# Towards an interlanguage of biological evolution

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# Towards an interlanguage of biological evolution

## Exploring students´ talk and writing as an arena for sense-making

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# Abstract

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The aim of this thesis is to explore what is involved when learning science, by focusing on students' appropriation of the school science language. The aspiration is to explore relations between, on the one hand, content-oriented aspects of making sense of a specific area in school biology, and on the other hand, more generic patterns that are linked to learning in general: the influence of different social languages, and also the conceptual, epistemological, and ontological constituents of learning something.

The strategy for empirically exploring what is involved when students make sense of biological evolution from a language perspective includes examination of instances in the classroom where meaning and sense of terms as well as semantic patterns are articulated in writing and talking. The analytic attention is on, on the one hand, students' individual writing, and on the other, students' talk in peer group discussions. The latter has guided the main part of the work, and one conclusion is that the students frequently shift between different social languages, mainly a colloquial and a scientific language. Both languages are a productive resource in students' appropriation of the school science language. This is understood to rely on the establishment of an arena, an interlanguage discourse, where scientific terms and theories may be introduced, negotiated, and made sense of, in particular in relation to colloquial language and everyday experiences. In that way, this interlanguage discourse is an arena for sense-making.

The students most frequently start their talk as a negotiation concerning conceptual notions that is linked to a discussion about epistemological pattern and sometimes the talk also is linked to ontological framing. The students negotiate the meaning of conceptual notions, which has both colloquial and scientific origins, for example variation, randomness, need, and development. Irrespective of the origin of the notions they are an asset in the students' sense-making process. Epistemologically the students make their argumentation plausible by referring to resources, for example names or theories. Furthermore, they structure their explanations both with internal logic, for example causality or teleological reasoning, and external linking between specific examples and general ideas. In each of these dimensions, the argumentation can have different quality. Links between the general and specific can be systematic rather than sporadic, explanations can be causal rather than teleological, and resources can be theories rather than names. Ontological framing is mainly done as negotiations about what is allowed to talk about or whether agency matters in a school science discourse.

# Contents

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However, the final decisions were made by me and none mentioned above is to blame for the collection of words and semantic patterns you are about to read, not necessarily agree with, but hopefully find interesting.

## Outline of the thesis

The thesis explores mainly two types of research questions, where the first type follows a tradition in science education research where you take on a macro perspective on evaluating to what extent an intended aim of an intervention is achieved. In this thesis, this is explored through an analysis of the students' learning outcome in teaching interventions; interventions that were theoretically informed, on a general level, by *design-based research* (cf. The Design-Based Research Collective, 2003). When exploring this first type of research question, the analytical attention is on the relations between learning goals and the students' learning outcomes, which are explored through the students' written language when they answer questions individually.

The second type of question, and which has guided the main part of the work, explores processes within the interventions. These processes are enacted in an arena where the students' talk is assumed to externalise the process of sense-making. In general, processes of sense-making, according to Bruner (1985), are constituted by *conceptual, epistemological and ontological aspects*. Theoretically, the analysis of the students' talk in this thesis is informed by research on the appropriation of *language* (cf. Brown & Ryoo, 2008; Lemke, 1990) with a special focus on *social languages* (Bakhtin, 1981), mainly colloquial and scientific languages. The students' efforts to make sense of the scientific language, through the use of colloquial language, may result in a new, personal, and dynamic language; an *interlanguage* (cf. Barnett, 1992; Gomez, 2007). When exploring this second type of research question, the analytical attention is on a microanalysis of the students' talk in peer group discussions, for example, in the light of the Vygotsky's (1986) idea about the tension between the *meaning* and the *sense* of words and expressions. The analysis addresses the ways that the students' talk mutually constitutes the meaning and sense of terms and their semantic relationships.

This thesis is divided into two main parts, where the first part consists of a background of the theoretical and methodological assumptions and considerations underlying the work, followed by a summary of findings, a discussion, and a summary in Swedish. The second part consists of the four papers/manuscripts that report the research that has been undertaken.

Part one of this thesis consists of the following chapters:

The 'Introduction' chapter summarises considerations and assumptions that underlie the formulation of the aim and research questions, questions that derive its origin from the two different research perspectives, macro and micro analysis, which were presented above.

In the chapter 'Theoretical influences', a general theoretical framework, informed by the work of Vygotsky is presented, starting out with the idea that learning involves a passage from social contexts to personal sense-making. One of the most influential tools in the transformation between the social and the individual planes is language, and in the chapter, the appropriation of the school science language is discussed. The chapter also consists of a literature review of previous research on learning biological evolution and a survey of different approaches to design-based research.

The chapter 'Empirical context' aims at describing the settings where the empirical work was done. This includes a presentation of the students, the teachers and the schools, but also the more specific contexts that framed the activities where the data was generated.

In 'Analytical procedure', steps when proceeding from empirical data to analysis are discussed. Since these steps are different in relation to the research questions, the text is organised in two sections, one for each of the research questions. Firstly, the analysis of students' writing is presented in terms of internal and external validation. Secondly, several ways of analysing students' talk is presented, focusing on both content-oriented aspects and more generic patterns. Concerning the content area, biological evolution, the analysis focuses mainly on epistemological aspects, but also on conceptual and ontological aspects. The analysis of generic patterns includes, for example, social languages and quality in reasoning.

The chapter 'Findings' consist of, firstly, a summary of the four papers / manuscripts, one by one, that are appended in part two of this thesis. Secondly, the conclusions of the four studies are brought together and presented.

In the chapter 'Discussion and implications', some methodological considerations are discussed followed by a discussion of the main findings.

Part two of the thesis consists of the following four papers/manuscripts:

Paper I

*Making sense of biological evolution – productive interaction of colloquial and school scientific language*

Clas Olander and Åke Ingerman, University of Gothenburg
Submitted 2009

Paper II

*Arguing biological evolution in small groups: The constituents of learning demand in pedagogical context*

Clas Olander and Åke Ingerman, University of Gothenburg
Submitted 2009

Paper III

*Teaching biological evolution – internal and external evaluation of learning outcomes*

Clas Olander, University of Gothenburg
Published 2009 in *Nordic Studies in Science Education, 5*(2), 171-184.

Paper IV

*Students' language use when talking about the evolution of life – negotiating the meaning of key terms and their semantic relationships*

Clas Olander and Åke Ingerman, University of Gothenburg
Accepted for publication in *Nordic Studies in Science Education*

# 1.Introduction

The general background of this thesis is grounded in a curiosity of what is involved in learning science, a curiosity that grew during many years of teaching when trying to scaffold students' efforts at making sense of science. This, my professional background, also guided the choice of general research design, which involves close collaboration with practicing teachers. The work reported in this thesis follows one of the main tenets of research in Science Education - developing understanding of what it takes to make sense of a specific content area - and this thesis contributes to this endeavour by focusing on students' appropriation of language when making sense of biological evolution. The aspiration of my work is to explore relations between, on the one hand, content-oriented aspects of making sense of a specific content area in school biology, and on the other, more generic patterns that are linked to learning in general: the influence of different social languages, and also the conceptual, epistemological, and ontological constituents of learning something.

In the recent *Handbook of Research in Science Education* (Abell & Lederman, 2007), the ultimate purpose of science education research is ambitiously expressed as the *improvement of science teaching and learning throughout the world*. In order to achieve this purpose, the authors argue that research must meet two conditions: "be grounded in the real world of students and teachers and school systems and society" and "be open to new theoretical frameworks, research methodologies, and strategies, even as we embrace existing tried and true methods" (p. xiii). In relation to the second condition, Chatterji (2004) suggests a 'mixed method' approach which, among other things, includes designs that combine qualitative and quantitative research evidence, include formative and summative evaluation phases, and use several feedback loops in the design. One research approach that aims at embracing all the above-mentioned characteristics, of being iterative, grounded in practice and engaging mixed methods, is design-based research. It is a kind of hybrid approach between 'academic' and 'developmental/evaluation' research since it has both a theoretical orientation and pragmatic aspirations. The aim is to develop domain-specific theories about both the process of learning and the scaffolding strategies that are designed to support that learning. Design-based research could be a bit 'messy', according to Brown (1992), mainly because it includes enacting specific learning approaches in authentic practice as well as an iterative design. Another aim is to lend legitimacy both to academia and practice – the theory must do real work (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003).

As already hinted at in the previous section, 'outline of the thesis', two types of research questions are addressed, and these questions have grown successively while working. This implies that the methods and perspectives employed are mixed in line with what Chatterji (2004) suggests above: quantitative and qualitative, summative and formative, macro and micro, and with the aspiration of contributing both to the fields of academia and practice. It is not evident that the perspectives are possible to combine in one thesis, but the perspectives have been present during the work process; a process that may have been 'messy', but one central assumption has informed the work employed in this thesis. It is an assumption that derives its origin from the idea of Vygotsky (1978) that in development and learning there is a passage from social contexts to personal sense-making, in other words, we meet, what are to us new ideas in social settings – they are introduced by others. However, the reverse passage, referred to as externalisations by Vygotsky (1986), occurs when personal reasoning is reintroduced on the social plane.

Thus, there is a continuous two-way transformation; on the one hand, what we meet in social life provides the tools for the process of internalisation, which is a kind of individual sense-making. On the other hand, there are externalisations, for example, in this thesis the students' talk and writing, which make the individuals' reasoning public in a collective arena, hence providing tools for internalisation. This line of reasoning is expressed by Sfard (2007) as the "ongoing transformations in human forms of doing as the result of two complementary processes, that of *individualization of the collective* and that of *communalization of the individual.* /../. The processes of individualization and communalization are reflexively interrelated" (p. 569, italics in original). The transformation is not a passive copying of others language and Bakhtin (1981) and Wertsch (1998) suggest the term appropriation instead of internalisation. It is a process of "taking something that belongs to others and make it one's own" (p. 53), which according to Sfard (2007) also implies the inevitability of personal variations.

A central issue in science education research is the idea of two spheres, labelled the *everyday* and the *scientific*, for example, specified as different ways of articulating concepts, language or knowledge (Warren, Ballenger, Ogonowski, Rosebery & Hudicourt-Barnes, 2001). There seems to be a consensus that the spheres could be analytically identified and separated with recourse to, for example, Bakhtin's (1981) notion of social languages. However, there is no consensus when it comes to what the identification of different spheres implies in relation to learning and teaching. Seeing everyday and scientific as a hard dichotomy, the focus could, according to Warren *et al.* (2001), on the one hand depict the different spheres as incommensurable and regard the everyday informal language as a source of creating barriers to robust learning, which have to be overcome, for example, by a process of conceptual change (Anderson, 2007; Duit & Treagust, 2003). On the other hand, the focus could be on bridging the two accounts, not viewing them as an either-or issue, and valuing the everyday informal language as an "asset that needs to be continually made use of in classrooms and in learning, but also to be studied and, explored and analysed in terms of its possibilities and its limitations" (Varelas, Pappas, Kane, Arsenault, Hankes, & Marnotes Cowan; 2008, p. 67).

