to the content. The affiliation to subgroup (iii) appears 19 times in the table. Students belonging to this subgroup argue (in the present lesson) referring equally to the surface form and to the content of a given statement when they are asked whether it belongs to scientific or everyday language. Affiliation to subgroup (i) appears only three times in Table 6, twice for student 13 and once for student 20. These students' arguments mainly refer to the category *surface form* in the course of one (student 20) or two (student 13) lessons. Subgroup (ii) appears 13 times. Students belonging to this subgroup (in the present lesson) argue referring more frequently to *content structure*.

[Insert table 5 about here] [Insert table 6 about here]

The tasks used to stimulate the meta-discourse always required the students to explain their decisions. Many students argued in the following way: If the given statement belonged to everyday talk, they referred to the content of the statement (and not to the absence of the phrase 'to exert force on'), for example in talking about the statement of Thomas, Figure 3:

> 'Thomas' statement belongs to everyday talk. The word 'force' means energy.' (351)

If the given statement uses the term 'force' in a scientific way, they argue on the basis of the presence of the phrase 'to exert force on' and also, in many cases, of its content. For example the statement of Maria, Figure 3:

> 'Maria's statement is scientific because two interacting bodies can be found, one of which is the person, the other the force is exerted on.' (343)

In the previous section we showed that students faced with the aforementioned dilemma frequently decided to follow their communicative interest and ignore scientific aspects – even when asked by the teacher to look for interacting bodies. It is noteworthy that within the meta-discourse the majority of students made reference to the surface form of a given statement and to its content. Therefore iii appears frequently in Table 6. This means that while dealing with scientific phrases within a meta-discourse, interacting bodies (as an essential element of the concept of force) are likely to be included in students' utterances in a discussion.

Achievement test and cognitive ability test

As explained in previous sections, the students took the verbal part of the cognitive ability test before the teaching sequence started. At the end they took an achievement test on the basic ideas of mechanics which had been within the scope of the teaching sequence ('test 2' in Figure 4). The results matched the level of performance the students had shown in the previous half of the year and were rated as 'normal' by the teacher (average of 60% correct solutions, $\sigma = 18.4\%$), but there was only a weak correlation between scores on this test and on the verbal component of the cognitive ability test ($+0.09$). This means that the cognitive ability test is a weak predictor of success in the achievement test. Although the study did not aim to endorse the appropriateness of the teaching method, it is noteworthy that the method does not seem to have advantaged those students who achieved high scores in the verbal component of the cognitive ability test – notwithstanding the fact that discussion about language was an essential part of the teaching sequence.

Translation task in the follow-up test

The translation task was designed to obtain more information about the role of surface form and intended deep structure (page 19). The students had to translate, if possible, informal sentences into scientific ones. We might distinguish several stimuli which lead students to translate given sentences:

1. students translate if triggered by the surface form (assumption 1 explained on page 19),
2. students translate if triggered by the deep structure (content, assumption 2),
3. students translate if the word 'force' is mentioned.

The results may be summarised as follows: If, and only if, the deep structure (content) of the given statement triggers a translation, do students translate the given sentence into a scientific one, that is into a sentence using the phrase ‘to exert force on’. Thus only condition 2 triggers a translation. This means that even if the surface form follows the pattern subject – (transitive) verb – object (condition 1) students avoid translating it if they cannot associate the given sentence with the scientifically correct concept. They also avoid the translation if the given (informal) sentence contains the word ‘force’ as for example in the sentence ‘the iron ball has much force’ (condition 3). There was only one exception – one student who had probably misunderstood the task tried to translate all the sentences. This means that within this type of task students are able to detect everyday uses of the word ‘force’. Furthermore, they are not tempted to translate the sentence into a seemingly scientific form just because the given sentence contains the word ‘force’.

There are two sentences in Table 2 which may be translated in two different ways – one related to the surface form, another related to the intended deep structure (sentences three and six, marked with an asterisk). The 20 students gave in total 40 translations for these two sentences, but only six solutions can be interpreted as being sustained by the surface form. This means that similar to the lessons when students were asked to *use* the term force scientifically, the (intended) deep structure seems to be much more influential than the surface form.

Discussion and Implications

Tables 4 and 6 give an overview of the ways in which students used the term ‘force’ and how they understood it. At first glance it is remarkable that there were no students whose utterances seemed to develop towards a scientific style: Every student changed his or her use of the word ‘force’ depending on the situation. The detailed analysis reveals that the change often observed between scientific and everyday talk did not happen casually but was dependent on the given situation: When students are asked to use the term ’force’ scientifically, they are faced with what we describe as a dilemma between the surface form and their communicative interest. This dilemma appears in particular in complex situations, for example the crash test discussed earlier. The dilemma is characterised by two different and mutually exclusive choices for the students: either they follow the scientific pattern and ignore the topic of the discussion or they follow their own communication interest and ignore the need to express an interaction of two objects. Neither choice offers any real possibility to consolidate a physical concept of force.

Moreover, the frequent change between scientific and everyday talk can be interpreted as a result of problem solving: Students who are asked to talk scientifically have to locate appropriate objects interacting with each other. They have to accept that these objects affect another object. The strategies described can be thought of as strategies for avoiding a discrepancy between students' preconceptions and what a scientific sentence might express. Even they may serve as a way to escape the dilemma between surface form and communicative interest. This leads to a language which is influenced by students' preconceptions as well as the linguistic model given by the teacher.
As reported above, within this study the majority of the students followed their communicative interest when using the term 'force'. They often did not regard elements related to the surface form of their sentences. The translation task in the follow-up test confirmed that the main influence on students' utterances is the intended deep structure and not elements of the surface form. The analysis of students' argumentation within the meta-discourse led to the result that the dominance of content related aspects in their utterances diminished in favour of formal aspects. Thus, students become aware of the presence or of the absence of certain words in a given statement, for example, the presence of a transitive verb and an object. By comparing scientific- with everyday language with respect to formal aspects, essential parts of the physical concept of force are introduced into students' debate.

When students were asked to use the term 'force' scientifically, very few utterances expressing an interaction between objects using common verbs like 'to pull', 'to push' or 'to hit' could be found. This is surprising because the teaching method emphasises that sentences using transitive verbs of this kind, and those using 'to exert force on', are of the same grammatical structure. This observation suggests that developing an adequate concept of force, and learning to talk scientifically, cannot be disassociated into two consecutive steps, i.e. first idiomatically describing interacting bodies, then describing interacting bodies using scientific phraseology. It is more likely that students face two challenges simultaneously: accepting that objects interact and describing the phenomenon scientifically (thus talking of interacting objects). A way of talking in everyday language whilst talking about interacting objects can scarcely be observed within the data. Whenever the students use their everyday language, they talk about force in the sense of momentum or energy, as being the property of one object. This means that everyday language and pre-instructional ideas are so closely associated that the idea of interacting objects is normally not expressed at this language level.

Hence, an interesting new question arises. Brown and Ryoo (2008) report considerable benefits from their 'content-first-approach'. The idea of this approach (investigated within biological contexts) is to treat the content using informal language, then to reutter in scientific terms. This approach is persuasive because it takes account of the dual nature of the challenge faced by the students when they are being introduced to new scientific ideas: they have to become familiar with new concepts and with a new language. The content-first-approach therefore disaggregates science instruction into explicit conceptual and language components, not only referring to its logical, but also to its chronological, structure. The data reported in this study, however, suggest that in the case of the term 'force', this chronological disaggregation may be impossible due to the close association between everyday language and pre-instructional ideas. In the case of the topic 'force', students have to become familiar with new ideas whilst using a new language at the same time. This may account for the difficulties students have in understanding the concept of the term 'force'. This observation can be directly related to a claim made by Gee (2005): 'Lifeworld language is problematic for science' (p. 30). He argues that 'there are good reasons to encourage children, even early on, to marry scientific activities with scientific ways with words, and not lifeworld languages, though lifeworld languages are obviously the starting point for the acquisition of any later social language, as Vygotsky pointed out.'

The theoretical framework for the analysis of students' utterances explained in the opening sections of this article is based on two research fields, namely pre-instructional ideas about mechanics and second language learning. We will now connect our results to second language learning.

We have discussed how formulaic phrases which are used in a seemingly automated way play an important role for language learners because they tune to some extent their production of sentences. Using such sentences puts learners in a position to communicate in a way which their explicit knowledge of grammatical rules would not allow them to do. During the teaching sequence presented in this paper, the phrase 'an object exerts a force on a another object' is emphasised many times by the teacher and the teaching material. Students get to know that this phrase indicates a scientific use of the term 'force'. So it may be expected that students will use it very frequently when they are asked to use the word 'force' scientifically. But Table 4 shows that only during lesson 4 is the scientific phrase used many times. It is surprising that many students remain on the level of everyday language even though they are asked to use the word 'force' in a scientific way. This means that the scientific phrase, although emphasised and marked as *scientific*, is not used in an automated way. The formulaic scientific phrase does not figure in the way formulaic phrases often do when learning a second language.

In the section about the theoretical framework, a common conflict experienced by language learners was reported: they assign cognitive resources for processing either grammatical rules or contents. van Patten (1996) reports that learners normally decide to process contents and tend to neglect the importance of rules. Learners may regard applying grammatical rules as less important, in order to follow their communicative interest. So language learning in the classroom is fundamentally characterised by two contradictory aims: on the one hand to talk about something (using the new and foreign language) and on the other hand to learn to use appropriate vocabulary and generate correct sentences. It is difficult to pay attention to both aims at the same time unless the given context is very simple. Thus language learners face a dilemma between requirements related to grammatical rules and their communicative interests. This dilemma is analogous to that between surface form and communicative interest discussed in this paper. In this respect, using scientific phrases in science lessons may be compared to following grammatical rules in language lessons. Table 4 shows that, during lesson 4, students succeeded many times in using the word 'force' in a scientific way, that is to express an interaction between two objects. During this lesson the pole jumper was the object of the study. In contrast, during lesson 6 the majority of the students reverted to everyday speech. A crash test and the risk of a neck fracture was the topic of this lesson. It may be that the students were more affectively engaged in discussing this topic, in contrast to the topic of the pole jumper, so that they faced the dilemma described in a quite unique way. This encourages us to draw a relationship with the concept of interlanguage described by Selinker (1972). Whereas almost all students during lesson 4 appear to have understood the concept of force and to be able to use the term 'force' appropriately, they slide back into their everyday use of 'force' during lesson 6. This reappearance of linguistic phenomena which were thought to have been eradicated is what Selinker interprets as behavioral events following from language learning. From this point of view, the language the students revert to can be seen as a form of 'scientific interlanguage'. The frequent change from everyday to scientific use of the term 'force' which can be observed during the teaching sequence for almost every student can be viewed as this 'scientific interlanguage'. The strategies described provide a justification for this comparison because of their similarities to the central processes explained by Selinker: the language used by the students is influenced by their everyday use of 'force' (language-transfer from the 'native language') as well as its scientific use (second-language learning), depending on the context. The example provided by Eva (163)-(166) may be interpreted as the result of a process of overgeneralisation or transfer-of-training. The deeper analysis showed that the change between different language levels was not random but depended on pre-instructional ideas and the context of the actual discussion.

Fortunately the duration of the teaching sequence was long enough to see that after lesson 4 the students did *not* accomplish their learning of the concept of force. If the teaching sequence had ended with lesson 4, the results would encourage us to praise the underlying teaching method as appropriate for teaching the concept of force and the use of the term 'force' within some lessons. But Table 4 shows that during lesson 6, many students seem to behave like absolute beginners. So learning must go on. This is not surprising if we accept that we are dealing with language learning processes to some extent. So the period of time was long enough to observe what was reported in this paper. But it might be that it was not long enough to observe typical phases or steps such as are reported by Diehl et al. (2002). Table 4 gives no indication for these phases, neither concerning the whole group of students nor a subgroup. Hence, more research is needed to explore this possible relationship between language learning processes and science education.

The results of our study indicate some promising relationships between learning science and learning a foreign language. Thus, it is worth looking for suggestions in the field of language learning research to open up new ways for improving science education. But although relationships between second language learning and science education were pointed out in this article, it has to be emphasised that learning science is not the same as learning a foreign language. Some observations within the data are persuasive in suggesting relationships, others seem to be independent of the language learning processes. In addition we must note that whilst language learners are talking about commonplace events using a new language, science learners are talking about new and abstract fields of knowledge using a new and foreign language.