The ability of 'contextual shifting' between everyday and scientific frameworks of understanding is, according to Reveles and Brown (2008) an influential resource for students' academic identity construction, which in turn is fundamental to scientific literacy development – for all students, regardless of social, economic, or ethnic background. Reveles and Brown suggest that one way of achieving this 'contextual shifting' is to view language as a substantive resource in teaching: "to build semantic relationships that serve to connect word meaning in science with conceptual knowledge in science. /.../. Explicitly teaching students to learn to use and control scientific language as they acquire conceptual understanding can make science more inviting for students" (p. 1039). This ability to use, translate and distinguish between social languages is one of the aims of science education and the more confidently the students move between languages, the more mature is their understanding (Mortimer & Scott, 2003). When students work with making sense of the scientific language, through the use of everyday language, they may develop a new hybrid language; an *interlanguage* (Barnett, 1992; Lemke, 1990). With this more personal, dynamic, and mixed language, the possibility of connecting and bridging between informal and formal accounts of phenomena increases (Brown & Spang, 2008; Gomez, 2007). The bridging between social languages, through interlanguage, has been shown to be a productive construct, both when it comes to informing teaching and as an analytical tool in research (cf. Ash, 2008; Brown & Ryoo, 2008; Varelas, Pappas & Rife, 2006)

**The language of science**

The link between language and learning is, according to Lemke (1990), that learning science involves a growing mastering of the scientific language (learning to talk science) and one aim of teaching science in schools is to introduce the language of the scientific community (Mortimer & Scott, 2003). Language, in general, provides us with words and terms, grammar, and semantics and it is, according to Brown and Ryoo (2008), the combination of conceptual and language components that has the ability to enhance students' conceptual understanding.

The school's scientific language makes use of numerous terms, for example, beaker, sublimation, and consumer, which are either new to the students or used in unfamiliar contexts. On the other hand, these terms have become part of the toolkit that teachers use when making sense of science content. However, meaning making involves contextualisation and no single term has any fixed meaning. Meaning relates, according to Lemke (1990) to the combination of terms into different *thematic patterns,* a network of semantic relationships that describes the science content: "the meanings of sentences are not made up out of meanings of words. We must arrive at both simultaneously by fitting words and their semantic relations within the sentence to some thematic pattern and the relations among its thematic items" (p. 35). In other words, it is the combination of terms (the pattern) that is the aim of teaching and learning, the whole (the pattern) becomes more than the parts (the terms). Making sense of science involves identifying thematic patterns: "placing anything said or written in the context of some larger, familiar thematic pattern of semantic relationships" (p. 202).

Since the thematic patterns used in school science are, initially, unfamiliar to the students, the teaching must make connections between the scientific language and the language that students already use when coming to school. Learning involves connecting to things we encountered before and, according to Lemke (1990), what we encounter has to fit some familiar thematic pattern, it has to make sense. Talking about phenomena in a new way requires eliciting and bridging our previous understanding, and making sense in the light of what we have already experienced. Thus, learning involves and requires sense-making of relationships; between different social languages as well as the relations to what we have encountered before.

**Different social languages constitute the learning demand**

The awareness of different spheres has historically informed approaches of how to understand students' learning. One striking characteristic mentioned before is that science language makes use of many specific terms, and consequently it is suggested that teaching pay attention to these terms. When focusing on terms, it is the conceptual aspects of making sense that come to forefront; however, the epistemological and ontological aspects do not get the same amount of attention. The epistemological and ontological aspects are part of 'the nature of science' and influence students' understanding of, as well as motivation to engage with, science in schools (cf. Brown, Reveles & Kelly, 2005; Warren *et al.* 2001).

One of the most important implications when it comes to epistemology and ontology is that intentions, purpose and agency have a potential as explanations in everyday life and language use. Furthermore, in everyday life every event is not regarded as possible to explain or not in need of explaining, while in the science classroom 'everyday events' like raining and falling objects are supposed to be explained; events that the students' might not think are in need of explaining - they are just 'natural' and obvious (Ogborn, Kress, Martins & McGillicuddy, 1996). In science, explanations are based strictly on causal links, and ontologically science assumes a worldview where the natural world is possible to explain and these explanations deal with mechanisms articulated as laws and theories. The assumptions above are embedded in our worldviews (Cobern, 2000) and articulated as social languages that are the specific ways of talking about and making sense of the world within subgroups in society, for example, professions, interest or age groups (Bakhtin, 1981).

The notion of learning demand was introduced by Leach and Scott (1995, 2002) in order to pay attention to the *differences between social languages*: the language of school science and the everyday social language that students bring to school. In this respect, learning demand constitutes the intellectual task facing the students in school science in terms of mastering the school's scientific language, and thus presupposes differences in social language. If the learning demand of specific phenomena is identified and articulated, then teaching could more accurately focus on the challenges that students encounter when trying to make sense of this particular science topic. Different topics in school science generate different learning demands, for example, learning about electricity generates one learning demand and learning about photosynthesis generates another. However, according to Leach and Scott (2003), in general the learning demand consists of conceptual, epistemological, and ontological aspects (cf. Bruner, 1985). The learning demand relates to differences in the conceptual tools used, differences which relate to ontological assumptions and epistemological underpinnings of the conceptual tools.

When using learning demand as a design tool, it is possible, according to Mortimer and Scott (2003), to identify the learning demand for a group of learners, mainly because in daily life the first choice of language is the everyday language and the assumption is that the students will arrive at school sharing a common social language. This social, rather than individual, aspect is phrased thus: "the concept of learning demand is linked more closely to differences between social languages and the meanings that they convey than to differences in the 'mental apparatus' of individuals. Thus learning demands are *epistemological* rather than *psychological* in nature" (p. 123, italics in original). As a tool for planning teaching, the notion of learning demand has shown potential, especially when applied to topics in school physics and chemistry, as, for example, 'electricity', 'particle model of matter', and 'energy' (Scott, Leach, Hind & Lewis, 2006). However, as mentioned before, different topics generate different learning demands, and according to Lewis (2008), more attention has to be paid to examples dealing with biological phenomena. Furthermore, up until now, proportionately more attention has been paid to the conceptual aspect of the learning demand, and less to epistemological and ontological issues.

**Students' sense-making of biological evolution**

Learning demand can be viewed as a gap - the distance between everyday and scientific accounts of a phenomenon - and, consequently, greater distances will create greater learning demand (Leach & Scott, 2002). Learning biological evolution is one of the areas where significant differences have been found between everyday and scientific accounts, connected to the conceptual, epistemological, and ontological aspects.

The conceptual notions that are most important in relation to this thesis are linked to variation, especially the origins and possible consequences of variation. The mere recognition of variation within populations is identified as a key factor when explaining biological evolution (Bishop & Anderson, 1990; Andersson & Wallin, 2006). Furthermore, students have difficulties in paying attention to the role of randomness in the process of shaping variation (Bizzo, 1994, Klymkowsky & Garvin-Doxas, 2008); instead, students favour explanations that draw on individuals' needs or intentions (Southerland, Abrams, Cummins & Anzelmo, 2001; Kampourakis & Zogza, 2008). Scientifically, biological evolution is defined as a *cumulative change in gene frequencies and the characteristics of organisms or populations over time.* In contrast, students often view the process of change as if every individual in a population gradually changes (Greene, 1990). Selection is a consequence of the meeting between the variation within a population and the environment. The process of evolution could be explained by taking into account a series of components: variation, heredity, survival rate, reproduction rate, and accumulation of changes; components which the students, according to Ferrari and Chi (1998), employ with different scientific merits.

Epistemologically, the assumption that events have a purpose or goal is a rationale for *teleological* reasoning. This is a kind of reasoning that clearly is part of everyday language, according to Keleman and DiYianni (2005), mainly because children “exist in artefact-saturated environments” (p. 6) and these artefacts are made for a purpose – they are designed. When explaining biological evolution, the use of teleological reasoning is widespread (Baalman & Kattmann, 2001; Jiménez-Aleixandre, 1992; Kampourakis & Zogza, 2009) and stands in contrast to the accepted explanation model in science, the causal explanation. However, there seems to be no way of escaping reasoning in terms of teleology; these formulations are an integral part of our language and moreover, anthropomorphisms and teleological expressions have heuristic, emancipatory, and pedagogical value for learners, as shown in studies concerning learning science in general (Brown & Ryoo, 2008; Gomez, 2007; Varelas, Pappas & Rife, 2006) and specifically when learning biological evolution (Ash, 2008; Kattmann, 2008). The rich occurrence and heuristic value of anthropomorphic and teleological expressions guides Zohar and Ginossar (1998) when they suggest that the instruction in school bring teleological expressions to the table and discuss expressions like ‘need’ in the context of biology. Then teaching could connect to the students’ everyday experience and language and at the same time clarify interpretations that are more in line with the language of school science.

Ontology refers to our view of how the natural world is constituted, a view that is influenced by our *worldviews*, which are composed of cultural factors and fundamental ideas that we often take for granted, expressed by Cobern (1996) as “the non-rational foundation for thought, emotion, and behaviour” (p. 584). Religious beliefs are the fundamental idea that is most frequently discussed in relation to biological evolution (Reiss, 2009), and specifically studied in a U.S. context (Smith & Siegel, 2004). In a Swedish context, a more prominent issue is whether explanations of the world should include a purpose or not; in other words, if agency matters or if the mechanistic explanations in science are valid (Irzik & Nola, 2009). However, in everyday life agency *does* matter and taking on a mechanistic worldview, even for short moments in the classroom, might cause difficulties and conflict for students.