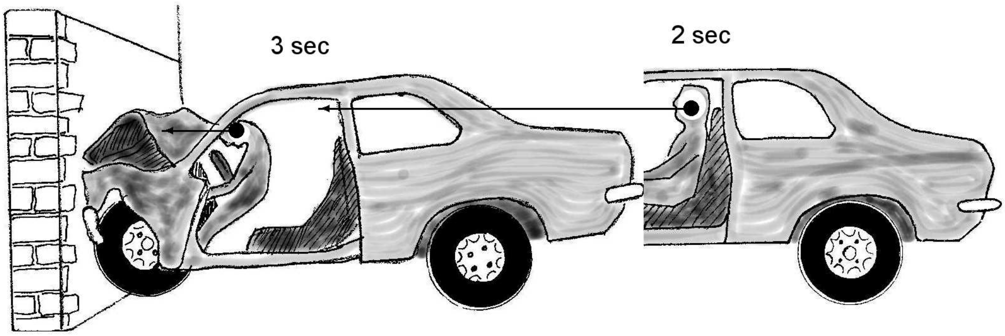

Figure 1: *Example topic (used in lesson 6, see Table,4): The picture was presented to the students after having watched a slow-motion video of the crash test. The arrows indicate the velocity of the head of the dummy. The difference of the two arrows ($\Delta\vec{v}$) was also marked in the picture in the course of the lesson. It indicated that there must be a force exerted on the head of the dummy in the direction opposite to its motion. The potential risk of neck-fracture in accidents like this comes into the scope of the discussion at this point. The students are asked to describe the movement of the crashtest-dummy using the term 'force' scientifically.*

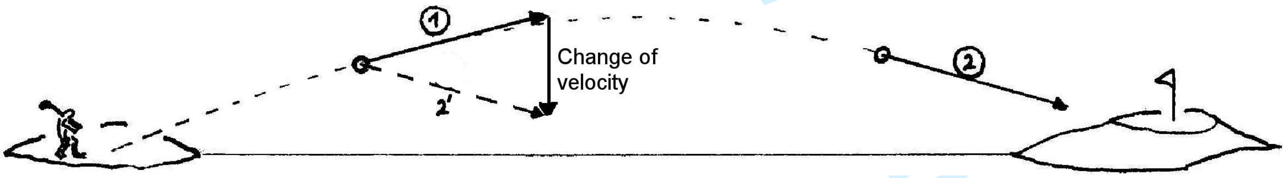

Figure 2: *Students have to write a statement using the term 'force' scientifically to talk about the time interval between 1 and 2. It was emphasised that the statement must not refer to the beginning of the motion of the ball. The idea for this task was taken from the Force Concept Inventory (Hestenes, 1992).*

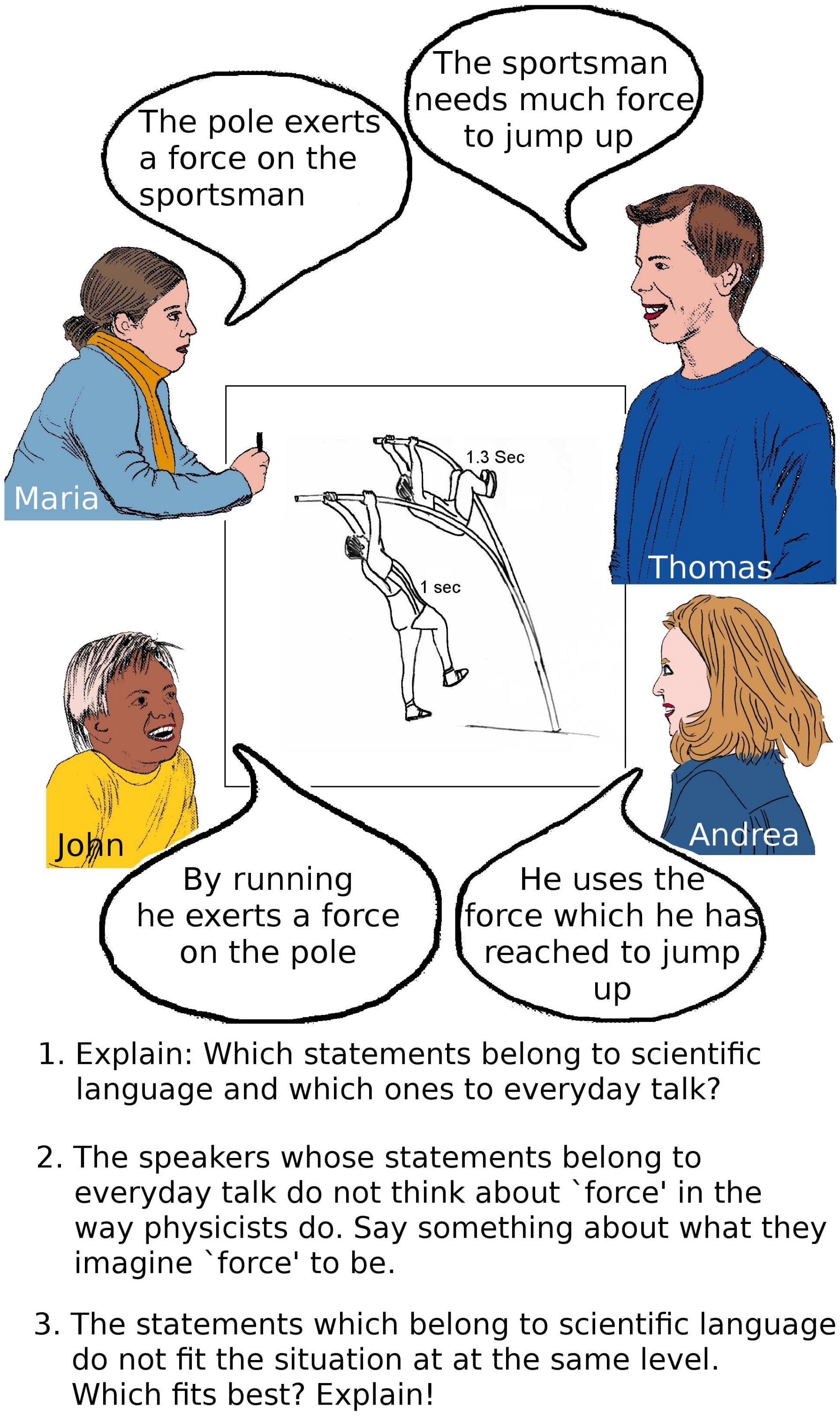

Figure 3: *Example task used in lesson 5 (see Table 6): Tasks like this were used to get students engaged into a meta-discourse: they have to explain whether the given statements belong to scientific or everyday use of the term 'force'. Moreover, the students are asked to adopt the speaker's point of view (in the case of everyday talk) and to explain possible perspectives on the term 'force'. The two statements which seem to be scientific (both Maria and John use 'to exert force on') are not of the same quality. The students are asked to differentiate these statements.*

start	5 weeks	5 weeks	**end**	6 months	
	teaching sequence section 1	teaching sequence section 2		students were taught other topics	
cognitive ability test		videotapes, audiotapes, logs, written tasks	test 2		test 3 (follow-up)

Figure 4: *Data collection over time: The teaching sequence covered a time period of approximately two and a half months. During the second section of the teaching sequence qualitative data via camcording, logs and written tasks were collected. In addition, at the beginning of the teaching sequence the students took the verbal component of the cognitive ability test (for details see page 18). Six months after test 2 they took another test (test 3).*

Categories Type 1	Example	Description
quantity	'there's a lot of force needed'	the word 'force' may be replaced by another word signifying something such as a quantity, for example 'energy' or 'momentum'
actor	'the force pulls the ball down'	the word 'force' is used in a sense 'acting' on other objects
interaction	'the ground exerts a force on the ball'	the word 'force' is used to denote an interaction between two objects (this was intended by the teaching sequence)
attempt	'he exerts the ball'	the whole sentence gives the impression that the speaker tries to use the correct phrase but does not succeed
others	'the force exerts a force on the ball'	uses of the word 'force' not clearly belonging to one of the categories above
Categories Type 2	**Example**	**Description**
surface form	'this is scientific because the word 'exert' appears in the text'	the speaker assigns a 'scientific' (or everyday) use referring to the *surface form* of a given sentence
content structure	'this is scientific because the description fits well to the given situation'	the speaker assigns a 'scientific' (or everyday) use referring to the *content* of a given sentence

Table 1: *The category system: categories of type 1 were used when students were asked to use the term 'force' scientifically; categories of type 2 were used when students were asked to participate in a meta-discourse.*

Sentence No	surface form sustains translation	intended deep structure sustains translation	sentence
1	yes	yes	Lars pushes the car
2	yes	no	The iron ball has much force
3*	no	yes	The ball bounces back from the ground
4	no	no	It's favourable to save force
5	yes	no	The engine needs energy
6*	no	yes	The ball is kept by the ballplayer

Table 2: *The translation task in the follow-up test (half a year later): Students are given six sentences using idiomatic language which had to be translated into scientific ones (if possible). The scheme indicates whether the translation is sustained either through surface form or intended deep structure. The asterisks indicate that two translations are possible, one referring to the intended deep structure, another possibly related to the surface form. The original test is available online (Rincke, 2007, p. 235).*

subgroup	description: students whose utterances in the lesson
I	belong to categories *interaction* or *attempt* more often than to *quantity*, *actor* or *others*
II	belong in some cases to categories *interaction* or *attempt*, but utterances belonging to *actor*, *quantity* or *others* occur more often or at least equal to *interaction* or *attempt*
III	never belong to categories *interaction* or *attempt*
IV	do not contain the term 'force'
V	no utterance (but student present during lesson)

Table 3: *Scheme indicating the way in which the group of 20 students was divided into further subgroups (analysing their use of the word 'force'). This division refers only to categories of type 1, see Table 1 (above).*

No of students	lesson 1	lesson 2	lesson 3	lesson 4	lesson 6	lesson 8
1	I	IV	I	I	V	I
2	I	IV	IV	I	I	IV
3	IV	IV	IV	I	IV	I
4	V	V	IV	I	IV	I
5	V	V	II	I	IV	IV
6	I	I	II	II	V	I
7	IV	IV	I	I	II	I
8	III	III	III	III	III	IV
9	I	I	III	I	III	V
10	I	IV	I	II	-	V
11	I	III	III	II	IV	III
12	I	I	III	II	III	II
13	III	IV	I	II	I	I
14	V	V	IV	II	III	I
15	V	IV	III	II	I	I
16	I	III	III	I	III	III
17	II	I	II	II	III	II
18	IV	I	III	II	III	II
19	V	IV	III	I	IV	III
20	V	II	I	I	III	IV

Table 4: *Students' affiliation to subgroups I-V during those lessons which are characterised by tasks in which students are asked to use the term 'force' scientifically. The shading indicates the categories to which students' utterances belong. See Table 3* for details concerning I-V, but roughly one can say 'the darker the gray the more scientific the talk'. (A '-' indicates that the student was absent.) This division refers only to categories of type 1, see Table 1 (above).

subgroup	description: students whose utterances in the lesson/test
i	belong more frequently to the category *surface form*
ii	belong more frequently to the category *content structure*
iii	belong equally to the categories *surface form* and *content structure*
iiii	cannot be assigned uniquely (students' utterance too short to categories uniquely)

Table 5: *Scheme indicating the way in which students were divided into further subgroups (analysing their argumentation structure within the meta-discourse). This division refers only to categories of type 2, see Table 1 (above).*

No of students	lesson 5	lesson 7	follow-up test
1	iii	-	iiii
2	iii	-	iiii
3	ii	-	ii
4	iii	-	ii
5	iii	-	iii
6	iii	ii	iii
7	iii	-	iiii
8	ii	ii	ii
9	iii	-	iii
10	iii	-	iiii
11	iii	ii	iii
12	iii	ii	iii
13	i	i	iiii
14	iii	-	iiii
15	iii	ii	iii
16	iiii	-	ii
17	iiii	ii	iiii
18	iii	-	iiii
19	ii	-	iiii
20	iiii	-	i

Table 6: *Students' affiliation to subgroups i-iiii. The table shows the results for two lessons which are characterised by students' meta-discourse and for the meta-discourse-related task in the follow-up test. The table indicates the categories to which students' utterances belong. For details concerning i-iii see Table 5.* Dark gray (i) indicates that the argumentation refers clearly to the surface form of a given statement. Lighter gray (ii) indicates that the argumentation refers clearly to the content of a given statement. Light gray (iii) indicates that the argumentation refers to the surface form and to the content. (Unfortunately many students were absent in one lesson ('-'). For this reason the results of the follow-up test are included in the table.) This division refers only to categories of type 2, see Table 1 (above).

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It's rather like Learning a Language

Development of talk and conceptual understanding in mechanics lessons

Although a broad literature exists concerning the development of conceptual understanding of force and other topics within mechanics, little is known about the role and development of students' talk about the subject. The paper presents an in-depth investigation of students' talk whilst being introduced to the concept of force. The main research goal was to investigate and understand how students develop an understanding of the concept of force and how they use and understand the term 'force'. Therefore we make relation to the research field of students' ~~preconcepts~~ preconceptions and the field of second language learning. Two classes of N=47 students were video-taped during a time period of nine lessons, each transcribed and analysed using a category system. Additional data was obtained via written tasks, logs kept by the students, and tests. The detailed analysis of the talk and the results of the tests indicate that students are facing difficulties in using the term 'force' scientifically similar to those in a foreign language instruction. Vygotsky (1962) already recognised a relationship between learning in science and learning a language. In this paper important aspects of this relationship are discussed based upon empirical data. We conclude that in some respects it might be useful to make reference to the research related to language learning when thinking about improving science education. In particular, according to Selinker's concept of interlanguage describing language learning processes within language instruction (Selinker, 1972), the language used by the students during physics lessons can be viewed as a 'scientific interlanguage'.