## Relations between school science and science

Perhaps it is obvious, as Mortimer and Scott (2003) conclude, that science and school science differ; however, the relations between them have implications and they are explored by Chevallard (1989), when discussing the notion of *didactic transposition*. Transposition is seen as the steps that have to be taken when science (where knowledge is produced and put to use), is transformed into school science (where knowledge is learnt and taught). The process undergoes four steps, according to Bosch, Chevallard and Gascón (2005), starting in science settings where the scientific knowledge are produced and used by scientists. Secondly, this body of scientific knowledge is transformed into knowledge to be taught, which is formulated in the school curriculum. The third step is when the knowledge is interpreted and actually taught by teachers in classrooms, and finally there is the knowledge that students actually learn. These steps are exemplified in the domain of genetics by Gericke (2008) with a special focus on the use of models in textbooks.

Although I question the idea that the purpose of didactics is to 'make science teachable', I welcome the effort to reflect on the relation between science and school science. The notion of didactic transposition points to the fact that science and school science differ in crucial respects, not least when it comes to aim. In science, knowledge is used to produce more (general) knowledge, whereas in school science, knowledge is (or could be) used to prepare students for citizenship (Roberts, 2007). Taking the discussion above into consideration, I argue that the present thesis explores manifestations of school science, rather than manifestations of science.

## Context of the data generation

The empirical data in this thesis were generated during two design-based research projects, which had similar approaches, both with respect to the intended learning outcome and to the teaching strategy that would scaffold the students' sense-making process. The intended learning outcome was that the students should be able to use a scientific theory as a tool when encountering new contexts. Since science teaching often connects everyday experiences to models, theories, or concepts it is important whether these are seen as product (ends or goal) or process (means). Learning a model, theory, or concept could be an end point, a *goal to attain*, but then it is possible that the students learn more or less by heart; students repeat the right words. A model, theory, or concept could also be put to use as theoretical leverage, tool or *means in the process of sense-making*. This distinction is expressed by Bakhtin (1981) as: "When verbal disciplines are taught in school, two basic modes are recognised for the appropriation and transmission – simultaneously – of another's words (a text, a rule, a model): 'reciting by heart' and 'retelling by one's own words'" (p. 341). A possible arena for the retelling and successive appropriation of scientific language is peer group discussions where interlanguage serves as a tool. This is in line with how the notion of tool is expressed by Brown, Collins and Duguid (1989): "Tools share several significant features with knowledge: They can only be fully understood through use, and using them entails both changing the user's view of the world and adopting the belief system of the culture they are used [in]" (p. 33). The aspiration, when planning teaching in the projects, was to regard theory as a means in the process of sense-making; hence the expression *theory as a tool*.

When discussing the *meaning* and *sense* of a word Vygotsky (1986) touched upon the idea that words could be seen as tools in social practices, which relates to the use of words in this thesis like: words, terms, notions, and concepts. Vygotsky made a distinction between *meaning* as the stable zone of a word, pointing towards the collective, generalised, and lexical meaning, while *sense* is more situated and dependent on the context of the talk, thus pointing to the local, personal, and creative meaning. In order to make sense of a word, it has to be contextualised, for example, when the participants' sense (Vygoskyan sense) of a word is articulated, argued for and opposed, there is a possibility of reaching shared meaning; this shared meaning could be approaching the generalised meaning that Vygotsky referred to. The words that this thesis focuses on are specific words, technical terms, which often reside within language use in science, and hence *term* is most often used. However, when interpretations of terms are contextualised, negotiated and contrasted, through sense-making, the interpretations that are 'talked into existence' (Ogborn *et al.* 1996) might come closer to what Vygotsky articulated as meaning. This meaning is in its turn close to my understanding of a notion or a concept: a more generalised and collectively shared meaning. The core point is that whether speaking of words, terms, notions or concepts, they cannot be apprehended as end points in understanding or entities that speak for themselves – it is in the sense-making process that terms might come closer to concepts.

The teaching aim in the interventions was to weave a 'scientific story' around a specific theory, thus using a product of science as guidelines for a coherent system of ideas (Hammer & Elby, 2003). The teaching strategy was to connect the theory with carefully selected key terms; this selection of key terms was a result of a didactical analysis of relevant scientific terms for explaining biological evolution and research concerning students' reasoning about the same topic (Andersson, Bach, Hagman, Olander & Wallin, 2005). The teaching strategy included making use of communicative activities where the theory of evolution was to be 'talked into existence' (Ogborn *et al.* 1996). Learning goals and teaching strategy are influenced and framed by normative considerations, for example, the school curricula and syllabuses. Since the work reported in this thesis was carried out in collaboration with teachers in their own school practice, the function in practice and comparisons with goals in curricula and syllabuses guided the work. Taking this into account, it is even more important to keep a critical eye on the aims and teaching strategies, both in the experimental teaching and in the current practice in science education.

**Current practice in science education**

What then are the aims and teaching strategies of the current practice in science education, especially in relation to language? According to Driver, Newton and Osborne (2000), the current practice "still reflects a basically 'positivist view' of science in which the book of nature is read by observations and experiments" (p. 288). The dominant communicative pattern in classrooms is reported to follow the teacher-led triadic exchange of initiation-response-evaluation, IRE (cf. Edwards & Mercer, 1987; Mehan, 1979; Mortimer & Scott, 2003; Sinclair & Coulthard, 1975) and there are few opportunities for students to discuss ideas in groups (Erduran, Simon & Osborne, 2004; Lemke, 1990; Newton, Driver & Osborne, 1999; Wellington & Osborne, 2001). On the other hand, according to Mäkitalo, Jakobsson and Säljö (2009), there is an increasing tendency in school science practice to challenge teacher-dominated classroom interaction; interaction that includes more attention to students' group work and problem-based learning. That small group work appears with a greater frequency is also concluded by Bennett, Hogarth, Lubben, Campbell and Robinson (2010) in a literature review about the use and effects of small group discussions in school science teaching. The increased interest in small group work is, according to Bennett *et al.*, connected to an increased attention on literacy skills (cf. Norris & Phillips, 2003; Roberts, 2007) and formative assessment (cf. Black & Wiliam, 1998; Black, Harrison, Lee, Marshall, & Wiliam, 2003). In spite of the increasing popularity of small group discussions Bennett *et al.* conclude that not much is known about what happens when employing the approach in the classroom.

Regarding the aim of the teaching, there are different points of view; for example, according to Wells (1999), the aim is to reach shared semantic patterns, socialise students into the scientific discourse and at a more general level socialise them into being educated citizens. This is a view in line with the aspiration that the aim of teaching in school is citizenship and scientific literacy. Furthermore, the view that Wells (1999) advocates points to the idea that knowledge is socially constructed (Driver, Newton & Osborne, 2000), viewing learning as a process of enculturation and participation (Sfard, 2007) and appropriation of cultural tools and practices, as phrased by Lemke (2002):

> If you ask most teachers of science what their main goal is, they will probably say: for my students to understand the basic concepts of physics, chemistry, biology, or whatever other field is being studied. The critical words here are 'understand' and 'concept', and both of these terms assume a fundamentally psychological approach to learning. /../ If we see the goals of science education in terms of what students will be able to do, and how they will be able to make sense of the world, rather than in terms of our speculations about what may be going on in their brains, then we need to see scientific learning as the acquisition of cultural tools and practices, as learning to participate in very specific and often specialized forms of human activity (p. 159)

The promising trends in the current discussion in the science education community are an increasing attention to an aim for science education in line with scientific literacy (cf. Brown, Reveles & Kelly, 2005; Laugksch, 2000: Roberts, 2007; Webb, 2007). In the Swedish curricula (National Agency of Education, 2000), the aim of schooling is scientific literacy articulated in terms of fostering citizenship (for a more thorough analysis see appendix A). The arguments for this are in line with what Millar (1996) gave as the four reasons that justify the inclusion of natural science in the school syllabuses. Millar argued with economic, utility, democratic and social/cultural arguments, and all four arguments have implications for the individual student and the society. Especially the two latter arguments, democratic participation and science as cultural heritage, are addressed in other trends in science education: students' ability to 'talk science' (cf. Ash, 2008; Lemke, 1990; Mortimer & Scott, 2003; Ogborn *et al.* 1996; Varelas *et al.* 2008), which includes argumentative skills (cf. Erduran, Simon & Osborne, 2004; Jiménez-Aleixandre & Erduran, 2008; Zohar & Nemet, 2002). The relations between scientific literacy and argumentation are also discussed later in this thesis in the section 'Argumentation in science education'.

Theoretically, most of the trends mentioned above are based on Vygotsky's idea about the social origins of development and learning, thus involving a transformation from social contexts to personal sense-making. This implies, according to Leach and Scott (2003) that both individual and sociocultural views of learning have to be considered, which has implications for classroom practice. Driver, Newton and Osborne (2000) more specifically articulate the connection as: "we are persuaded to view the practice of argument by pupils in groups as an important mechanism for scaffolding the construction of argument by pupils individually" (p. 292). The kind of peer group discussions that Driver, Newton and Osborne refers to are claimed to support students' learning, especially if the discussion includes different explanatory models (Jiménez-Aleixandre, 1992; Passmore & Stewart, 2002; Wallin, 2004), paired problem-solving (Jensen & Finley, 1996), or dialectical argumentation (Asterhan & Schwarz, 2007).

## Aim and research questions

The aim of this thesis is to explore what is involved when learning science, by focusing on students' appropriation of the school science language. A strategy for empirically exploring what is involved when students make sense of biological evolution from a language perspective would include examination of instances in the classroom where meaning and sense of terms as well as thematic patterns are articulated in writing and talking. The aim is also to contribute to the description of what constitutes the learning demand for biological evolution.

As discussed previously with reference to, for example, mixed-method approach and design-based approach, it is possible to apply at least two perspectives; a macro and a micro perspective. For the sake of a rough clarification, the differences could be described as follows: the macro analysis often involves longer time frames and written data; furthermore, the analysis and findings frequently have a quantitative framing and its purpose is to make generalisations. The microanalysis often involves shorter episodes consisting of oral communication, and the analysis and findings are informed by qualitative methods pointing more to situated and contextual knowledge claims. In this thesis, both perspectives are considered, although the microanalysis of processes has become the main interest, with the analysis focusing on the students' talk while participating in teaching activities. This is also in line with a view that potential learning is a consequence of participation, and includes stepwise appropriation of the scientific discourse.

These two kinds of aim in the thesis correspond to two sets of questions:

**The first set of questions** is more in line with a macro perspective and focuses on design-based interventions and evaluations of learning outcomes; a 'before and after teaching' perspective. To what extent do the students appropriate school science ways of reasoning about biological evolution, as it is externalised in writing answers individually? In what ways do the students' written answers develop from before to after teaching?