Introduction

In recent years the role of language in science education has been emphasised by many authors. Many investigations concentrate on the flow of discourse within classroom talk (e.g., Bellack, Kliebard, Hyman & Smith, 1966, Lemke, 1990, Mortimer & Scott, 2000, Mortimer & Scott, 2003, Scott, 1998, Sutton, 1998), and others make relation to the quality of scientific explanations given to students (e.g., Ogborn, Kress, Martins & McGillicuddy, 1996)~~, finally many~~. Many more perspectives on classroom talk can also be found. The study reported in this paper ~~aims at~~ is an investigation of students' understanding and use of a single scientific term which is difficult to learn~~. The particular term in this studywas~~, the term 'force'. In this study, 'force' serves as an example. By means of a detailed analysis of students' utterances (i.e. their output) we seek to retrace the process of meaning-making of individuals. Furthermore, the analysis ~~highlights the interdependency between this~~ illuminates the interdependency of the process of meaning-making and the language levels used by the students.
Besides the term 'force', there ~~exist~~ are many more scientific terms which are regarded as ~~being~~ similarly difficult to learn (e.g., 'voltage' ~~or~~ and 'temperature'). One important reason for these difficulties is their nonspecific use in everyday talk. Often, in everyday talk 'force' ~~acquires~~ carries the sense of 'energy' or 'momentum'. Sometimes the attribute of 'vitality' is involved. Hence, in order to clarify the scientific concept of force~~it appears recommendable~~, teachers are recommended to contrast the scientific use of the term 'force' with its everyday use. From the students' point of view, learning the scientific concept of force requires them to distinguish everyday and scientific usage. ~~Therefore~~ So the situation in physics lessons may be experienced as similar to language lessons: In both cases learners have to ~~internalise~~ appreciate that words acquire their sense ~~dependent on~~ in a way that is dependent on, and in relation to, other words making up the whole sentence. For this reason, the results reported in this paper are linked ~~against~~ to theory and results ~~within~~ in the field of language learning research. ~~The~~ This relation to language learning ~~is regarded as one possibility~~ offers one possible way to improve our understanding of learning processes experienced by the students.
In this paper, ~~the underlying teaching method is reportedand described, too. Though this method~~

~~was~~ not only methods and results of the analysis of students' output is reported, but also the applied teaching method. This method has been elaborated and piloted before, ~~the discussion about~~ so its applicability is not our primary interest, i.e. the teaching sequence is not the subject of the investigation. The design of the teaching sequence is informed by a ~~vygotskian view on~~ Vygotskian view of learning as a dialogic process. In this view, new ideas appear firstly on the social plane of talk and interaction. During discussion and working through the ideas every individual has to make sense of the new ideas for ~~her or his own~~her- or himself. Our analysis concentrates on this individual process of meaning-making and its interdependency with use of language.

Theoretical background

The aim and purpose of the study requires a theoretical framework for the analysis of students' utterances. Since the study ~~bases~~ is based upon a teaching method for introducing the students to the concept of 'force', a second framework is needed ~~explaining~~ to explain how and why the teaching method was chosen in the way it is reported ~~during the following sections~~ in the sections that follow. The framework for the teaching method ~~opens up~~ takes a broad view on internalising the concept of force as a process which includes both ~~,~~ dialogic structured social interaction and individual meaning-making. After that we introduce ~~a framework for~~ the framework on which the analysis of ~~individual uterances. Thereby~~ utterances is based on. In this we concentrate on individual meaning-making and ~~relate~~ link the findings to the research ~~field~~ fields of students' ~~preconcepts and the field of~~ preconceptions and language acquisition.

The teaching method

Discourse analysis of classroom talk ~~represents~~ is an important and influential ~~research field concerning~~ strand of research on the relation between language and science education. It provides an insight into the way meanings are shaped and shared in classroom talk. In order to clarify the background for our teaching sequence, we summarise ~~relevant results for~~ research results that are relevant to the development of the teaching method.

Sometimes, ~~the~~ classroom talk is regarded as a 'language game' in which every participant highlights a special role defined by permitted moves inside the game (Bellack et al., 1966). Thus ~~,~~ the metaphor of the language game is a vehicle ~~of~~ for describing and analysing the flow of discourse. The term 'language game' is ~~essential~~ central for the writings of Wittgenstein (Wittgenstein, 1958). Wittgenstein used the term 'language game' as a ~~framework~~ way to explain how words acquire their sense: Words do not *have* any sense themselves – they acquire it in the course of a language game. ~~Those~~ These language games are activity structures where people act and talk together, and words take on their sense according to their function within ~~this~~ the game. In ~~his~~ the well known book 'Talking Science', Lemke (1990) refers to this philosophical framework (p. 185) and extends it to a theory of social semiotics with respect to science education. ~~Lemke~~ He claims that the 'triadic dialogue' (p. 217)~~is a very common form of interaction~~, also known as I-R-F-pattern ('Initiation - Response - Feedback', Mehan, 1979; Edwards & Mercer, 1987) or as I-R-E pattern ('Initiation - Response - Evaluation', Sinclair & Coulthard, 1975), is a very common form of interaction. Lemke identifies other recurring patterns, for example the student-questioning dialogue ~~or~~ and the teacher-student debate. Such social 'activity structures' (p. 186) serve as tools for meaning-making. In this view meaning can be thought of as a result of social activities. Learning science therefore includes learning to talk like members of the social community of scientists. In consequence, Lemke asks teachers to 'model scientific language by explaining to students how they themselves are combining terms together in sentences' (p. 170). Thus he recommends that ~~the so called~~ so-called meta-discourse ~~to~~ should play an important role in science education. ~~Similar as~~ Like Lemke, Gee ~~recognises~~ treats scientific language as an *academic social language*, i.e. a 'way of using language so as to enact a particular socially situated identity and to carry out a particular socially situated activity' (Gee, 2005). He claims that 'one does not know what a social language means in any sense useful for action unless one can situate the meanings of the social language's words and phrases in terms of embodied experiences' (p. 23). So scientific terms and phrases have to be regarded as being part of a social language, used within a social community and embedded in particular activity structures and situations.

~~In addition to this strand focusing on discourse analysis another strand exists concerning~~ Another research strand concerns the quality and nature of ~~a teacher' s~~ teachers' explanations in science education. Ogborn et al. (1996) point out that the 'act and art of explaining to a class is much less discussed than scientific ideas to be explained' (p. 2) and develop a framework for what they call a scientific explanation. This framework is governed by the metaphor of a 'story', although not thought of as a narrative but rather as a set of cooperating protagonists, each of them characterised by special capabilities. Within this framework, terms like 'force' or 'energy' ~~form protagonists which are~~ identify protagonists capable of 'doing' something with or to other protagonists. In this view a scientific explanation is a 'story' about these protagonists, ~~operating within their cooperation and by this means~~ interacting with each other and hence explaining causal connections (p. 9). Sutton (1998) also draws upon the metaphor of 'science as a story', ~~too, also~~ again not implying narrative. Sutton recommends emphasising in science education that scientific knowledge is a result of social interactions: 'The word 'story' has many advantages in comparison with 'fact' or 'truth'. It involves learners and invites them to think 'Is it reasonable?"(p. 37).

In the course of the last decade many contributions to the role and ~~practise~~ use of language in science education have been influenced by the writings of L. S. Vygotsky. ~~and point out that the increasing impact of Vygotsky 's writings could account for the growing interest in the role of language in science education. Vygotsky~~ Vygotsky claimed that 'higher psychological structures' (such as scientific conceptual knowledge) appear 'first between people as an interpsychological category and then inside the child as an intrapsychological category' (Vygotsky, 1978, p. 128). This means that language plays a key role when students are introduced into new ways of thinking and talking about the world. In this view, the process of internalising new ideas or new languages originates in the social plane. Individuals construct their meaning with respect to the social language which they experience in the given situation.

Within the strand of research ~~projects~~ informed by Vygotsky's writings Mortimer and Scott (2000) characterise content, form and patterns of utterances ~~based upon their~~ using a 'flow of discourse analytical framework' (Mortimer & Scott, 2000, p. 129). They expand the I-R-F-pattern by differentiating ~~as to whether~~ students' utterances which match the intended learning goal ~~or~~ and do not (content) and ~~attributing it to either~~ classifying utterances either as a description, explanation or generalisation (form). In addition, the nature of teachers' (and students') interventions is described (pattern). These interventions are divided into three major groups: 'developing scientific knowledge; supporting student meaning-making; and maintaining the teaching narrative' (Mortimer & Scott, 2000, p. 131). Mortimer and Scott distinguish two social languages used in the classroom – the scientific ~~language~~ and the spontaneous ~~,~~ or everyday, language. 'This, of course, can lead to teacher and students talking about the same phenomenon in quite different ways.' (Mortimer & Scott, p. 128). Mortimer & Scott (2003) refine their analytical framework by discussing 'five linked aspects, which focus on the role of the teacher in making the scientific story available, and supporting students in making sense of that story' (p. 25)~~, i. e.~~ . There are teaching purposes, content, communicative approach, patterns of discourse, and teacher interventions. Their framework is based on a sociocultural view of teaching and learning ~~mainly relying~~ which mainly relies on the writings of Vygotsky. They emphasise 'that the analytical framework is offered both as a tool for thinking about and analysing science teaching after the event, and as a model to refer to, *a priori*, in thinking about the planning and development of science teaching' (p. 25). In our case, the framework was used to ~~sustain~~ inform the planning process of the lessons. This led to the following guidelines:

First, everyday and scientific language were clearly differentiated (cf. Mortimer & Scott, 2003). It was explained to the students that any scientific use of the term 'force' explicitly denotes at least two partners involved in an interaction, e.g. 'the ball exerts a force on the ground'. Thus the students were given an easy-to-use criterion to indicate any scientific use of the term force. In all tasks and texts used during the teaching sequence mixing up the different languages was studiously avoided. Thus a common problem in textbooks was avoided, namely that everyday and scientific use of specific terms appear within the same text without any appropriate explanation ~~to~~ of the different language ~~uses,~~

uage (see for example Bennett (2003, p. 169) referring to English textbooks or Rincke (2004) ~~for German ones~~to German ones). The term 'force' was not introduced to the students by giving them a short definition, but ~~giving lots of~~ by giving many examples illustrating that~~within scientific uses~~ , within scientific usage, the term 'force' has other 'capabilities' than ~~within everyday uses~~ it has in everyday use (cf. Ogborn et al., 1996).

Second, the meta-discourse suggested by Lemke (1990) played an important role: The aim of the meta-discourse was to engage students in a discussion about language including syntactic and semantic features of informal everyday talk ~~or~~ and of formal scientific use of the term 'force'. Thus, the simple criterion ~~of~~ for differentiating between scientific and everyday language explained above was accompanied by profound discussions about what the meaning of a given description could be~~or to what extent~~ , or about the extent to which it describes what was to be described. Students were encouraged to discuss the differences between everyday and scientific use of the term 'force', referring particularly to the different ideas associated with the given statements.

This teaching method is not only influenced by Lemke but also by Noam Chomsky who introduced the ideas of deep structure and surface form to model the relationship between language and thought (Chomsky, 1957). Chomsky's idea of the surface form of language is related to the criterion mentioned above: In the first step a scientific use of the term 'force' in this teaching sequence can be identified by the students by searching for (at least) two interacting objects. This interaction ~~normally is~~ is normally described by the phrase 'one object exerts a force on the other object'. ~~Thereby~~ Hence this criterion refers only to the surface form. Chomsky's idea of the deep structure of language is related to the meta-discourse. During this meta-discourse students discuss the ideas related to a given statement. Appropriate descriptions of the motion of a ball or a skater are identified and inadequate uses of the term 'force' are revealed even if two interacting objects seem to appear in the text.

One overarching idea governing both ~~,~~the design of the teaching sequence and the analytical framework for students' utterances should be emphasised at this point. This idea refers to the relation between *scientific* and the *spontaneous* or *everyday language* and it is related to the *content* of Mortimers and Scotts framework. ~~Above all, the~~ The relation between these two languages has been discussed by Vygotsky (1962)~~: He~~ , who compared it with the relationship between the native and a foreign language of a speaker: 'The influence of scientific concepts on the mental development of the child is analogous to the effect of learning a foreign language, a process which is conscious and deliberate from the start. In one's native language, the primitive aspects of speech are acquired before the more complex ones. The latter presupposes some awareness of phonetic, grammatical, and syntactic forms. With a foreign language, the higher forms develop before ~~the~~ spontaneous, fluent speech. [...] It is not surprising that an analogy should exist between the interaction between the native and the foreign language and the interaction of scientific and spontaneous concepts, since both processes belong in the sphere of developing verbal thought. However, there are also essential differences between them. In foreign language study, attention centers on the exterior, sonal, physical aspects of verbal thought; in the development of scientific concepts, on its semantic aspect. The ~~developmentmental~~ two developmental processes follow separate, though similar paths' (p. 109). For this reason, we chose two different points of departure for the analytical framework explained in the next section: One refers to students' ~~preconcepts~~ preconceptions (Vygotsky's semantic aspects), the other to language learning processes.

The analysis of utterances: Langage and (scientific) concepts

One conspicuous feature of scientific language ~~may be seen in~~ is its special technical vocabulary. ~~But in addition to the~~ In addition to subject-specific terminology, many morphologic and syntactical features particular to ~~the~~ scientific language can be identified. These features distinguish scientific- from everyday language. At first glance it might seem that the difficulties experienced by students with ~~the~~ scientific language follow from these ~~rare~~ distinctive features with which students are not familiar. But Bennett (2003, p. 153) explains 'Whilst the research has confirmed that the language of science can pose difficulties for pupils, other research has suggested that the problem is less to do with the technical vocabulary of science than might be expected.' ~~So it may be assumed that these difficulties do~~ In fact these difficulties appear to emerge not in the first place ~~emerge~~ from the technical vocabulary but from the fact that scientific conceptualisations (in many cases very far removed from every day experience) are closely connected to scientific language~~and often far from everyday experience~~. On the other hand, everyday language is connected to typical and well known pre-instructional conceptions ~~(preconcepts)~~ informed by everyday experience (e.g., Hestenes, Wells & Swackhammer, 1992). Thus, the difference between scientific and everyday language largely reflects the differences between scientific concepts and ~~those~~ the ideas used and expressed by the students.

~~Like it was done by~~ As Brown and Ryoo (2008) did in their 'content-first-approach', we disaggregate science instruction into 'explicit conceptual and language components' (p. 534), because we assume that students experience at least two ~~developments during scienceeducation~~kinds of development whilst being taught science: They become familiar with scientific concepts and with a new language connected to these concepts – not only single new words. Related to this distinction our perspective ~~onto~~ on what is happening in the classroom is informed by two perspectives:

Our first point of departure is the research field concerned with students' ~~preconcepts~~ preconceptions about mechanics (e.g., Jung, Wiesner & Engelhardt, 1981; Wiesner, 1994; Hestenes et al., 1992), which is closely connected to ~~the~~ educational research on conceptual change (e.g., Duit, 2003). The knowledge provided by this research field offers a profound insight into students' pre-instructional ideas about force, energy, momentum, velocity or acceleration. The present study is based on a teaching sequence ~~concerning an introduction into~~ to introduce the concept of force, ~~therefore we mainly draw~~ so we draw mainly on the knowledge ~~about~~ of students' pre-instructional conceptions ~~about~~ of force and their difficulties with the scientific concept of force. These pre-instructional conceptions are in large part expressed ~~by common ways to use~~ through common ways of using 'force' in everyday conversation. Dependent upon the context, it is used synonymously with energy or momentum, in addition to many other uses. It~~is~~ 's in this broad range of meanings from informal everyday ~~use~~ uses to more scientific uses that the problem of polysemy arises which challenges both teaching and learning (Strömdahl, 2007). The pre-instructional conceptions expressed ~~within vernacular often have the distinction of~~ in vernacular language often treat 'force' as a property of a single object, e.g. 'She is a very forceful person'. Teaching the concept of force in mechanics lessons includes stimulating and supporting students not to replace but to complement the informal ideas by a scientific concept of force which expresses an interrelation between at least two objects. More details ~~concerning~~ of the various features of pre-instructional conceptions will be discussed later in this ~~text~~ article when the system of categories used to analyse transcribed videotapes will be explained.

In addition to pre-instructional conceptions, the framework is ~~founded~~ based on second language learning. Assuming that students experience a language learning process when they acquire a new scientific concept, we need a framework which allows us to map observations made in mechanics lessons to theoretical or empirical results of research in second language learning.
~~Literature research~~ The extensive research literature in the field of (second) language learning ~~bears~~ includes some remarkable contributions which help us to understand what happens in science lessons. We will summarise the most important ~~topics~~ aspects which we will draw upon in the following sections:

The role of formulaic phrases

~~As well~~ Language learners as native speakers do not generate their sentences ~~by far not~~ only by using grammatical rules. Much of what we articulate consists of phrases not formed creatively but retrieved from memory as a whole (Bärenfänger, 2002). These phrases can be regarded to some extent as automated or formulaic. Language learners profit from the use of formulaic phrases~~: Memorising~~, memorising and using formulaic phrases permits language learners to extend their abilities to communicate. Automated phrases free them, to some extent, from using their limited vocabulary and knowledge of grammatical rules, thus they are able to express complexities which they would not be able to do based on their knowledge of rules and vocabulary. ~~Such~~ These formulaic phrases serve to some extent as 'islands of reliability' (p. 126) – as they do not ring false for language learners because they are retrieved wholesale from memory. Native speakers accelerate their production of sentences by using formulaic phrases. Such phrases do not have to be complete sentences – often they consist of only a few words. Consequently, it is recommended that language learners memorise short phrases or at least some words that belong together rather than single words: ‘So this (phrase) is another piece of information about a new item which it may be worth teaching. When introducing words like *decision* or *conclusion* we may note that you *take* or *make* the one but usually *come* to the other’ (Ur, 1996, p. 61). ~~Similar~~ Similarly state Bleyhl and Timm (1998)~~, p. 263~~: ‘A single word is like nothing, it requires a linguistic environment’ ~~.~~(p. 263).[1]

Either following grammatical rules or communicating with somebody – a common conflict

Edmondson (2002) ~~summarises~~ notes that learning outcomes while learning a new language depend on the quality of cognitive and affective processing achieved by the learner. The deeper the learner engages, cognitively and affectively, the higher the achievement (p. 62). On the other hand, this engagement leads to higher cognitive loads and thus limits the learning outcomes. It can often be observed that learners decide whether to concentrate on following grammatical rules or on communicating a specific content. This decision can be seen as a process of assigning resources either for processing rules or contents. Edmondson concludes that learning grammatical rules or communicating with somebody are in many cases ~~mutual~~ mutually exclusive alternatives. ~~It can be frequently observed that the learner decides~~ Learners can frequently be observed to concentrate on the content and neglect grammatical rules (van Patten, 1996).

Native language - interlanguage - second language

Novice learners of a new language may use it in quite a simple manner due to their limited knowledge. But simplicity is not the most significant feature of a novice’s spoken or written sentences. Novices develop to some extent an individualised language which is influenced not only by the language to be learned but also by their native language. ~~It was Selinker who~~ Selinker introduced the term ‘interlanguage’ to label this specific language used by and depending on the learner (Selinker, 1969, 1972). In order to develop a theory of second-language learning, he distinguishes three linguistic systems, the native language of a speaker, his interlanguage and the target language (the language the learner is attempting to learn). A theory of second-language learning should be able to predict beha-

[1] translated by author

vioral events following from language learning processes. Obviously, not every sentence spoken by a language learner can be ~~undoubtedly related~~ related unequivocally to language learning processes. Investigating such learning processes requires that relevant behavioral events in the performance of a language learner can be separated from common behavioral events that are not relevant to the theory. Selinker (1972) claims that ‘One set of these behavioral events [...] is the regular reappearance in second-language performance of linguistic phenomena which were thought to be eradicated in the performance of a learner’ ~~.~~ (p. 211). He points out that the ‘well-observed phenomenon of backsliding by second-language learners from a TL [target language] norm is not, as has been generally believed, either random or toward the speaker’s NL [native language], but toward an IL [interlanguage] norm’ (p. 216). The phenomenon of backsliding is ~~especially observed~~ particularly noticeable ‘when the learner’s attention is focused upon new and difficult intellectual subject matter or when he is in a state of anxiety or other excitement [...]’ (p. 215). Five processes are regarded as being central for the learner’s interlanguage performance, i.e. (1) language-transfer (rules or structures are derived from the native language), (2) transfer-of-training (unfavourable influence by the training material), (3) strategies of second-language learning (the learner derives rules from the target language), (4) strategies of second-language communication (strategies to communicate in spite of missing linguistic competence), and (5) overgeneralisation (of rules belonging to the target language). Selinker points out that ‘beyond the five so-called *central* processes there exist many other processes which account to some degree for the surface form of IL utterances’ (p. 220). Other approaches ~~were~~ have been developed (e.g., ‘Approximative Systems’, Nemser, 1971) which are similar to Selinker’s approach to some extent. Further research ~~was done~~ has been carried out especially concerning the strategies of second-language learning (e.g., O’Malley & Chamot, 1990) and second-language communication (e.g., Bialystok, 1990) and has resulted in refined category systems of strategies.

Diehl, Pistorius and Dietl (2002) observed that language learners essentially have to master fundamentally three steps or phases on their path from beginners to becoming advanced users: During the first phase they tend to memorise short phrases and use them in a formulaic manner. According to Diehl et al. the second phase is triggered by ~~a~~ cognitive overload caused by the increasing ~~amount~~

number of formulaic phrases to be remembered. Thus the learners begin to seek ~~for~~ new methods to master their communication needs. They start to work their way through the variety of linguistic forms. Diehl et al. call ~~it~~ this the 'turbulent phase', because ~~the learners behave like~~ learners behave as though they have never been taught language, and there is no avoiding this phase. During the third phase, the learners fit their interlanguage to the target language, as long as they are disposed to discard temporary self-made 'rules' which belong to their interlanguage.

Even though it is not possible to describe and compare the overall spectrum of second-language learning theories in this paper, we should say something about the relation between the aspects referred to here and the overarching field of research ~~concerning~~ on second-language learning. Above we summarised the discussion about the role of formulaic phrases, the conflict between following grammatical rules and communicating with somebody, and the concept of interlanguage. This discussion focuses on the language used by the ~~learner~~learners, i.e the learners' output. There exist further research focusing on the learners' output e.g., the research field which concentrates on learners' mistakes and errors and the field which concentrates on differences between the native language of a learner and a certain target language. The former aims at clarifying the reasons ~~of mistakesand~~ for mistakes, thereby fostering the progress of language learning (e.g., Knapp-Potthoff, 1987). The latter ~~bases~~ is based on the hypothesis that the difficulties experienced by a language learner arise from the differences between his or her native language and a certain target language (e.g., Stockwell & Bowen, 1965; Gass & Selinker, 1983; Kellerman, 1995). Edmondson and House (2000) argue that within the research fields concentrating on learners' output, the strand based on Selinker's idea of interlanguage is especially comprehensive and therefore promising (p. 219). It comprises the investigation of the variety of mistakes as well as of interferences between native and target language.

~~Besides~~ In addition to the research field concentrating on learners' output~~there exist~~, there are also more general theories which include the learner's input (provided by the teacher or other learners) and the student-teacher interaction (for a comprehensive discussion, see~~e.g.,~~, for example, Ellis, 1985; Larsen-Freeman & Long, 1991; Mitchell & Myles, 1998). In this paper we concentrate on learners' output. Therefore we will especially rely on Selinkers concept of interlanguage. A broader perspective including student-teacher interaction with respect to language learning theories may be promising but is not discussed in this paper.

The study

Research question

The main research goal was to investigate and understand the process ~~of students ' developing~~ by which students develop an understanding of the concept of force~~as well as~~, and the way students use and understand the term 'force'. Moreover the study asks to what extent results ~~of~~ from language learning research can help us to understand the empirical data. This means that the study asks to what extent observations made within students' classroom talk in physics lessons can be linked to language learning processes.

Design: Sample and teaching method

~~47~~ Forty-seven students participated in the study. They were on average 14 years old and came from two classes ~~of different public secondary-schools~~in different public secondary schools. Both classes were taught by the same teacher. The underlying teaching sequence ~~covered~~ included an introduction to the basic ideas of mechanics. The first section (about eight lessons) focused on the description of motions. ~~Thus, an introduction into~~ This prepared the way for an introduction to the dynamic concept of force ~~was prepared~~ which, at the end of the second section (about nine lessons), ~~resulted in the 'second~~ led to Newton's 'second law' $\vec{F} \cdot \Delta t = m \cdot \Delta \vec{v}$. A teaching sequence structured in a similar way ~~was already proposed~~has previously been proposed, for example by Wiesner (1994), and evaluated with positive results by Wodzinski and Wiesner (1994).[2] The detailed design of every

[2] A detailed description of the whole material including all texts and tasks can be found in Rincke (2007) or via internet using the persistent identifier urn:nbn:de:hebis:34-2007101519358, for example by typing https://kobra.bibliothek.uni-

lesson, in particular concerning the method ~~how~~ by which the students were introduced to the term and concept of force, followed the guidelines explained in the ~~according theoretical framework section.~~ theoretical background section. The whole teaching sequence was piloted with 55 students before being used within the study.

Examples

At the beginning of the second part of the teaching sequence, the students themselves camcorded several scenarios, for example playing with a ball, riding a bicycle or skating. Afterwards these films were analysed on a personal computer. This analysis aimed at describing the motion ~~at most accuracy~~as accurately as possible. To do so, for example, speeds and directions of the motions were measured. While analysing the filmed motions, students realised that ~~a~~ the velocity of a person or a ball never changes without the influence of another object, ~~i.e.~~e.g. the ground, a staircase, the air, the ~~earth~~ Earth or something else.