**The second set of questions** is more in line with a micro perspective and focuses on students' talk when they discuss in peer groups; a 'process' perspective. To what extent do the students appropriate school science ways of reasoning about biological evolution, as it is externalised in discussions with peers? What terms and thematic patterns are negotiated and focused on in the students' discussion? In what ways are conceptual, epistemological, and ontological constituents of biological evolution construed in the students' discussion? In what ways are social languages connected to these constituents?

# 2. Theoretical influences

The overarching aim of this thesis was previously formulated as exploring what is involved in science learning or, more precisely, what is involved when students are engaged in making sense of a particular content area of science in formal settings. Part of the answer lies in the assumption by Lemke (1990) that learning science involves appropriating the language of science; learning to use a specific conceptual language in relation to specific phenomena. You learn this, like you learn any other language, by using it in communicative settings, for example, in speech and writing with those who already master the language. It is a matter of making sense of specific terms, specific grammar, and perhaps most of all, in the case of the scientific language, a specific thematic pattern; a pattern that combines significant terms into meaningful relationships, which are to be understood in terms of language use in a specific field, in this case school science. We will return to Lemke and conceptual issues as well as epistemological and ontological considerations that are linked to learning the particular content area that is focused on in this thesis. However, first a more general outline, already touched upon in the Introduction, will be presented concerning learning and development, where the start of the discussion is ideas from Vygotsky and the implications of these ideas in relation to this thesis.

## Core points from the work of Vygotsky

The aim of this section is to discuss the previously mentioned central idea in the writings of Vygotsky: that in development and learning there is a passage from social contexts to personal understanding. This means that we first encounter what are to us new ideas in a social context; these ideas are communicated in various ways, for example, by means of talk, drawings, mathematical models, and writings. These encounters take place on an intermental or social plane and could be initiated by people, for example, parents, friends, or teachers, but also by books and other media. The encounters provide the tools for the process of internalisation, a kind of individual sense-making, the passage to the intramental or individual plane.

> Any function in the child's cultural development appears twice, or on two planes. First it appears on the social plane, and then on the psychological plane. First it appears between people as an interpsychological category, and then within the child as an intrapsychological category. This is equally true with regard to voluntary attention, logical memory, the formation of concepts, and the development of volition. We may consider this as a law in the full sense of the word, but it goes without

> saying that internalisation transforms the process itself and changes its structure and functions. Social relations among people genetically underlie all higher functions and their relationships (Vygotsky, 1960, p. 163)

Vygotsky uses the word *transform* in relation to internalisation, thus claiming, according to Wertsch, 1985, that "internalisation is not a process of copying external reality on a preexisting internal plane; rather, it is a process wherein an internal plane is formed /…/. The external reality at issue is a social interactional one. /…/. The specific mechanism at issue is the mastery of external sign forms" (p. 66 - 67). In order not to signify some kind of passive transferral in relation to the notion of internalisation, Wertsch (1998) suggests the use of the term *appropriation*, "with the understanding that the process is one of taking something that belongs to others and making it one's own" (p. 53). The line of argument for this goes back to Bakhtin (1981) and the idea that 'one's own' words are always related to others: "the word in language is half someone else's. It becomes 'one's own' only when the speaker populates it with his own intention, his own accent, when he appropriates the word, adapting it to his own semantic and expressive intention" (p. 293). Furthermore, Wertsch (1991) connects this to another expression from Bakhtin: "users of language 'rent' meaning" which "assumes that meaning is always based on group life" (p. 68).

**Higher mental functions**

The notion of higher mental functions, especially their social origins, is important in the writings of Vygotsky, and he exemplifies such functions with thinking, formation of concepts, and memory (Vygotsky, 1986). These three functions have implications for the design and the analysis of data in this thesis, and they will be discussed below, mainly focusing on their connection with students' use of language.

The links between *thinking* and language are viewed by Vygotsky as relations between outer verbal speech and inner non-verbal speech and he concludes that "all our observations indicate that inner speech is an autonomous speech function. We can confidently regard it as a distinct plane of thought /…/ It still remains speech, i.e. thought connected to words" (p. 248-249). However interesting thinking and its origins are to psychologists like Vygotsky, thinking becomes difficult to capture when operationalised in educational research. What people are thinking is not easily accessible to researchers; on the other hand, externalisations could be a source of information: "To study an internal process it is necessary to externalise it experimentally, by connecting it with some outer activity; only then is objective functional analysis possible" (p.

227). The discussion above has influenced the choice of generating data in this thesis; which is from externalisations, when students write or talk while performing activities in school.

The process of the *formation of concepts* is connected to the idea of everyday/ scientific ways of making sense of the world; both ways of sense-making originate in encounters on the social plane, although their development differs. The everyday concepts are, according to Vygotsky, "saturated with experience" and they "are strong in what concerns the situational, empirical and practical" (Vygotsky, 1986, 192/194). Scientific concepts are conscious and deliberate in character, and they are products of schooling: "school learning is concerned with the assimilation of the fundamentals of scientific knowledge" (Vygotsky, 1978, p. 84). Development of the scientific concepts starts with its verbal specification, while a spontaneous concept is first known as object and then verbalised as concept; in this way, according to Vygotsky (1986), spontaneous concepts grow upwards and scientific concepts downwards.

Another higher mental function with a social origin that Vygotsky refers to is *memory*. The social roots of memory are also advocated by Tharp and Gallimore (1988) with the help of the story below. At the same time, the story introduces another core idea, the zone of proximal development:

> A 6-year old child has lost a toy and asks her father for help. The father asks where she last saw the toy; the child says, "I can't remember." He asks a series of questions: "Did you have it in your room? Outside? Next door?" To each question, the child answers no. When he says, "in the car?" she says "I think so" and goes to retrieve the toy. In this mundane conversation are the roots of higher mental functions /../ Without the father's assistance, she is able to recall only (as typical to her age) isolated bits of information; she is unable to choose a strategy to organize the information toward a particular goal-oriented purpose. But with the assistance, her performance reveals a level of development to come (p. 7)

The ways that students assist each other in coordinating explanations from smaller pieces of information is part of the analysis in this thesis. Such assisted coordination, I assume, will have most potential if the students are invited to act and discuss within what Wegerif (2008) labels as a 'dialogic space', where different opposing views of understanding a topic are held together in tension.

**Zone of proximal development**

The cited story above, from Tharp and Gallimore (1988), touches on the idea of the zone of proximal development (Vygotsky, 1978), the zone between the students' actual level of development and an assisted higher level, which is introduced as a "general developmental law for the higher mental functions" (p. 90). The zone is, according to Vygotsky, "*the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers*" (p. 86, italics in original). The notion of the zone of proximal development is, according to Wertsch and Addison Stone (1985), introduced "to deal with two practical issues of educational psychology: the assessment of children's cognitive abilities and the evaluation of instructional practices" (p. 165).

The points made by Wertsch and Addison Stone above are related to evaluation and assessment of instruction in terms of cognitive development. In this thesis, it is argued that possible implications of the findings concerning students' reasoning are a pool of explanations, or a zone of possible explanations. These are what individual students write, but they are also examples of the range of what could be the reasoning after assistance; either discussed with peers or used by the teacher in instruction, an instruction that Brown and Ferrara (1985) suggest should aim at the upper boundaries of the child's zone – the level of potential development. This connects to instruction where the notion of proximal development is also applicable, according to Wertsch and Addison Stone (1985), and they quote Vygotsky from a Russian text: "*instruction is good only when it proceeds ahead* of development, when it *awakens and rouses to life those functions that are in the process of maturing or in the zone of proximal development*" (p. 165, italics in original). The nature of the instruction that helps the child to appropriate is labelled 'scaffolding' by Bruner (1985) and includes the tutor directing the child's attention, reducing degrees of freedom, indicating critical features, and demonstrating possible solutions.

There is an evident risk of the above-mentioned scaffolding turning into an unreflecting predesigned learning trajectory in line with what Ben-Zvi and Sfard (2007) metaphorically relates to the Greek myth of 'Adriane's thread'; according to the myth Adriane's beloved Theseus blindly follows her thread and finds his way out of a labyrinth. Sfard contrasts this view of the learning process with another Greek myth, Daedalos' wings. In this myth, Icarus, the son of Daedalos, is given wings fixed with wax and Daedalos gives only one piece of advice to his son: do not fly close to the sun, which sadly enough Icarus does and falls down. In order to not get lost in either Ariadnes' or Daedalus' myths, Sfard (1998) suggest two metaphors for learning: acquisition and participation – accompanied by the advice of not choosing one of them. The acquisition metaphor regards learning as a more personal process, and the learner acquires or receives something from a facilitator, for example, a teacher. On the other hand, the participation metaphor relates more to collective knowledge building, enculturation, where the learner participates in activities rather than accumulating private possessions. 'Learning as participation' is in line with Vygotsky's view (1986) of the historical and social roots of learning. Sfard (2007) describes the participationist perspective on learning as an initiation "to patterned, historically established forms of activity" and "sense-making is to be interpreted as students' effort to make sense of *foreign forms of talk* about the worlds rather than trying to phantom the nature of this world in a direct manner." (p. 124, italics in original)

The scaffolding that Bruner (1985) referred to is aimed more at a gradual handover of responsibility, from assisted to unassisted performance (Wood, Bruner & Ross, 1976). The handover is governed by approriation of language and the language could be introduced by teachers or peers; Bruner (1985) expresses it as follows:

> … the Vygotskian project [is] to find the manner in which aspirant members of a culture learn from their tutors, the vicars of the culture, how to understand the world. That world is a symbolic world in the sense that it consists of conceptually organized, rule-bounded belief systems about what exists, about how to get to goals, about what is to be valued. There is no way, none, in which a human being could possibly master that world without the aid and assistance of others for, in fact, that world *is* others (Bruner, 1985, p. 32, italics in original)

Thus Bruner suggests that the conceptual, epistemological, and ontological aspects are involved when we make sense of the world; aspects that we need assistance to appropriate.

In relation to my thesis, there are another three major implications of Vygotsky's idea of the zone of proximal development. Firstly, there is the claim that "the acquisition of language can provide a paradigm for the entire problem of the relation between development and learning" (Vygotsky, 1978, p. 89). Secondly, the possibility that collaboration with peers can contribute to development and learning (p. 86); however, according to Forman and Cazden (1985), the role of peer interaction does not receive much attention from Vygotsky. In this thesis, the interconnection of the two claims above (the use of language in peer group discussions) is explored – although from different analytical starting points (see meaning and sense in the next section).