After having filmed and analysed some motions in the ~~described way~~ manner described the phrase ‘one object exerts a force on another object’ was introduced to the students. This introduction was closely connected to the examples given ~~by~~ in the videotapes by ‘translating’ the interaction of the bodies viewed in the videotape into ‘scientific’ descriptions: ~~The~~ for example, the statement ‘the earth pulls the ball down’ was translated into the sentence ‘the earth exerts a force on the ball downwards’. ~~Then students~~ Students then had to write down some statements about their films using ‘force’ in the ‘scientific’ way. Thus, the term ‘force’ was not introduced by a definition ~~in the way found in several textbooks; it was introduced in the context of students’ social activities and~~ as is done in several textbooks, but by giving examples which showed how the term ‘force’ interacts with other terms within a given phrase. This way of ~~introduction was brought through~~ introducting ‘force’ was informed by Wittgenstein’s idea of ‘language games’ (Wittgenstein, 1958) as activity structures determining the word’s sense. Furthermore, it is associated with Gee’s idea of scientific terms as

kassel.de/handle/urn:nbn:de:hebis:34-2007101519358 being part of a social language (cf. p. 4).

The scene shown in ~~figure~~Figure 1 fell within the scope of one lesson (note that all lessons discussed in this paper refer to the second section of the teaching sequence – so lesson 1 in ~~figure~~Figure 1 refers to the first lesson of the second section of the teaching sequence). The overarching question was to understand the risk of a neck fracture in a head-on collision. First, students watched a movie showing a crash test in slow motion. Then the scene was described and discussed using words and expressions without any support from the teacher. After that the students talked informally. Then ~~figure~~Figure 1 was presented to focus on the motion of the head of the dummy. The vector difference $\Delta\vec{v}$ of the two given arrows (velocities) was marked in the picture, indicating that there must be something exerting a force on the head of the dummy. The students were now asked to refer to the motion of the dummy and to use the term 'force' scientifically.

[Insert figure 1 about here]

Figure 2 refers to a similar task presented in the test at the end of the teaching sequence. Students had to make a statement using the term 'force' scientifically and referring to the motion of the ball during the time period from 1 to 2. The accompanying text emphasised that the statement must not refer to the beginning of the motion (i.e. the action of the sportsman).

[Insert figure 2 about here]

Figure 3 gives examples of tasks involving students in a meta-discourse. ~~They~~ Students are given four statements and have to explain whether the term 'force' is being used scientifically or not. In addition they are asked what else ~~(other)~~ the speakers may ~~talk~~ be talking about if it is not 'force' in a scientific sense. Thus, different understandings of the word 'force' ~~could~~ can be discussed. Students were given the chance to talk ~~specially about their preconcept~~ specifically about their preconception and its possible contrast to the scientific concept of force.

[Insert figure 3 about here]

Design of the study: Data collection

All lessons ~~belonging to~~ in the second section of the teaching sequence were audio- and videotaped, then transcribed (approximately nine lessons in each class). In addition, the students kept a log. ~~Here~~ In this they wrote down their ideas ~~to~~ about some of the given tasks~~, they~~ . They also had to do some tasks in pairs and to write down their findings. Thus, at the end of the teaching sequence every written or spoken sentence could be assigned to its speaker and was accessible ~~in the following~~ for the subsequent rule-based analysis. Due to the large amount of the text material, a smaller group of students had to be chosen for this analysis. This choice was made according to the number of words uttered by the students ~~with respect to the number of all~~ relative to the total number of words spoken. In the first class (19 students in total) those students were selected ~~,~~ whose utterances amounted ~~equal or more than~~ to six percent ($\approx 1/19$) or more of the total number of words spoken in all lessons. This means that the whole group of ~~all students had~~ students would have to be included ~~into~~ in the analysis in the ~~hypothetic~~ hypothetical case that all students had participated in the discussions to the same extent. But in our case a smaller group of seven students was ~~found~~identified, each of them contributing ~~equal or more words than 1/19~~ 1/19 or more of all words spoken. Some students ~~of~~ in this smaller group contributed up to $3/19$ of all words spoken. ~~Corresponding to this~~Consequently, among the remaining group of 12 students~~some where found~~ , there were some who had contributed ~~noticeable~~ noticeably less than $1/19$ of all words spoken. The group of seven students was chosen for the analysis. The ~~added up amount~~ sum of all words spoken by these seven students ~~covered about~~ amounted to 80 percent of all words spoken by the whole class. In the second class (28 students in total), following the same method 13 students were selected, whose utterances ~~covered equal or more than~~ represented three percent ($\approx 1/28$) or more of the words spoken by the whole class. As in the previous case, this smaller group ~~covered~~ contributed approximately 80 percent of all words spoken. The coincidence of approximately 80 percent may be surprising ~~and~~ but is not a result of the way the smaller groups were selected. In the end the utterances of a ~~group~~ sample of 20 students ~~in total were included into~~ was included in the detailed analysis.

The investigation of the text material was done by means of a content analysis following the approach of Philipp Mayring (Mayring, 2000, 2003; Kohlbacher, 2006; Krippendorf, 1980). This ~~approach to content analysis~~ aims at a rule-based, traceable process ~~of~~ for unveiling implicit properties of a given text corpus. It is centred on the development and application of categories which fit the research interest. This system of categories has to fulfil certain quality factors, especially concerning its reliability. For this study the system of categories was developed through a pilot study (55 students) undertaken one year before the main study began. The main goal of this pilot study was to improve and ~~tweak~~ adjust the teaching sequence, especially ~~with respect to the tasks to be~~ in respect of the tasks used. Nevertheless, ~~also in this pilot~~ as in the main study, all lessons ~~of~~ in the second section of the teaching sequence were video-taped and transcribed. This was done in order to develop the category system ~~. The result was a draft-version~~ which was further developed ~~in accordance with the following steps~~as follows:

- About 50 % of the text material was read (according to the recommendation of Mayring, 2003, p. 75).
- A summary of this part of the text material was generated in a rule-based manner: ~~Therefore~~ a set of criteria was established determining which utterances from students should contribute to the summary. The criteria were deduced from the theoretical background explained above ~~whereas it was~~ by a method intended to prevent the investigators from interpreting single utterances in a holistic way, i.e. ~~supposing~~ inferring what the influence on the student under consideration by other utterances ~~could~~ might have been. For this reason, at this ~~stadium~~ stage of the analysis there were no criteria ~~included directly asking for~~ directly focusing in the emergence of an interlanguage. A possible result indicating something similar to interlanguage was regarded as ~~being the subject of~~ a subject for a subsequent interpretation.

  The set of criteria concerned utterances in the text indicating ~~to what extent~~ the extent to which speakers

  1. feel secure while using the phrase ‘to exert force on’ (see ‘island of reliability’, page 10)

2. use the phrase ‘to exert force on’ in a seemingly automated or formulaic manner (see page 10),
3. seem to suffer from a conflict between the ~~claim~~ requirement to use the word ‘force’ scientifically and their communication aims (see page 11),
4. apply known pre-instructional ideas about force to a given task (see page 9), and
5. reveal a correct scientific concept when being asked to talk scientifically (see page 9).

The summary ~~extracted~~ produced by this procedure showed that many utterances ~~referred~~ corresponded to the criteria ~~No.~~ 2, 4 and 5. The first and third ~~criterion~~ criteria appeared to be unsuitable, because conflicts or the impression of security ~~emerge~~ very seldom emerged from single utterances~~very seldom~~. However, later we will show that ~~there are manifesting conflicts when looking~~ conflicts ermerge when we look deeper into the data. Now it was possible to establish a refined set of criteria which resulted in a new system of categories: ~~No.~~ numbers 4 and 5 (~~see above) resulted in~~ above) became the categories we will from now on refer to as ‘type 1’, see ~~table~~Table 1. Criterion no. 2 ~~resulted in the categories of~~ became the categories ‘type 2’ (~~table~~Table 1).

[Insert table 1 about here]

Thus, the category system is divided into two parts: Categories of the first ~~part~~ group (type 1) concern the use of the term ‘force’ by students. ~~It is~~ These are therefore related to situations in which students were explicitly asked to use the term ‘force’ scientifically (see for example ~~figure~~Figure 2). The second ~~part~~ group of categories (type 2) refers to the way students talk about their own understanding of the term ‘force’. ~~It is~~ These are therefore related to situations in which ~~they~~ students were involved in a meta-discourse. During this meta-discourse students were, for example, given a few different short texts describing ~~a~~ an example of motion. In the texts, the word ‘force’ was ~~either used~~ used either scientifically or as in everyday discourse (see ~~figure~~Figure 3). Students had to explain how the use differed.

The whole text material (all utterances of 20 selected students in total) was divided into four portions, all of which were analysed independently by four pairs of investigators. One part of the text material (about eight percent) was analysed by all pairs of investigators and Cohen's Kappa was computed ($\kappa_1 = 0.81$, $\kappa_2 = 0.64$, $\kappa_3 = 0.86$, $\kappa_1 = 0.72$) to provide ~~security for~~ evidence of a sufficient level of reliability. The ~~reached level~~ level reached can be seen as satisfactory, especially ~~with respect to the~~ in the light of the fact that some categories ~~ask~~ require the investigator to interpret the utterance to some extent.

Additional data were collected, ~~figure 4gives an overview~~as shown in Figure 4: All students were tested ~~with~~ using the verbal component of ~~the~~ a cognitive ability test (Heller & Perleth, 2000). At the end of the second part of the teaching sequence ~~they~~ students had to pass a test related to the contents of the teaching sequence. This test included some basic tasks related to the first part of the teaching sequence (which is not ~~in~~ within the scope of this article) and some tasks similar to those which had been discussed during the second part.

[Insert figure 4 about here]

Six months later the students were tested once again. This test (test 3 in ~~figure~~Figure 4) included a task very similar to the one shown in ~~figure~~Figure 3. In addition, a new type of task was given. This ~~type~~ was designed to ~~get~~ collect more information about the way in which students take into account elements from content or from surface form of sentences when reading about 'force'. The main idea of this type of task was that the students had to translate given (common usage) sentences into scientific ones. Firstly they had to decide whether a translation is impossible or possible. Secondly they had to translate if possible. The design of the given sentences ~~, i.e.~~ (and hence the design of the task~~shall~~) will be explained in more detail. The sentences were manipulated ~~to relate to~~ in the light of two assumptions:

1. The first assumption was that sentences following the pattern, subject – transitive verb – object, encourage students translating it into a scientific one because this pattern is the same as using the phrase 'to exert force on'. This assumption relates to the surface structure of the sentence.

2. The second assumption was that sentences denoting an action effected by one object ~~onto another object~~ on another stimulates the students to translate also. Note that these actions may not necessarily use transitive verbs. This assumption refers to the deep structure of the sentence. The sentence 'the ball is kept by the ballplayer'~~for example~~ , for example, does not follow the pattern subject – transitive verb – object~~, thus (accepting the explained assumptions~~ . Thus (accepting assumptions explained above) it may not support a translation due to its surface form. But it may stimulate students to translate it in a manner similar to 'the ballplayer exerts a force on the ball' because the given sentence communicates an action ~~effecting~~ effected on the ball (intended deep structure stimulates a translation). But a translation like 'the ball exerts a force on the ballplayer' would of course ~~be correct, too~~also be correct. The latter translation may be interpreted as being sustained by the surface form in a more general ~~view~~way, i.e. following a pattern like subject – ~~verbs~~ verb – object.

In the test six sentences were given, systematically varying the two features explained (see ~~table~~Table 2). Sentences ~~nos.~~ 2 and 4, the intended deep structure of which do not support a translation, however, mention the word 'force' in an informal sense. These sentences are believed to ~~particularly challenge~~ pose a particular challenge to students' understanding of the concept of force: Those students who are aware of an adequate scientific concept of force are expected to avoid the translation ~~although~~ even though the word 'force' is explicitly mentioned~~!~~ . The asterisks in the table indicate those sentences which may be translated in two different ways (either sustained by the surface form or the deep structure, similar to the ~~given example~~ example given above).

[Insert table 2 about here]

Analysis

The category system is divided into two parts as shown in ~~table~~Table 1. Categories ~~within~~ in the first part are used when students are explicitly asked to use the term ‘force’ scientifically. Those ~~within~~ in the second part are used when students are asked to participate in a meta-discourse. During the teaching sequence, six lessons were characterised mainly by tasks asking the students to use the term ‘force’ scientifically. Thus, the utterances had to be categorised ~~by~~ using categories of type 1. In the course of two, nearly whole, lessons the students were ~~employed with~~ engaged in a meta-discourse, so categories of type 2 had to be applied. In the following sections the results ~~of~~ from these lessons will be discussed.

Students’ use of the term ‘force’

In order to gain a systematic insight into the way students ~~use~~ used the term ‘force’, the group of 20 selected students was further divided into five ~~additional~~ subgroups I-V. This division was made in each of the six lessons and was related to the assigned categories ~~as it is shown in table~~shown in Table 3. Subgroup (I) ~~includes~~ included those students who mainly used ~~the scientific phrase~~ scientific phrases (or attempted to do so), i.e. their utterances belonged to *interaction* or *attempt*, more often than to *quantity, actor* or *others*. Subgroup (II) includes students whose utterances belonged to the categories *actor, quantity, others* ~~equal~~ as often as or more often than to *interaction* or *attempt*. Subgroup (III) ~~denotes~~ included those students who never used the term ‘force’ to express an interaction between different bodies (i.e. no scientific use in the course of the lesson). Table 4 offers an overview over the results: ~~Student nos.~~ Students 1, 2, 6, 7, 9 and 13 ~~use the scientific phrase or try to use it~~ used ‘force’ scientifically quite often (during three or more ~~times~~ lessons, they belong to subgroup (I))~~Student~~. In the course of four lessons, student no. 17 belongs ~~four times~~ to subgroup (II). This means that scientific and everyday use of the term ‘force’ are quite mixed (see ~~table~~Table 3). Students 8 and 16 belong ~~four or five times~~ to subgroup (III) in the course of four or five lessons. This means that they almost never use the term ‘force’ in the way the teaching sequence intended them to. Overall ~~the table~~ Table 4 gives the impression that students use the term ‘force’ in a very heterogeneous way. Surprisingly, there is little, ~~if~~ or no evidence that students had progressed towards becoming familiar with scientific ~~use~~ usage over time. It is therefore reasonable to investigate in more detail ~~under which conditions~~ the conditions under which students imply an interaction ~~while~~ when using the term ‘force’ and ~~under which conditions~~ the conditions under which they tend to fall back into everyday speech. The following examples of students’ utterances are translated into English as close to the original as possible. All utterances can be found in the original work of Rincke (2007) (available via ~~internet~~the Internet). In Rincke (2007), each utterance is ~~counted~~numbered. We will give the original number in parenthesis, ~~thus the~~ so that an interested reader can examine each utterance in its original language.

[Insert table 3 about here] [Insert table 4 about here]

The dilemma between surface form and communicative interest

The following examples show that many students who are asked to use ’force’ scientifically seem only to see two different and mutually exclusive choices~~:~~. They choose either to follow the linguistic model given by the teacher or to follow their own communicative interest. The first choice is centred on the surface form, the latter ~~relate~~ relates to the content, or deep structure, of the statement. It can be observed quite frequently that students following the surface form (so trying to use the phrase ‘to exert force on’) tend to ignore the topic of the discussion or, in some cases, obviously do not understand what they themselves are talking about. The example given by Eva (student ~~no.~~ 13 in ~~table 4, found in their~~ Table 4) in her log, illustrates this very clearly. She refers to a videotape showing two students throwing a ball back and forth:

Eva: ~~"~~‘One person exerts a force on the ball and throws it to another person. The other person catches the exerted ball. The other person exerts a force on the ball and throws it back. The ~~to~~ exerted balls are thrown back and forth.~~"~~’ (163)-(166)

Eva seems to test the new phrase – she uses several fragments of the phrase ‘to exert a force on a ball’ with different grammatical functions, for example ‘exerted’ with the function of an adjective. One ~~may~~ might suppose that Eva ~~tries to detect what function~~ is trying to detect the function of the different fragments of the phrase~~may have~~. She seems to ~~be concentrated~~ concentrate on following the pattern given by the teacher ~~, the content being~~ and to regard the content as unimportant. In the context of the crash test (see ~~figure~~Figure 1) which was discussed in lesson 6 (see ~~table~~Table 4) only a few utterances following the scientific linguistic pattern can be found. For example, Eva says:

Eva: ~~"~~‘The man exerts a force on the windshield~~"~~’ (277)

~~That~~ This is obviously correct, but the discussion is ~~on those things effecting~~ about the things which affect the man (crashtest-dummy). The lesson deals not with the destruction of the windshield but with the risk of being hurt. Peter (student ~~no.~~ 15 in ~~table~~Table 4) says:

Peter: ~~"~~‘The engine exerts a force on the car so it crashes against the wall with high speed.~~"~~’ (277)

~~Similar to above~~Like the utterance discussed above, this might be correct in a way but ~~it~~ is clearly off-topic.

~~Certainly the~~ The majority of the utterances in this lesson ~~are~~ were not off-topic, but ~~the~~ a majority of the students ~~however entirely ignore~~ entirely ignored the fact that they ~~are~~ were asked to use ’force’ scientifically. This is surprising because the teacher ~~gives~~ gave a lot of hints, ~~narrows the discussion on~~ narrowed the discussion to only a few aspects, and, in the end, ~~asks~~ asked explicitly who or what is exerting a force on the man. Salim (student ~~no~~ 14 in ~~table~~Table 4) ~~responds~~responded:

Salim: ~~"~~‘The pressure from the wall when he’s going towards the wall [...].~~"~~’ (260)

Within this quite complex context of a crash test students are faced with a particular dilemma: We would describe it as a dilemma between surface form and students’ communicative interest. This dilemma is characterised by two different and mutually exclusive choices for the students: ~~Either~~ either to follow the scientific pattern and ignore the topic of the discussion or to follow their own communicative interest and ignore the necessity ~~of expressing~~ to express an interaction of two objects. Unfortunately neither the first nor the second choice stands a good chance of winning the teacher’s approval, because neither fulfils the requirement to use the term ‘force’ scientifically.

Strategies: How to avoid an unfamiliar use of the word ‘force’

Referring again to the example of a pole jumper (lesson 4 in ~~table~~Table 4), the scientific use of the term ‘force’ can be observed more often than in the lesson concerned with the crash test (note that the example task shown in ~~figure~~Figure 3 was not within the scope of this lesson but that of lesson 5). As in the ~~case of the~~ crash test lesson, the students watched a video of ~~the~~ a pole jumper in slow motion and then described the motion in everyday ~~talk~~language. Then, after one student had used the word ‘force’ spontaneously in his description, the whole class was asked by the teacher to describe the motion using the term ‘force’ scientifically (at this point categorising the ~~video~~ utterances using categories of type 1 starts). But even within this context a frequent change ~~can be observed~~ between scientific and everyday uses of the term ‘force’ can be observed. The following analysis posits that these changes do not happen casually; perhaps this could be interpreted as a process of problem solving: When students are asked to talk scientifically, they have to locate appropriate objects interacting with each other. Furthermore, they have to trust that these objects have the potential to ~~effect something on~~ affect another object. In many contexts~~this percieved~~, this ‘active’ role has to be assigned to objects like the ‘ground’ or – in this case – the ‘pole’. Students often do not have any trust in the capacity of these objects to interact. This may be the reason why they fall back into the everyday way of arguing, because this allows ~~avoidance of~~ them to avoid attributing a seemingly ‘active’ role to inanimate objects such as the ground or the pole. Peter (student ~~no.~~ 15 in ~~table~~Table 4), for example, says:

Peter ~~"~~‘He exerts a force on the pole and goes, yes, is catapulted up by the pole.~~"~~’ (196)-(197)

This pattern can be found in a variety of utterances~~, another~~. Another example is given by Vivien (student ~~no. 6 in table~~in Table 4) who refers to a person playing with a ball:

Vivien ~~"~~‘A person exerts a force on the ball, the ball drops with much force on the ground.~~"~~’ (167)-(168)

It may be easy to assign an active ~~part~~ role to a person because this ~~alignes to common preconcepts~~aligns with common preconceptions. But it is difficult to do the same in the case of the ground because this seems to be far from everyday experience. The ground in this view is nothing more than an inanimate barrier, ~~incapably~~ incapable of exerting anything. Thus the speaker argues in scientific terms as long as it is an ‘active’ object exerting a force (a person). In ~~the case that~~ case where it might be the pole or the ground exerting a force on the ball, the speaker resorts to everyday talk. Everyday uses of the term ‘force’ do not compel students to talk about objects interacting with other objects. ~~The~~ This kind of falling back into ~~common parlance~~ everyday ways of talking can be found very frequently within the data.

In addition, two more strategies for handling seemingly interacting objects appear~~:~~. (1) Often students invent ~~to some extent a particular~~ a story and attribute it to a given situation, a story which typically provides ‘true active partners’. Figure 2 gives an example of a task. Students have to provide a statement ~~to the depicted situation using~~ about the situation depicted using the word ‘force’ scientifically. The vertical arrow points to the ~~earth~~ Earth which is just represented ~~through~~ by a horizontal line. The majority of the students do not include the ~~earth~~ Earth in their descriptions. They prefer to talk about the sportsman hitting the ball although it is emphasised specifically in the ~~accompanying~~

~~text to~~ text accompanying the task that the statement must not refer to the beginning of the motion (the action of the sportsman). (2) A quite elegant way of solving the problem of handling seemingly active objects~~which can be observed sometimes within the data~~, which can sometimes be observed in the data, is to use a rather impersonal style of talk: ‘There is a force exerted on the ~~breaking skater’ may serve as~~ braking skater’ is an example. ~~The statement expresses the interaction required to be described~~ This statement identifies the interaction being discussed without stating who or what is exerting the force. So the speaker does not ~~tend~~ need to assign an active role to the ground which is exerting the force on the (~~breaking~~braking) skater.

These different strategies may be collectively described as strategies of avoidance. They provide a way to cling ~~onto preconcepts~~on to preconceptions. The way in which the word ‘force’ is used scientifically obliges students to assign unfamiliar roles to objects. This seems to be a tough challenge. Students ~~normally are~~ are normally aware of mapping their statements to their ideas ~~of~~ about a given situation. This means that they do not talk scientifically to ~~fulfill~~ fulfil what the teacher asks them to do – they talk scientifically if there is almost no gap between their ~~preconcept~~ preconception and what the scientific phrase ‘to exert a force on’ ~~may intend~~intends. Otherwise, if there is an enormous gap between students’ ~~preconcepts~~ preconceptions and what a scientific statement ~~would express~~expresses, they prefer to relapse into everyday talk.

Student’s way of participating in the meta-discourse

When students engage in a meta-discourse, two patterns of argumentation can be identified~~:~~. If asked whether a given statement belongs to everyday- or scientific talk, students may refer to the surface form of the statement (i.e. the presence of particular keywords). The second pattern is ~~that they refer to its deep structure~~ referring to the deep structure of the statement (i.e. ~~the contentof the statement~~its content). If following exclusively the second pattern~~they do not make relation to the presence or absence of typical~~ , students do not argue on the basis of the presence or of the absence of certain words or phrases like ‘to exert force on (see ~~table~~Table 1, categories of type 2). Figure 3 gives an example of a task. As mentioned above, two lessons were characterised by tasks stimulating this meta-discourse. To get an insight into how students argue, the group of 20 students was divided into four subgroups~~following the scheme indicated in table~~, using the scheme shown in Table 5. As in the previous case, this division was made for the two lessons (and for the results of the meta-discourse related task during the test half a year later). Table 6 shows the results. Although some data is missing, the table clearly shows that the majority of the students make reference to the surface form as well as to the content~~: -~~. The affiliation to subgroup (iii) appears 19 times in the table. Students belonging to this subgroup argue (in the present lesson) referring equally to the surface form and to the content of a given statement when they are asked whether it belongs to scientific or everyday language. Affiliation to subgroup (i) appears only three times in ~~table~~Table 6, twice for student ~~no.~~ 13 and once for student ~~no.~~ 20. ~~This means that there are few examples for utterances belonging~~ These students' arguments mainly refer to the category *surface form* in the course of one (student 20) or two (student 13) lessons. Subgroup (ii) appears 13 times~~, this means that the utterances of these students belong~~ . Students belonging to this subgroup (in the present lesson) argue referring more frequently to *content structure*. ~~Subgroup (iii) appears 19 times. These students argue referring equally to the surface form and to the content of a given statement when they are asked whether it belongs to scientific or every day language.~~

[Insert table 5 about here] [Insert table 6 about here]

The tasks used to stimulate the meta-discourse always required the students to explain their decisions. Many students ~~argue~~ argued in the following way: If the given statement ~~belongs~~ belonged to every-day talk, they ~~refer~~ referred to the content of the statement (and not to the absence of the phrase 'to exert force on'), for example ~~(see~~ in talking about the statement of Thomas, ~~figure 3)~~Figure 3:

> 'Thomas' statement belongs to everyday talk. The word 'force' means energy.' (351)

If the given statement ~~belongs to the scientific use of the~~ uses the term 'force' ~~they argue with the~~

in a scientific way, they argue on the basis of the presence of the phrase 'to exert force on' and ~~, in addition, in many casesto its content, for example (see~~ also, in many cases, of its content. For example the statement of Maria, ~~figure 3)~~Figure 3:

> 'Maria's statement is scientific because two interacting bodies can be (343) found, one of which is the person, ~~another which is the force~~ the other the force is exerted on.'