The third implication is more general and relates to the aim and direction of research in science education:

> Each school subject has its own specific relation to the course of child development, a relation that varies as the child goes from one stage to another. This leads us directly to re-examination of the problem of formal discipline, that is, to the significance of each particular subject from the viewpoint of overall mental development. Clearly, the problem cannot be solved by using any one formula; extensive and highly diverse concrete research based on the concept of the zone of proximal development is necessary to resolve the issue (Vygotsky, 1978, p. 91)

The kind of research exemplified in this thesis is in line with this claim – a contribution to an in-depth analysis of the ways a specific content is made sense of by students. This content or domain specific feature is often pointed to by researchers who work in line with design-based research (cf. Andersson & Wallin, 2006; Cobb, Confrey, diSessa, Lehrer & Schauble, 2003; Lijnse, 2000)

## Meaning and sense - important features of language

As noted above, Vygotsky suggested that language is the main bridge between development and learning, and in *Thought and Language* (1986) he unfolds the previously mentioned distinction between *meaning* and *sense* of a word. Meaning is the stable zone of a word, pointing to the collective, generalised, and lexical meaning, while sense is more situated and dependant on the context of the talk, thus pointing to the local, personal, and creative meaning.

> The sense of a word, according to him [Paulhan] is the sum of all the psychological events aroused in our consciousness by the word. It is a dynamic, fluid, complex whole, which has several zones of unequal stability. Meaning is only one of the zones of sense, the most stable and precise zone. A word acquires its sense from the context in which it appears; in different contexts, it changes its sense. Meaning remains stable throughout the changes of sense. The dictionary meaning of a word is no more than a stone in the edifice of sense, no more than a potentiality that finds diversified realization in speech (Vygotsky, 1987, p. 244-245).

In Vygotsky's use of meaning and sense, Wertsch (1985) traces two possibly opposing ideas; on the one hand, language use as decontextualisation of the meaning of a word and on the other, language could be used to contextualise the meaning of a word, which is a word's sense. However, the two perspectives, meaning and sense, "operate simultaneously in determining the structure and interpretation of speech" (p. 95); one of the aspects might be in focus but is reflected in the light of the other, and vice versa.

In this thesis, the distinction between meaning and sense is employed when analysing students' talk. Furthermore, as Wertsch suggests, the two perspectives, decontextualisation and contextualisation, are considered. On the one hand, students' decontextualisations of scientific terms introduced by the teacher are analysed (paper IV), as well as students' contextualisation of colloquial and scientific terms (paper I and II).

## Renderings of everyday and scientific spheres in science education research

When discussing the two spheres, mostly labelled *the everyday* and *the scientific*, certain characteristics are commonly used to describe and differentiate between the two. The everyday sphere is often described with words such as ”improvisation, ambiguity, informality, engagement, and subjectivity” while the scientific side is described with words such as ”rationality, precision, formality, detachment, and objectivity” (Warren, Ballenger, Ogonowski, Rosebery & Hudicourt-Barnes, 2001, p. 530). On the other hand, according to Anderson, 2007, what the existence of these spheres implies for learning and teaching is a dividing line between research approaches, for example, the relations between the spheres are depicted as *complementary* (cf. Vygotsky, 1986), *dichotomous* (cf. Chi, 2005; Shtulman, 2006), or *continuous* (cf. Brown & Ryoo, 2008; Warren *et al.* 2001). However, first a brief analysis of how the spheres are labelled in the research literature and what this could imply in relation to research interests and status will be made.

The variety in labelling everyday concepts and knowledge is evident when looking at the 8,400 entries in Reinders Duit's (2009) bibliography *Students' and Teachers' Conceptions and Science Education (STSCE).* These conceptions are, according to Roth (2008), labelled as: pre instructional-, naive-, non standard-, canonical-, alternative or mis-conceptions. Other labels to be found in research literature are: spontaneous or informal (Vygotsky, 1978), folk theory (Windschitl, 2004), folkbiology (Medin & Atran, 1999), traditional or indigenous knowledge (Snively & Corsiglia, 2001), intuitive or commonsense (Sherin, 2006), vernacular (Brown & Spang, 2008), life world languages (Varelas *et al.* 2008), or colloquial (Lemke, 1990). The scientific accounts and language could also be labelled in different ways (significantly, there is less diversity in labelling these), for example, formal (Vygotsky, 1978), academic (Varelas *et al.* 2008), schooled (Tharp & Gallimore, 1988), or institutionalised (Bruna, Vann & Perales Escudero, 2007). The imbalance in number when labelling the spheres is an indication of status as well as research interest in science education. Apparently, the scientific sphere seems to be more or less taken for granted and unproblematic, while the labelling (and number of studies) of the everyday side indicates a lower status, and a need of investigations of the 'unfamiliar others' view of the scientific content.

**Complementary relations**

In the discussion that refers to everyday and scientific *concepts*, one standpoint is that the spheres are complementary. This is what Vygotsky (1986) argues when stating that "the strong side of one indicates the weak side of the other, and vice versa" (p. 158); what differs is the origin and the aim of the concepts. With respect to origin and aim, Vygotsky often refers to the everyday concepts as spontaneous since they arise from day-to-day experiences and they are formed in a process not aimed at mastering the concepts. The opposite is valid for the scientific concepts; they are introduced in formal settings (often school) where the aim is to master the concepts. Introduction of both types of concepts involves a passage from social interaction to individual understanding; both appear first on the social level (between people) and then, after personal sense-making, are they transformed to the individual level. It is noteworthy that Vygotsky's framework includes all sciences (not exclusively natural sciences), and he often uses the notion *formal* concepts and knowledge (Vygotsky, 1978).

**Dichotomous relations**

The everyday and scientific accounts could be viewed as being in opposition to each other, a dichotomy; often with the assumption that students' everyday experiences result in *mis*conceptions (Chi, 2005; Ingram & Nelson, 2006) or *naïve* theories (Shtulman, 2006; Vosniadou, 2007). When these are brought to school they are perceived as making students' learning more difficult. In studies that draw on the conceptual change model, first introduced by Posner, Strike, Hewson and Hertzog (1982) and thoroughly elaborated in Vosniadou (2008), the everyday and scientific accounts are seen as dichotomous. When viewing the relation as a dichotomy, the accounts are mainly understood in terms of conceptual understanding; depicted as altered status of different explanatory models or change/exchange of individuals' ideas (Anderson, 2007; Hewson, Beeth & Thorley, 1998). The everyday concepts are seen as originating from everyday experiences, and these everyday concepts are depicted as barriers or less powerful in relation to further learning. Consequently, the starting point when designing teaching for conceptual change is often, according to Duit and Treagust (2003), to regard students' everyday knowledge as alternative knowledge that has to be changed to (or exchanged for) scientific knowledge. In contrast, Scott, Asoko and Leach

(2007) suggest that it is school science that offers students an alternative way of explaining natural phenomena. In everyday language, it makes sense to say that firewood burns down and disappears, while in science language, matter is conserved, although transformed.

**Continuous relations**

Instead of regarding everyday views as being incompatible with scientific views and, thus, in need of replacement, everyday language could be seen as an asset when learning the scientific language (Varelas *et al.* 2008). The same possibility is expressed by Warren *et al.* (2001) when they depict the everyday expressions as an intellectual resource in a continuum between the everyday and the scientific accounts. Drawing conclusions from studies with minority students, Warren *et al.* find that students' familiar ways of discussing ”do not lack complexity, generativity, or precision” (p. 548)

> We think it is crucial that the diverse ideas and ways of talking and knowing of all children be brought in contact with each other as well as with standardly views and modes of organizing explanations and arguments /…/ We see contact among different perspectives as a creative critical process /…/ in which diverse ways with words and ways of seeing are probed, challenged, and perhaps even transformed to the benefit of all students (p. 548).

The idea of continuum, especially in relation to scientific literacy and language use, is proposed and exemplified by Wallace (2004), in the areas of 'authenticity, multiple discourses, and third space', and all three of the constructs involve alterations between everyday and scientific language use, for example, authenticity refers to a continuum of *expressions*. Multiple discoursers points to the continuum of *voice* (private and public genres of discourse), and "the term representing the continuum for the Third Space is *meaning*, emphasizing the semiotic dimension of language use /.../. Points along the continuum would represent hybrid meanings for scientific words and events" (p. 911). Balgopal and Montplaisir (in press) take the three constructs above as their point of departure in a study that concerns students' written essays about natural selection; according to the authors the students' reach conceptual understanding of natural selection when they enter the dialogic context of both everyday and scientific expressions, voice, and meaning.

**Interlanguage, a hybrid that connects the spheres**

Students' efforts at making sense of the scientific language, through the use of everyday language, may result in a new and more personal language; an *interlanguage* (Barnett, 1992; Gomez, 2007). This bridging of two social languages is described as 'hybridisation' by Bakhtin (1981) and Lemke

(1990) labels the interlanguage bridging as ”a sort of hybrid between colloquial andtechnical register” (p. 173). The notion of interlanguage and hybrid language is often used in the knowledge domain of foreign language learning. However, if we take the standpoint that learning science involves appropriating language and learning to talk science, the idea of a hybrid language or interlanguage becomes useful when analysing the use of language in school science settings.

One feature of the interlanguage is that it opens up and provides an arena where reasoning could be tested and ideas probed, for example, by *imitating* the scientific language or the expressions of peers and teachers. When discussing the zone of proximal development, Vygotsky (1978) argued for a “revaluation of imitation in learning” (p. 87), and Sfard (2007) shows that imitating is involved in learning mathematics. She argues that thoughtful imitation is a way of adopting another person’s perspective and thus entering a new discourse, the discourse of school mathematics. The entering of a new discourse could, according to Bakhtin (1981) simultaneously be performed as an ‘authoritative discourse’ and an ‘internally persuasive discourse’ (p. 342); however, Cazden (2001) argue that when we transform the “authoritative discourse of others into our own words, it may lose its authority and become more open. We can test it, consider it in dialog – private or public – with other ideas, and ‘reaccentuate’ it (Bakhtin’s term) in our own ways” (p. 76).