In the previous section we showed that students faced with the aforementioned dilemma frequently ~~decide~~ decided to follow their communicative interest and ignore scientific aspects – even when asked by the teacher to look for interacting bodies. It is noteworthy that within the meta-discourse the majority of ~~the students make relation~~ students made reference to the surface form of a given statement and to ~~it's content – therefore~~ its content. Therefore iii appears frequently in ~~table~~Table 6. This means that while dealing with scientific phrases within a meta-discourse, interacting bodies (as an essential element of the concept of force) are ~~more likely~~ likely to be included in students' utterances in a discussion.

Achievement test and cognitive ability test

As explained in ~~the~~ previous sections, the students ~~passed~~ took the verbal part of the cognitive ability test before the teaching sequence started. ~~In~~ At the end they ~~passed~~ took an achievement test ~~related to~~ on the basic ideas of mechanics which had been within the scope of the teaching sequence ('test 2' in ~~figure~~Figure 4). The results ~~met~~ matched the level of performance the students had ~~revealed~~ shown in the previous half of the year and were rated as 'normal' by the teacher (average of 60% correct solutions, $\sigma = 18.4\%$), but there was only a weak correlation ~~formed between~~ between scores on this test and on the verbal component of the cognitive ability test (+0.09). This means that the cognitive ability test is a weak predictor of ~~the~~ success in the achievement test. Although the study did not aim to endorse the appropriateness of the teaching ~~methodology~~method, it is noteworthy that the ~~methodology~~ method does not seem to have advantaged those students ~~achieving~~ who achieved high scores in the verbal component of the cognitive ability test – notwithstanding the fact that ~~the~~ discussion about language was an essential part of the teaching sequence.

Translation task in the follow-up test

The translation task was designed to obtain more information about the role of ~~the~~ surface form and ~~the~~ intended deep structure (page 20). The students had to translate ~~– if possible –~~ , if possible, informal sentences into scientific ones. ~~One can expect several conditions under which students translate the~~ We might distinguish several stimuli which lead students to translate given sentences:

1. students translate if triggered by the surface form (assumption 1 explained on page 20),
2. students translate if triggered by the deep structure (content, assumption 2),
3. students translate if the word ‘force’ is mentioned.

The results may be summarised as follows: If, and only if, the deep structure (content) of the given statement triggers a translation, do students translate the given sentence into a scientific one, that is into a sentence using the phrase ‘to exert force on’. Thus only condition 2 ~~exclusively~~ triggers a translation. This means that even if the surface form follows the pattern subject – (transitive) verb – object (condition 1) ~~they~~ students avoid translating it if they cannot associate the given sentence with the scientifically correct concept. They also avoid the translation if the given (informal) sentence contains the word ‘force’ as for example in the sentence ‘the iron ball has much force’ (condition 3). There was only one exception – one student who had probably misunderstood the task tried to translate all the sentences. This means that within this type of task students are able to detect everyday uses of the word ‘force’. Furthermore, they are not tempted to translate the sentence into ~~another~~ a seemingly scientific form ~~although~~ just because the given sentence contains the word ‘force’.

There are two sentences in ~~table~~ Table 2 which may be translated in two different ways – one related to the surface form, another related to the intended deep structure (sentences three and six, marked with an asterisk). The 20 students gave in total 40 translations for these two sentences, but only six solutions can be interpreted as being sustained by the surface form. This means that similar to ~~in~~ the lessons when students ~~are~~ were asked to *use* the term force scientifically, the (intended) deep structure seems to be much more influential than the surface form.

Discussion and Implications

Tables 4 and 6 give an overview of the ways in which students ~~use~~ used the term ‘force’ and how they ~~comprehend~~ understood it. At first glance it is remarkable that there ~~are~~ were no students whose utterances ~~seem~~ seemed to develop towards a scientific style: Every student ~~changes~~ changed his or her ~~uses~~ use of the word ‘force’ depending on the situation. The detailed analysis reveals that the ~~often observed change~~ change often observed between scientific and everyday talk ~~does~~ did not happen casually but ~~depends~~ was dependent on the given situation: When students are asked to use the term ’force’ scientifically, they are faced with what we describe as a dilemma between the surface form and ~~students’~~ their communicative interest. This dilemma appears in particular ~~within~~ in complex situations, for example the ~~cited crash test~~ crash test discussed earlier. The dilemma is characterised by two different and mutually exclusive choices for the students: ~~Either~~ either they follow the scientific pattern and ignore the topic of the discussion or they follow their own communication interest and ignore the ~~necessity of expressing~~ need to express an interaction of two objects. ~~Both choices do not offer~~ Neither choice offers any real possibility to consolidate a physical concept of force.

Moreover, the frequent change between scientific and everyday talk can be interpreted as a result of problem solving: Students who are asked to talk scientifically have to locate appropriate objects interacting with each other. They have to accept that these objects ~~effect something on~~ affect another object. The strategies described can be thought of as strategies for avoiding a discrepancy between students' ~~preconcepts~~ preconceptions and what a scientific sentence might express. Even they may serve as a way to escape the dilemma between surface form and communicative interest. This leads to a language which is influenced by ~~the preconcepts~~ students' preconceptions as well as the linguistic model given by the teacher.

~~It was reported that~~ As reported above, within this study the majority of the students ~~follow~~ followed their communicative interest ~~and often do~~ when using the term 'force'. They often did not regard elements related to the surface form of their sentences. The translation task in the follow-up test ~~confirms that~~ confirmed that the main influence on students' utterances ~~are mainly influenced by~~ is the intended deep structure and not ~~by elements from~~ elements of the surface form. The analysis of students' argumentation within the meta-discourse ~~leads~~ led to the result that the dominance of content related aspects in their utterances diminished in favour of formal aspects. ~~By means of regarding aspects of the surface form, students are asked to think about interacting objects. Thus~~Thus, students become aware of the presence or of the absence of certain words in a given statement, for example, the presence of a transitive verb and an object. By comparing scientific- with everyday language with respect to formal aspects, essential parts of the physical concept of force are introduced into students' debate~~by means of the meta-discourse~~.

When students ~~are~~ were asked to use the term 'force' scientifically, very few utterances expressing an interaction between objects using common verbs like 'to pull', 'to push' or 'to hit' ~~can~~ could be found. This is surprising because the teaching method emphasises that sentences using ~~such transitive verbs~~ transitive verbs of this kind, and those using 'to exert force on', are of the same grammatical structure. This observation suggests that developing an adequate concept of force, and learning to talk scientifically, cannot be disassociated into two consecutive steps, i.e. first idiomatically describing interacting bodies, then describing interacting bodies using scientific phraseology. It is more likely that students face two challenges simultaneously: accepting that objects interact and describing the phenomenon scientifically (thus talking of interacting objects). A way of talking in everyday language whilst talking about interacting objects can ~~hardly~~ scarcely be observed within the data. Whenever the students use their everyday language, they talk about force in ~~a~~ the sense of momentum ~~,~~ or energy, as being the property of one object. This means that everyday language and pre-instructional ideas are so closely associated that the idea of interacting objects is normally not expressed at this language level.

~~Thereby~~ Hence, an interesting new question arises~~:~~. Brown and Ryoo (2008) report considerable benefits from their 'content-first-approach'~~:~~. The idea of this approach (investigated within ~~biologic~~ biological contexts) is to treat the content using informal language, then to reutter in scientific terms. This ~~persuasive approach accounts for~~ approach is persuasive because it takes account of the dual nature of the challenge faced by the students ~~whilst~~ when they are being introduced to new scientific ideas: ~~They~~ they have to become familiar with new concepts and with a new language. The content-first-approach therefore disaggregates science instruction into ~~'~~explicit conceptual and language components~~' —~~, not only referring to its logical~~— but also chronological structure!~~, but also to its chronological, structure. The data reported in this study, however, suggest that in the case of the term 'force', this chronological disaggregation ~~seems to~~ may be impossible due to the close association between everyday language and pre-instructional ideas. In the case of the topic 'force', students have to become familiar with new ideas whilst using a new language at the same time. This may account for the difficulties students have in understanding the concept of the term 'force'. This observation can be directly related to a claim made by Gee (2005): 'Lifeworld language is problematic for science' (p. 30). He argues ~~'I believe~~ that 'there are good reasons to encourage children, even ~~clearly~~ early on, to marry scientific activities with scientific ways with words, and not lifeworld languages, though lifeworld languages are obviously the starting point for the acquisition of any later social language, as Vygotsky pointed out.'

The theoretical framework for the analysis of students' utterances explained in the opening sections of this article is based on two research fields, namely ~~the field concerned with~~ pre-instructional ideas about mechanics and ~~the field of~~ second language learning. We will now connect our results ~~and the summary related~~ to second language learning.

~~It was explained that~~ We have discussed how formulaic phrases which are used in a seemingly automated way play an important role for language learners because they tune to some extent their production of sentences~~: ~~. Using such sentences puts learners in ~~the ~~a position to communicate in a way which their explicit knowledge of grammatical rules would not allow them to do. During the teaching sequence presented in this paper, the phrase 'an object exerts a force on a another object' is emphasised many times by the teacher and the teaching material. Students get to know that this phrase indicates a scientific use of the term ~~force~~'force'. So it may be expected that students ~~tend to~~ will use it very frequently ~~in the case that~~ when they are asked to use the word 'force' scientifically. But ~~table~~Table 4 shows ~~clearly~~ that only during lesson 4 is the scientific phrase ~~is~~ used many times. It is surprising that many students remain on the level of everyday language ~~although~~ even though they are asked to use the word 'force' in a scientific way. This means that the scientific phrase, although emphasised and marked as *scientific*, is not used in an automated way. The formulaic scientific phrase ~~figures not~~ does not figure in the way formulaic phrases often do when learning a second language.

In the section about the theoretical framework, a common conflict experienced by language learners was reported: ~~They~~ they assign cognitive resources for processing either grammatical rules or contents. van Patten (1996) reports that ~~normally learners~~ learners normally decide to process contents and tend to neglect the importance of rules. Learners may regard applying grammatical rules as less important, in order to follow their communicative interest. So language learning in the classroom is fundamentally characterised by two contradictory aims: ~~On~~ on the one hand ~~talking~~ to talk about something (using the new and foreign language) and on the other hand ~~learning to~~ to learn to use appropriate vocabulary and generate correct sentences. It is difficult to pay attention to ~~these two~~ both aims at the same time unless the given context is very simple. Thus language learners face a dilemma between requirements related to grammatical rules and their communicative interests. ~~It is obvious that this dilemma is analoguous to the dilemma~~ This dilemma is analogous to that between surface form and communicative interest ~~reported~~ discussed in this paper. In this respect, using scientific phrases in science lessons may be compared to following grammatical rules in language lessons. Table 4 shows that, during lesson 4~~students succeed~~ , students succeeded many times in using the word 'force' in a scientific way, that is to express an interaction between two objects. During this lesson the pole jumper was the object of the study. In contrast, during lesson 6 the majority of the students reverted to everyday speech. ~~The~~ A crash test and the risk of a neck fracture was the topic of this lesson. It may be that the students were more affectively engaged in discussing this topic, in contrast to the topic of the pole jumper, so that they faced the ~~described dilemma~~ dilemma described in a quite unique way. This encourages us to draw a relationship with the concept of interlanguage described by Selinker (1972). Whereas almost all students during lesson 4 ~~are suggestive of having~~ appear to have understood the concept of force and ~~being~~ to be able to use the term ‘force’ appropriately, they slide back into their everyday use of ‘force’ during lesson 6. This reappearance of linguistic phenomena which were thought to ~~be~~ have been eradicated is what Selinker interprets as behavioral events following from language learning. From this point of view, the language the students revert to can be seen as a form of ‘scientific interlanguage’. The frequent change from everyday to scientific use of the term ‘force’ which can be observed during the teaching sequence for almost every student can be viewed as this ‘scientific interlanguage’. The strategies described provide a justification for this comparison because of their similarities to the central processes explained by Selinker: ~~The~~ the language used by the students is influenced by their everyday use of ‘force’ (language-transfer from the ‘native language’) as well as its scientific use (second-language learning), depending on the context. The example provided by Eva (163)-(166) may be interpreted as the result of a process of overgeneralisation or transfer-of-training. The deeper analysis showed that the change between different language levels ~~is~~ was not random but ~~depends~~ depended on pre-instructional ideas and the context of the actual discussion.

Fortunately the ~~period of time~~ duration of the teaching sequence ~~lasted~~ was long enough to see that after lesson 4 the students did *not* accomplish their learning of the concept of force. If the teaching sequence had ended ~~accidently~~ with lesson 4, ~~its result would entice~~ the results would encourage us to praise the underlying teaching method as ~~being appropriate to teach~~ appropriate for teaching the concept of force and the use of the term ‘force’ within some lessons. But ~~table~~Table 4 shows that ~~learning is going~~ during lesson 6, many students seem to behave like absolute beginners. So learning must go on. This is not surprising if we accept that we are dealing with language learning processes to some extent. So the period of time was long enough to observe what was reported in this paper.

But it might be that it was not long enough to observe typical phases or steps such as ~~it is~~ are reported by Diehl et al. (2002). Table 4 gives no indication for these phases, neither concerning the whole group of students nor a subgroup. Hence, more research is needed to explore this possible relationship between language learning processes and science education.