The use of a hybrid language could also be observed outside classrooms, for example, families visiting a marine centre connected everyday and science language in a continuum when making sense of what they saw (Ash, Crain, Brandt, Loomis, Wheaton & Bennett, 2007). True recognition of both languages is shown by Gomez (2007) when students made use of multiple discourses when working on a science fair presentation. The interplay between everyday and scientific resources enhanced students’ understanding of science. Another way of describing the interplay is made by Zabel (2007), when investigating students’ written narratives about evolution; narratives that are useful learning tools because they “allow students to conceptualise science contents with the help of familiar and well-known action” (p. 9). A way of expressing the hybrid mode of communication is labelled ‘double talk’ by Brown and Spang (2008), in the sense that both the teacher and the students used and shifted between vernacular and scientific language when performing a task involving the classification of organisms. Yet another example is when Ash (2008) focused on the interplay between everyday and scientific discourses when analysing a successful learning episode about biological adaptation, and also Varelas, Pappas and Rife (2006) found learning gains when exploring an intervention about evaporation, boiling and condensation. The outcome, students' ability to talk and reason like scientists, is attributed to switching back and forth between scientific and everyday discourses. This is in line with the advice by Lemke (1990) to let ”students translate back and forth between scientific and colloquial statements and questions” (p. 172). Students start with their colloquial language and along the way their version of the scientific language becomes an interlanguage.

## The language of science

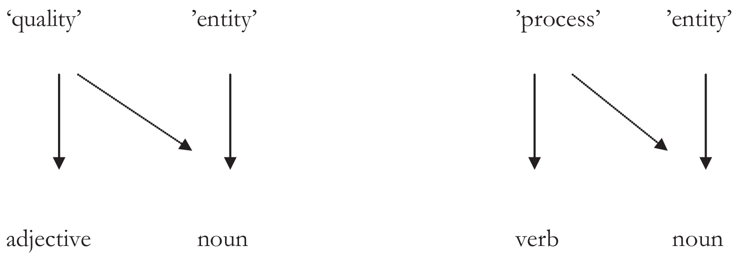
In this section, the presence and consequences of the above-mentioned types of spheres, everyday and scientific, are discussed with a focus on the language of science. Here, language is seen a collection of spoken and written words along with their semantic forms: meaning and sense. Three ways that the research literature pays attention to language are introduced: different use of words or vocabulary, grammar, and thematic pattern.

The language of science makes use of words that are specialised terms (Wellington & Osborne, 2001), terms that sometimes are quite unique to science, for example, 'refraction', 'electrolysis', and 'ion'. However, other words that are common in science language have interpretations also in everyday language, for example, 'energy', 'cycle', and 'consumer'. The words and terms are labelled entities by Ogborn, Kress, Martins and McGillicudy (1996) because they are new 'chunks of meaning', entities that are to be used in explanations and need to be "talked into existence for students" (p. 14). According to Wellington and Osborne (2001), the words of science belong to different categories depending on how the words acquire meaning; *naming* words, *process* words, and *concept* words. Naming words are used for familiar and often observable objects, such as 'iris' and 'pollen', or are related to unfamiliar objects belonging to school science laboratories, for example, 'beaker' and 'Bunsen burner'. Likewise, process words could be observable, like 'evaporation' and 'combustion' or more abstract, for example, 'evolution'. The concept words, for example, 'heat' and 'fruit', are especially difficult since they, according to Wellington and Osborne, cannot be understood in isolation; they are a part of networks with other words and depend on prior understanding. Although I question the assumption that it is *only* the concept words that need to be contextualised in the light of previous understanding, I agree with Wellington and Osborne when they advocate that language can develop if teaching aims at reaching shared meaning.

The introduction of scientific words and interpretations of everyday and scientific terminology is exemplified by Edwards and Mercer (1987) when a teacher and students are engaged in a conversation while looking at a pendulum, trying to define what makes a pendulum a pendulum. The students, aged 10 - 11, use everyday terms such as 'weight' and 'hang straight down from one finger', while the teacher gradually introduces the more scientific terms 'mass' and 'from a fixed point'. Edwards and Mercer claim that the teacher, by using the terms in an understandable context, "manage[s] to induct the pupils into a shared scientific discourse" (p. 155). A quite different assumption guided Brown and Ryoo (2008) when they carried out an intervention study in grade 5 of minority students about teaching and learning photosynthesis. In this study, conceptual understanding of the terms in everyday language is established initially, only then are the scientific terms introduced as alternatives. For example, the teacher encourage and allow the use of expressions such as 'plant food' (not glucose), 'energy pouch' (not chloroplast), 'light' (not photon), and 'the air that humans breathe out' (not carbon dioxide). A control group was introduced to the scientific terms from the outset, but the experimental group performed significantly better judged by a pre and post-test design. The outcome is explained by Brown and Ryoo with the 'content-first' strategy; first teaching scientific concepts in everyday language and then providing instructional scaffolds leading to scientific language. This teaching approach is based on a conceptual continuity between students' everyday and scientific communication, which seemed to ease these minority students' feelings of anxiety and cultural conflict.

The language of school science, especially in text books, is dense and frequently uses a grammar with nominalisations (Wellington & Osborne, 2001). The grammar of scientific language makes it different and unfamiliar in comparison to everyday language. The frequent use of grammatical metaphors, especially nominalisations, in scientific language is a field of research proposed principally by social linguists such as Halliday (2004). In the introduction to *The Language of Science*, Halliday stresses that the approach does not deal with words but with grammatical classes. Grammatical metaphors are exemplified with the words *length* and *motion:*

> These show the same phenomena of semantic junction; but it is a junction of category meanings, not of word meanings




> Thus, the word length expresses a complex meaning that is a junction of (the quality) ‘long’ and the category meaning of a noun, which is ‘entity’ or ‘thing’. Likewise motion expresses a complex meaning that is a junction of (the process) ‘move’ and the category meaning, again, of a noun (Halliday, 2004, p. xvi –xvii).

In *Talking Science: Language, Learning, and Values* (1990), Lemke refers to the work of Halliday, especially when discussing social semiotics. In science dialogue, two patterns are discernable, according to Lemke; people’s interaction with each other (activity structure) and people’s interaction with content, constructing complex meanings (thematic patterns). In this thesis, it is the latter structure, thematic patterns, that informs the analysis of everyday and scientific language. Thematic pattern is defined by Lemke (1990) as a “pattern of connections among the meanings of words in a particular field of science I will call their thematic pattern. It is a pattern of semantic relationships that describes the thematic content, the science content, of a particular topic area” (p. 12).

The analysis of language in this thesis focuses on the terms and thematic patterns, which in turn involves successive changes of domain in the analytical attention, back and forth between the students’ sense-making (contextualisation) of single terms and their combinations in specific contexts. The relations between (and significance for learning of) single terms and coherent explanations, like the theory of evolution, are described by Lemke as: ”the systems of related meanings that constitute a scientific theory are learned and used primarily through language and correspond to a thematic pattern of thematic items (key terms, or ‘concept words’) and their semantic relations to one and another” (p. 121)

## Argumentation in science education

The role of argumentation in science education is underplayed, Driver, Newton and Osborne (2000) concluded when they argued for teaching *about* science and not only *in* science. Since then, argumentation in school science settings has attracted growing interest, especially ”the value of argumentation for unpacking the nature of claims and warrants for knowledge” (Kelly, 2007, p. 453). When making a review of literature on argumentation in science education, Jiménez-Aleixandre and Erduran (2008) point to four areas where increased argumentation skills have potential for making a contribution: scientific literacy, critical thinking, higher order cognitive processes, and enculturation in scientific culture. Furthermore, through argumentation it is possible for the learner to elaborate and coordinate both cognitive and epistemic goals (Erduran, Osborne & Simon, 2005); and in argumentation, reasoning and knowing becomes accessible, both to the learners themselves and to others, and then it could enhance the possibilities of performing ‘assessment *for* learning’ (Black, Harrison, Lee, Marshall & Wiliam, 2003).

One definition of argumentation is that it concerns *coordination of claims and evidence* and, according to Toulmin (1958), all argumentation follows the pattern of referring to data when making a claim: the warrant is what justifies the connection between data and claim: *given* (the data) *so* (the claim) *since* (the warrant). Furthermore, a backing is used to strengthen the warrant and rebuttal refers to circumstances where the claim is valid or not. Toulmin's argumentation pattern, TAP (summarised in Figure 1 below) has been used in studies of argumentation in science education, mainly because it offers a conceptualisation of important elements in an argument, their relations and how they are linked in patterns of reasoning (Erduran, 2008; Simon, 2008)

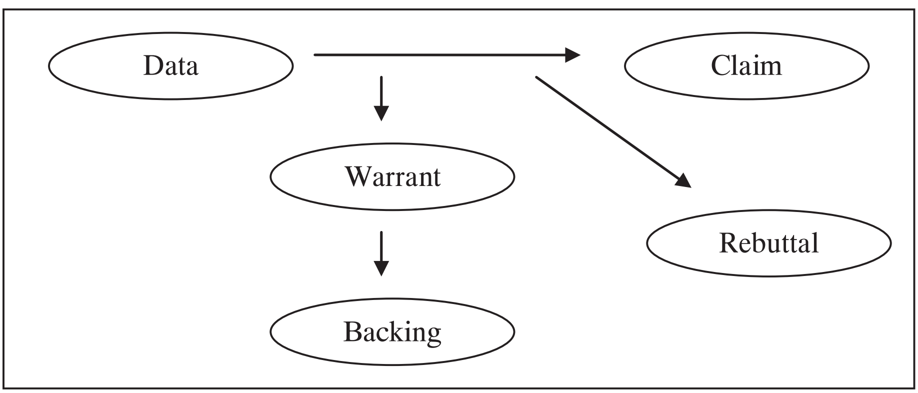



**Figure 1.** Toulmin's Argumentation Pattern (from Erduran, Simon & Osborne, 2004, p. 918)

The arrows in Figure 1 point to a temporal line, first considering data then making a claim, and this is probably the way that argumentation is apprehended in general, as well as in the classroom. For example, when students do lab work, the standard procedure is to first gather data and then make claims based on the data. In 'real life', according to Gott and Duggan (2007), the pattern is reversed in the sense that in daily life we are confronted with claims and our challenge is to find data (evidence) in order to judge the trustworthiness of the claims. For example, in the newspaper we can, in the same issue, read that fat is dangerous to eat as well as fat being essential to eat. Being a 'scientific literate' person then includes scrutinising the claims (fat is dangerous / fat is essential) and the warrants that are presented; in other words, scientific literacy in daily life involves judging data and evidence in order to make informed decisions.

When designing inquiry-based activities in school, the idea of seeding in dilemmas or conflicting views have informed both the design of socioscientific (SSI) tasks as well as more content-related tasks. For example, Zohar and Nemet (2002) used dilemmas in relation to genetics and Mäkitalo, Jakobsson, and Säljö (2009) introduced conflicting views in relation to the greenhouse effect. The fact that conflicting views can be expressed on different levels (the individual, the societal and the structural level) is explored by Ekborg, Ideland and Malmberg (2009) in relation to six different SSI tasks. Furthermore, conflicting views regarding more content-related issues are presented in *Ideas, Evidence and Arguments in Science* (Osborne, Erduran & Simon, 2003), which is a rich education material aimed at teachers' in-serve training.

Several reviews have investigated the effect of small group discussions on students' understanding of science, including understanding of evidence, attitudes to science and effects of different stimuli (cf. Bennett, Lubben, Hogarth, Campbell & Robinson, 2005). Improvements, with respect to the aspects mentioned above, are visible when interventions use specific programmes fostering collaborative reasoning and argumentation. However, according to Bennett *et al.*, improvements, in ordinary settings, depend on the input the students get, and the authors suggests a "combination of internal conflict (i.e. where a diversity of views and/or understanding is represented within a group) and external conflict (where an external stimulus presents a group with conflicting views) resulted in a significant improvement of students' understanding of evidence" (p. 3). The 'diversified or conflicting views' relate rather well to the previously mentioned notion of *dialogic space* (Wegerif, 2008).

## Learning demand

The previous sections' survey of renderings of the everyday and scientific spheres has pointed to several interpretations and approaches to the different demands that face students, teachers, and researchers. The recognition of a gap and how to cope with the gap is involved in students' sense-making of a topic, the teachers' planning of teaching activities in relation to this topic, and the researchers' analytical focus when exploring what is involved in these activities.

The recognition of a gap, in terms of *conceptual contrasts*, has previously informed approaches to teaching photosynthesis (Roth & Anderson, 1987), as well as matter and molecules (Berkheimer, Anderson, Lee & Blakeslee, 1988). In the introductory part of this thesis, an approach that operationalises the recognition of the supposed gap, in terms of *social languages*, was introduced: the notion of learning demand (Leach & Scott, 1995, 2002). In summary, the notion of learning demand pays attention to the differences between the social language of school science and the everyday social language that students bring to school. These differences give rise to an intellectual challenge that students face when trying to make sense of this particular science topic. Generally speaking, the learning demand is made up of differences in the conceptual tools used, and these differences, in turn, relate to epistemological and ontological assumptions.

In addition to the above mentioned issues, the notion of learning demand theoretically rest primarily on the idea of social language (Bakhtin, 1981). Here, a social language is understood as "a specific point of view of the world, forms for conceptualising the worlds in words, specific worldviews" (p. 291-292), and as characteristic discourses within a specific part of society, for example, a profession (Holqvist, 1981, p. 430). When the notion of learning demand is used as a design tool, it is, according to Mortimer and Scott (2003), possible to identify the learning demand for a group of learners because the students will arrive at school sharing a common social language. This relies on the assumption that students have shared many of the day-to day-experiences that form the ways the everyday language conveys meaning of phenomena.

The differences between the two types of language are discernable when it comes to how the conceptual tools are interpreted, for example, *energy* could be 'used up' expressed in everyday language, while energy is 'conserved' or 'transformed' in school science language. Many of the concepts taught in schools have been investigated from the perspective of 'students' alternative ideas'. The previously mentioned bibliography, *Students' and Teachers' Conceptions and Science Education* (Duit, 2009), is a good starting point when searching for typical student views of scientific topics.

In order to exemplify learning demand, I have taken two examples from the research conducted at the University of Leeds, both from learning physics. The first, about air pressure, is fairly short and only hints at what could be the differences between everyday and scientific accounts in the three aspects: conceptual, epistemological, and ontological.

> Learning an air pressure explanation for a 'simple' phenomenon such as drinking through a straw often creates problems for learners. Here the learning demand might involve:
>
> • using different concepts from those used in everydayexplanations ('air pressure' rather than 'sucking');
>
> • explaining in terms of a different ontology (treating air as something that can exert a large pressure, rather than treating it as 'nothing');
>
> •recognising that key epistemological features of scientific explanations include generalisability and empirical consistency (Leach & Scott, 2003, p. 102)

The next example concerns the planning of a teaching intervention about simple electric circuits (reported in Scott, Leach, Hind & Lewis, 2006 and Ametller, Leach & Scott, 2007), which makes use of two *design tools*: learning demand and communicative approach (Mortimer & Scott, 2003). When identifying the learning demand, the first step is to identify the school science knowledge to be taught. This step seems to be fairly unproblematic for teachers in the UK, since what to do in school year 7 is more or less explicitly stated in *Science: A Scheme of Work for Key Stage 3 (Unit 7J: Electrical circuits)*, which is available online. Scott *el al.* summarise this scheme in three points:

> - the current in a series circuit depends on the number of cells and the number of and nature of other components
>
> - current is not 'used up' by components
>
> - energy is transferred from batteries and other sources to other components in electrical circuits (p. 66)

As a comparison, the Swedish syllabuses state as goals to attain for compulsory school at school year 9, in connection with the area of electricity: "have a knowledge of the principles of electric circuits and be familiar with concepts such as electric current, voltage, electrical energy and its effects, as well as about different ways of generating electricity" (National Agency of Education, 2000, p. 50). Starting out with this, Swedish teachers have the responsibility and freedom to choose teaching methods, defining concepts, and in addition chose when to teach the topic (between school year 6 and 9).

The next step, when identifying the learning demand, is to review the literature on students' reasoning about simple electric circuits. Here, Scott *et al.* (2006) refer to two articles about conceptual issues, for example, students' tendency to reason about electricity in terms of source-consumer and the current differing along the circuit. The authors do not exemplify any ontological issues, but find two epistemological issues. The first is about the difficulty students have shown in combining the 'theoretical world' of models and the 'real world' of observation and measurements. The second epistemological issue is that students have difficulties applying scientific models generally and in a wide range of contexts.

With this, the authors have identified the learning demand as a gap; more or less a comparison of the earlier steps and results in five conceptual issues and one epistemological issue on which to focus. These issues that teaching needs to explicitly address are called *design briefs* and the teaching activities that should address those design briefs are called *worked examples* (Ametller *et al.* 2007). In the worked examples, there is one major 'innovation', an activity called 'the Big Circuit', which includes a bulb and a lamp, but the circuit goes all around the laboratory. The students are asked to predict what will happen when the circuit is completed; mostly, the students expect a delay in the bulb lighting up. The activity addresses the battery as a source and what actually happens in a circuit, for example, there is no delay when the circuit is completed, and the bulb immediately starts to shine.

## Making sense of biological evolution

In this section, the three constituents (conceptual, epistemological, and ontological) of the learning demand will be discussed. The text is based on the presentation in the introduction to this thesis (see "students' sense-making of biological evolution").

### Conceptual aspects of making sense of biological evolution

The most central conceptual aspects, in relation to this thesis, that were discussed previously are *variation, heredity,* and *selection*. If these are to be articulated as a thematic pattern in scientific language, the following quote from Stearns and Hoekstra (2000) is a relevant (although dense) explanation of adaptive evolution: "individuals must vary in reproductive success; some variation in the trait must be heritable; the trait must be correlated with reproductive success" (p. 9).

In biology as science, all terms can be contextualised on several biological organisation levels, for example: atom, molecule, cell, tissue, organ, organ system, individual organism, population, community, ecosystem and biosphere (BSCS, 1993; Zetterqvist, 2003). These organisation levels also have implications for teaching. Referring to genetics in school science, Knippels (2002) suggests that the levels of molecule, cell, organism, and population are more important than others, and that in teaching biological evolution, the levels of molecule (gene), organism, and population are essential. If selection is understood as variable reproductive success (fitness), it includes and presupposes both variation and heredity. Thus selection becomes the 'goal' term, and the next section starts by defining the other two, especially in relation to the levels of organisation.

In this thesis, variation is understood, if nothing else is stated, as variation within a population. This means that variation could be seen as variation between individuals, and if every individual is viewed as genetically unique, it means that we can regard populations as groups of unique and varied individuals. This *population focus* (variation within a population) is in contrast to a *typological focus* where a group is defined as an 'average individual'. When the typological group changes, the change is gradual, in every member of the group (Greene, 1990) and this view is not the scientific view. A typological focus is close to *essentialism,* an idea from Plato about 'true essence', which is unfolded in a species, inherent to a causal power; this way of reasoning does not recognise any variation (Mayr, 2004).

There are both environmental and genetic reasons for the origin of variation, but when explaining change over time (evolution), the genetic hereditary part of variation is brought into focus. The ultimate origin of variation is mutation, but whether mutation is a random process or not is a matter of discussion. Indeed, there are different mutation rates, for example, depending on environmental conditions or when different parts of the genome show different mutation rates. However, in this case randomness refers to the fact that the mutations as such do not have any purpose; their effect can only be judged afterwards and the effect depends on relations to the environment that the mutations interact with.Heredity is a process connected to maintenance of similarity and dissimilarity between generations; in other words, offspring resemble their parents but are not entirely identical. This interpretation of heredity applies mainly to sexual reproduction where the parental generation each contributes half the genome. The amount of genetic difference originates from mutations and then recombination and cross-over reinforce the effect. The possibility of similarity increases if the rate of the three processes, mutation, recombination, and, cross-over, is low. These processes shape the organism's genotype, while the phenotype (genotype and environmental influences) are the expressed variation. The process of selection works on the phenotypic variation, but one of the requirements for adaptive selection is that at least some of the variation is connected to the genotype.

An important point in school science is that heredity could be understood either as a passive or as an active phenomenon (Martins & Ogborn, 1997; Venville & Treagust, 1998). The transport of genetic information (meiosis and fertilisation) is, in the scientific sense, a rather passive passage of genetic information (DNA in chromosomes). The processes that shape similarity are passive in the sense that the genetic information is unchanged, and the active process would then be the shaping of dissimilarity of which mutations are the core part. In connection to teaching and learning, similarity and dissimilarity was the starting point in Knippels' (2002) teaching strategy: the yoyo strategy, where references to different organisation levels were made explicit throughout the teaching. Furthermore, Banet and Ayuso (2003) emphasise that explaining "intraspecific diversity (mutations and sexual reproduction) helps students understand some of the causes of the evolutionary mechanisms of species" (p. 399).

Natural selection has been the core notion in evolutionary biology ever since Darwin's book *On the origin of species by means of natural selection* from 1859, and it still is; however, natural (adaptive) selection has been divided into several sub categories, for example, sexual selection and kin-selection. Selection is a process of sorting and elimination: those individuals who are less adapted (in a broad sense) to the current environment do not (survive and) reproduce, and those who are better adapted do (survive and) reproduce. The important words are *less* and *better* (not least and best), in relation to others in the population and in a specific environment (Mayr, 2004).