The results of our study indicate some promising relationships between learning science and learning a foreign language. Thus, it is worth looking for suggestions in the field of language learning research to open up new ways for improving science education. But although relationships between second language learning and science education were pointed out in this ~~text~~article, it has to be emphasised that learning science is not the same as learning a foreign language. Some observations within the data are persuasive in suggesting relationships, others seem to be independent ~~from~~ of the language learning processes. In addition we must note that whilst language learners are talking about commonplace events using a new language, science learners are talking about new and abstract fields of knowledge using a new and foreign language.

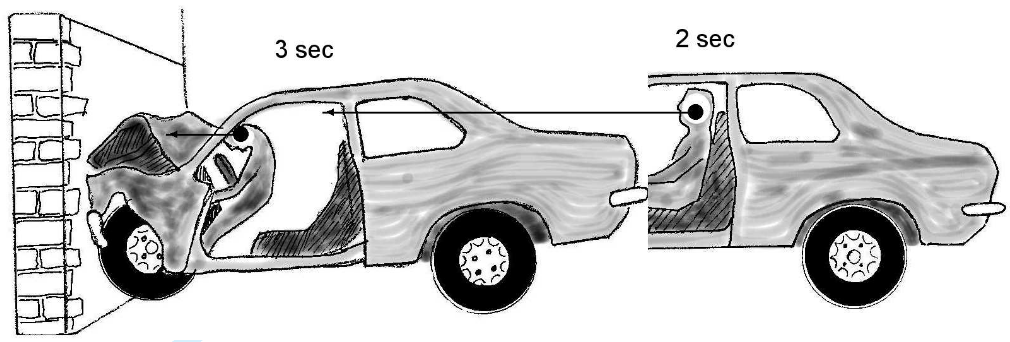


Figure 1: *Example topic (used in lesson 6, see Table,4): The picture was presented to the students after having watched a slow-motion video of the crash test. The arrows indicate the velocity of the head of the dummy. The difference of the two arrows ($\Delta\vec{v}$) was also marked in the picture in the course of the lesson. It indicated that there must be a force exerted on the head of the dummy in the direction opposite to its motion. The potential risk of neck-fracture in accidents like this comes into the scope of the discussion at this point. The students are asked to describe the movement of the crashtest-dummy using the term 'force' scientifically.*

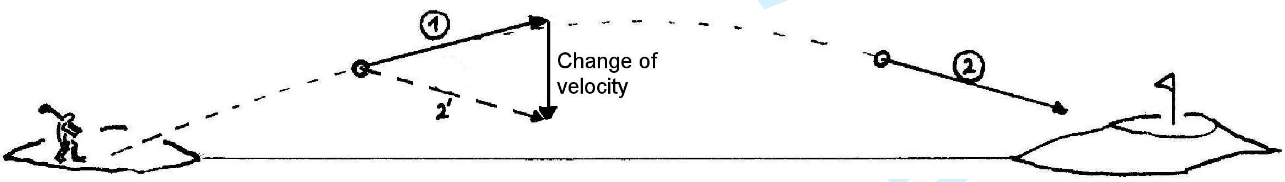
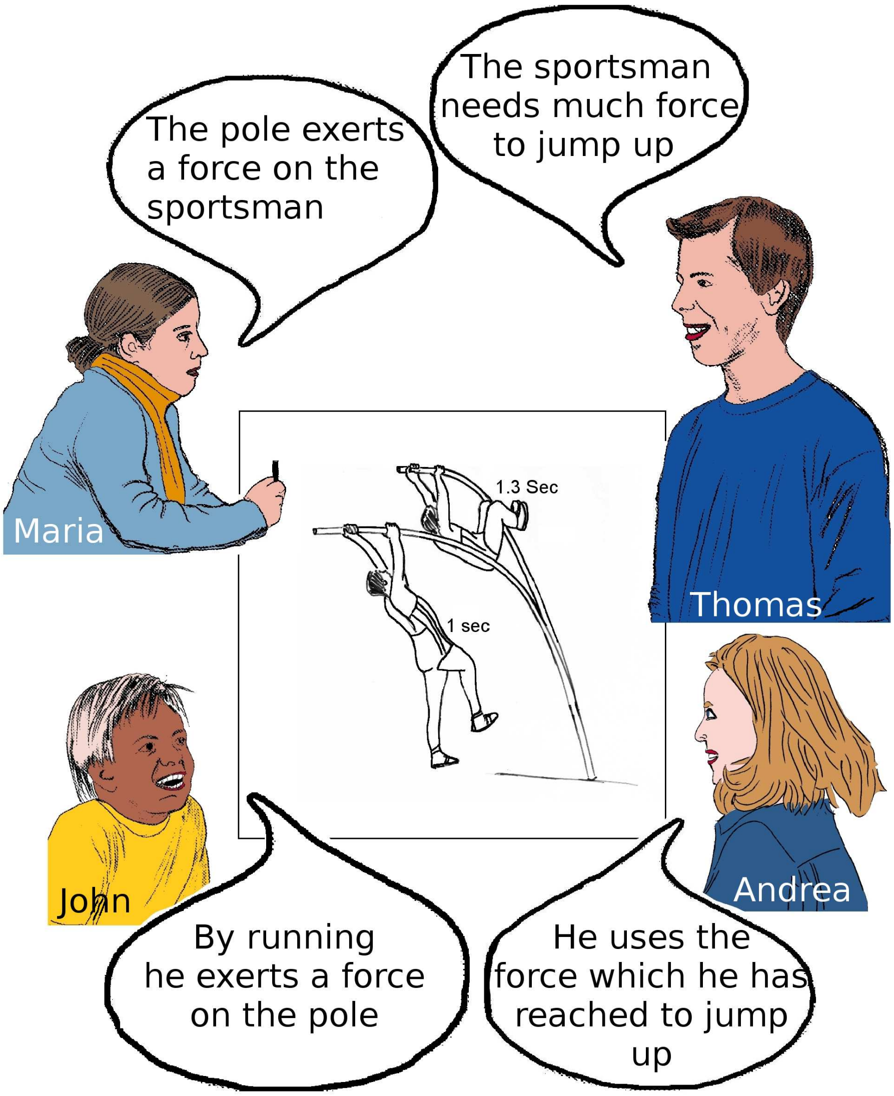


Figure 2: *Students have to write a statement using the term 'force' scientifically to talk about the time interval between 1 and 2. It was emphasised that the statement must not refer to the beginning of the motion of the ball. The idea for this task was taken from the Force Concept Inventory (Hestenes, 1992).*



1. Explain: Which statements belong to scientific language and which ones to everyday talk?

2. The speakers whose statements belong to everyday talk do not think about `force' in the way physicists do. Say something about what they imagine `force' to be.

3. The statements which belong to scientific language do not fit the situation at at the same level. Which fits best? Explain!

Figure 3: *Example task used in lesson 5 (see Table 6): Tasks like this were used to get students engaged into a meta-discourse: they have to explain whether the given statements belong to scientific or everyday use of the term 'force'. Moreover, the students are asked to adopt the speaker's point of view (in the case of everyday talk) and to explain possible perspectives on the term 'force'. The two statements which seem to be scientific (both Maria and John use 'to exert force on') are not of the same quality. The students are asked to differentiate these statements.*

start	5 weeks	5 weeks	**end**	6 months	
	teaching sequence section 1	teaching sequence section 2		students were taught other topics	
cognitive ability test		videotapes, audiotapes, logs, written tasks	test 2		test 3 (follow-up)

Figure 4: *Data collection over time: The teaching sequence covered a time period of approximately two and a half months. During the second section of the teaching sequence qualitative data via camcording, logs and written tasks were collected. In addition, at the beginning of the teaching sequence the students took the verbal component of the cognitive ability test (for details see page 20). Six months after test 2 they took another test (test 3).*

Categories Type 1	Example	Description
quantity	'there's a lot of force needed'	the word 'force' may be replaced by another word signifying something such as a quantity, for example 'energy' or 'momentum'
actor	'the force pulls the ball down'	the word 'force' is used in a sense 'acting' on other objects
interaction	'the ground exerts a force on the ball'	the word 'force' is used to denote an interaction between two objects (this was intended by the teaching sequence)
attempt	'he exerts the ball'	the whole sentence gives the impression that the speaker tries to use the correct phrase but does not succeed
others	'the force exerts a force on the ball'	uses of the word 'force' not clearly belonging to one of the categories above
Categories Type 2	**Example**	**Description**
surface form	'this is scientific because the word 'exert' appears in the text'	the speaker assigns a 'scientific' (or everyday) use referring to the *surface form* of a given sentence
content structure	'this is scientific because the description fits well to the given situation'	the speaker assigns a 'scientific' (or everyday) use referring to the *content* of a given sentence

Table 1: *The category system: categories of type 1 were used when students were asked to use the term 'force' scientifically; categories of type 2 were used when students were asked to participate in a meta-discourse.*

Sentence No	surface form sustains translation	intended deep structure sustains translation	sentence
1	yes	yes	Lars pushes the car
2	yes	no	The iron ball has much force
3*	no	yes	The ball bounces back from the ground
4	no	no	It's favourable to save force
5	yes	no	The engine needs energy
6*	no	yes	The ball is kept by the ballplayer

Table 2: *The translation task in the follow-up test (half a year later): Students are given six sentences using idiomatic language which had to be translated into scientific ones (if possible). The scheme indicates whether the translation is sustained either through surface form or intended deep structure. The asterisks indicate that two translations are possible, one referring to the intended deep structure, another possibly related to the surface form. The original test is available online (Rincke, 2007, p. 235).*

subgroup	description: students whose utterances in the lesson
I	belong to categories *interaction* or *attempt* more often than to *quantity*, *actor* or *others*
II	belong in some cases to categories *interaction* or *attempt*, but utterances belonging to *actor*, *quantity* or *others* occur more often or at least equal to *interaction* or *attempt*
III	never belong to categories *interaction* or *attempt*
IV	do not contain the term 'force'
V	no utterance (but student present during lesson)

Table 3: *Scheme indicating the way in which the group of 20 students was divided into further subgroups (analysing their use of the word 'force'). This division refers only to categories of type 1, see Table 1 (above).*

No of students	lesson 1	lesson 2	lesson 3	lesson 4	lesson 6	lesson 8
1	I	IV	I	I	V	I
2	I	IV	IV	I	I	IV
3	IV	IV	IV	I	IV	I
4	V	V	IV	I	IV	I
5	V	V	II	I	IV	IV
6	I	I	II	II	V	I
7	IV	IV	I	I	II	I
8	III	III	III	III	III	IV
9	I	I	III	I	III	V
10	I	IV	I	II	-	V
11	I	III	III	II	IV	III
12	I	I	III	II	III	II
13	III	IV	I	II	I	I
14	V	V	IV	II	III	I
15	V	IV	III	II	I	I
16	I	III	III	I	III	III
17	II	I	II	II	III	II
18	IV	I	III	II	III	II
19	V	IV	III	I	IV	III
20	V	II	I	I	III	IV

Table 4: *Students' affiliation to subgroups I-V during those lessons which are characterised by tasks in which students are asked to use the term 'force' scientifically. The shading indicates the categories to which students' utterances belong. See Table 3* for details concerning I-V, but roughly one can say 'the darker the gray the more scientific the talk'. (A '-' indicates that the student was absent.) This division refers only to categories of type 1, see Table 1 (above).

subgroup	description: students whose utterances in the lesson/test
i	belong more frequently to the category *surface form*
ii	belong more frequently to the category *content structure*
iii	belong equally to the categories *surface form* and *content structure*
iiii	cannot be assigned uniquely (students' utterance too short to categories uniquely)

Table 5: *Scheme indicating the way in which students were divided into further subgroups (analysing their argumentation structure within the meta-discourse). This division refers only to categories of type 2, see Table 1 (above).*

No of students	lesson 5	lesson 7	follow-up test
1	iii	-	iiii
2	iii	-	iiii
3	ii	-	ii
4	iii	-	ii
5	iii	-	iii
6	iii	ii	iii
7	iii	-	iiii
8	ii	ii	ii
9	iii	-	iii
10	iii	-	iiii
11	iii	ii	iii
12	iii	ii	iii
13	i	i	iiii
14	iii	-	iiii
15	iii	ii	iii
16	iiii	-	ii
17	iiii	ii	iiii
18	iii	-	iiii
19	ii	-	iiii
20	iiii	-	i

Table 6: *Students' affiliation to subgroups i-iiii. The table shows the results for two lessons which are characterised by students' meta-discourse and for the meta-discourse-related task in the follow-up test. The table indicates the categories to which students' utterances belong. For details concerning i-iii see Table 5.* Dark gray (i) indicates that the argumentation refers clearly to the surface form of a given statement. Lighter gray (ii) indicates that the argumentation refers clearly to the content of a given statement. Light gray (iii) indicates that the argumentation refers to the surface form and to the content. (Unfortunately many students were absent in one lesson ('-'). For this reason the results of the follow-up test are included in the table.) This division refers only to categories of type 2, see Table 1 (above).

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