In an attempt to summarise the parts that compose the (Darwinian) theory of evolution, Ferrari and Chi (1998) describe five principles or components: *individual variation, heredity, differential survival, differential reproduction, and accumulation of changes*. It is mainly the three latter components that together frame the notion of selection; however, taken separately, they could point to a different understanding. The component of differential survival is merely a step towards the most crucial component, which is differential reproduction; but survival is almost impossible to ignore when discussing evolution. Survival has come to be connected to evolution partly with the introduction of the notion of *fitness*. Apart from colloquial interpretations of the term fitness, for example, in relation to physical training, in science settings it could be interpreted as *survival of the fittest* (best fit) or, more appropriately, *survival of the fitter.* In order to avoid problems with the understanding of fitness, it should be clarified that fitness deals with reproductive success and is estimated first when the offspring themselves have reproduced. However, the expression is often changed to survival of *the strongest*. In biology, as a science, the notion of fitness is used in population genetics, as a mathematical measurement, and the words refer best/better to absolute and relative fitness, respectively. Close to the notion of fitness is the component of *accumulation*, which can be seen as the result of repeated selection, and accumulation points to a definition of evolution as the *cumulative change in gene frequencies and the characteristics of organisms or populations over time.*

Thus, when discussing evolution each of the three terms variation, heredity, and selection can be explained on, at least, three organisation levels: molecule, organism, and population, which is summarised below:

- Mutations in the DNA molecule are the ultimate origin of variation, and this is a random process. Individual organisms are, in a genetic sense, unique and populations have different degrees of variation. Recombination and crossovers in the process of cell division can enhance variation.
- Heredity is a process involved in maintenance of similarity and dissimilarity, which are strongly connected to the origin and maintenance of variation. Thus, heredity can refer to the organisation level of molecule (DNA), organism (the genotype), and population (accumulation of traits/genes).
- Selection is a consequence of the (hereditary) variation and its encounters with the environment. The notion of selection is foremost understood as sorting, selecting, and eliminating genes (carried by individual organisms) and with focus on differential reproductive rates among individual members of a population. The result of selection is observable on the organisation level of populations, where some genotypes become more or less frequent.

## Epistemological aspects of making sense of biological evolution

Epistemology is understood here both in its general philosophical sense, as the nature, origin, and limits of human knowledge, as defined by Encyclopaedia Britannica, and in a specific sense in relation to science and science education: ”Epistemology examines the ways in which knowledge claims in science are developed and justified, e.g. assessing the quality of data, examining the relationship between phenomena and theory” (Ryder, 2002, p. 639). However, epistemological issues are also situated in the sense that knowledge claims depend on the context, and the notion of *epistemic practices* is introduced by Kelly (2008): “Thus, I define epistemic practices as the specific ways members of a community propose, justify, evaluate, and legitimize knowledge claims within a disciplinary framework” (p. 99). Furthermore, epistemological issues are also close to many aspects that could be included in the nature of science, for example, ‘scientific method’ and the role of argumentation in order to make your claims trustworthy. In conjunction with argumentation, a learning demand can arise from different epistemological belifs, such as *realist, absolutist,* and *evaluativist* (see Table 1, Kuhn, Cheney & Weinstock, 2000).

**Table 1.** Levels of epistemological understanding

| Level | Assertions | Reality | Knowledge | Critical thinking |
|---|---|---|---|---|
| Realist | Assertions are COPIES of an external reality | Reality is directly knowable | Knowledge comes from an external source and is certain | Critical thinking is unnecessary |
| Absolutist | Assertions are FACTS that are correct or incorrect in their representation of reality (possibility of false belief) | Reality is directly knowable | Knowledge comes from an external source and is certain | Critical thinking is a vehicle for comparing assertions to reality and determining their truth or falsehood |
| Multiplist | Assertions are OPINIONS freely chosen by and accountable only to their owners | Reality is not directly knowable | Knowledge is generated by human minds and is uncertain | Critical thinking is irrelevant |
| Evaluativist | Assertions are JUDGMENTS that can be evaluated and compared according to criteria of argument and evidence | Reality is not directly knowable. | Knowledge is generated by human minds and is uncertain | Critical thinking is valued as a vehicle that promotes sound assertions and enhances understanding |

From Kuhn, Cheney & Weinstock (2000, p. 311)

When the students' reasoning is analysed in paper II (*Arguing biological evolution*), some of these levels are prominent, for example, knowledge claims referring to authorities (absolutist) or human negotiation (evaluativist), as well as assertion as facts, opinions or judgements.

Epistemological issues connected to teaching and learning biology in general and evolution in particular, are often depicted as different framings and choices of explanation. Some of these can be traced to the philosophies of Plato and Aristotle (Ariew, 2003). For example, *essentialism* is an idea from Plato where the 'true' essence of species is unfolded like a hidden causal power (Zogza, 2009). Explanations that draw on purpose or intentions are *teleological* and Keleman (1999) depicts this as a tendency to assume that objects exist for a purpose or function: "When seeing an unfamiliar artefact or strange anatomical part of an animal, the first question an adult will usually ask is 'what is that for?' – a query that assumes that the object can be teleologically explained in terms of its function" (p. 461). Perhaps this is a result of living in a technically immersed world where human-made artefacts have function, they are designed, for example, "a washing-machine is for cleaning clothes". Nevertheless, adults mainly attribute teleological explanations only to living things while children, up to the age of eight/nine years old, are, according to Keleman, 'promiscuously' teleological in the sense that they attribute purpose also to non-living things, for example ”clouds are for raining" and ”stones for throwing". Teleological reasoning is clearly part of everyday language, according to Keleman and DiYianni (2005), mainly because we live in an environment where artefacts have a purpose; they are designed to be used. Everyday language is closely connected to everyday experiences and this makes teleological formulations understandable: "A teleological explanation tends to make us feel that we really understand the phenomena in question, because it is accounted for in terms of purposes, with which we are familiar from our own experience of purposive behaviour" (Hempel & Oppenheim, 1948, p. 145).

The purpose or intention that is inherent in teleological reasoning is, according to Plato, due to external supernatural forces, a creator ('Demiurge'), and actions are for the best in a general sense; while Aristotle argued an internal force where actions are useful for the individual (Ariew, 2003). Despite the ambiguity of teleological expressions there seems no way of escaping them; reasoning in teleological terms is, for example, commonly used in the *Origin of Species* by Charles Darwin (Pramling, 2008). Teleological formulations are an integral part of our language, and Zohar and Ginossar (1998) suggest that the instruction in school puts teleological expressions on the table and discuss expressions like 'need' in the context of biology. This "will allow us 'to eat the cake and have it', in the sense that our students will be able to enjoy the positive heuristic value of anthropomorphic-teleological formulations, without having to scarify any of the soundness of their scientific understanding" (p. 695).

The type of explanation favoured in science is the causal explanation; a cause explains an effect. Teleological explanations reverse cause and effect; an effect (webbed feet) explains the cause (ability to swim): "birds living in water have webbed feet in order to be able to swim". There are two types of causality in the science of biology, according to Mayr (1961), proximate and ultimate, or as Ariew (2003) rephrased it, proximate and evolutionary explanations. Answers to questions that start with 'what is the cause' deal with either short-term (proximate) or long-term (evolutionary or ultimate) perspectives. Responses with short time scales are due to immediate previous events and they are appropriate in medicine and physiology, which are also called functional sciences since the aim is to explain function, for example, how insulin operates in the human body. On the other hand, evolutionary (ultimate) explanations involve longer time, always several generations, and selection.

The occurrence of two types of causation in biology makes Mayr (2004) conclude that biology consists of two different fields: *mechanistic/functional* and *historical* biology (p. 24). For example, physiology and medicine, which share experimentation as the principal method, belong to the mechanistic/functional field. They are similar to other natural sciences since they can be explained mechanistically by means of chemistry or physics, for example, diffusion in cells or phototropism in plants. On the other hand, Mayr views evolutionary biology as mainly a historical branch of biology. Here, experimentation is not always possible and instead Mayr suggests that historical narratives (tentative scenarios) become a method. Following this division of biology as science, Mayr finds that functional biology often poses the question 'how', while in evolutionary biology, 'why' is more often asked. This is in line with Ariew (2003) who suggests that answers to questions about 'how' should refer to proximate causes, while in the case of 'why-questions', evolutionary explanations are more fruitful. These 'why' questions are ambiguous (Mayr, 1988) in that they could mean 'how come' but also the more finalistic 'what for'. This is not an issue of either/or argued Abrams, Southerland and Cummins (2001), and they developed the idea that there are both proximate and ultimate answers to 'how and why' questions.

The main pedagogical point in connection with the proximate/ultimate/how/why discussion above is that students often do not distinguish them from each other (Abrams *et al.* 2001), and then the students give answers in a context that the teacher did not expect or the students confuse the contexts. This is especially confusing when talking about the notion of *adaptation*, where an evolutionary biologist would refer to both proximate and ultimate causation when answering 'why questions'. Abrams *et al.* conclude that if teaching stresses why questions "one can understand how other personally and academically familiar, non-mechanistic, goal-driven, why explanations might prevail" (p. 1279).

**Ontological aspects when making sense of biological evolution**

Ontology is understood here as the nature of reality in general and especially how the natural world is constituted. A learning demand can arise from different ontological categories, for example, whether an entity is matter (things) or process (events) (Slotta & Chi, 2006). Another example is given by Chi (2005) in the category of processes: "some processes (such as the apparent flow in diffusion of dye in water) are emergent and other processes (such as the flow of blood in human circulation) are direct" (p. 161). An ontological issue in the area of biological evolution, according to Ferrari and Chi (1998), is that when it comes to processes students perceive them as either event or equilibration processes (see Table 2 below from p. 1236). Evolutionary processes, such as natural selection are best explained as a (dynamic) equilibrium process.

**Table 2.** Distinction between event and equilibrium processes (adapted from Ferrari & Chi, 1998)

| *Event* | | *Equilibrium* |
|---|---|---|
| Distinct actions | vs | Uniform actions |
| Bounded (begins and ends) | vs | Unbounded (ongoing) |
| Sequential | vs | Simultaneous |
| Contingent and causal | vs | Independent and random |
| Goal-directed | vs | Net effect |
| Terminates | vs | Continuous |

It is probably in relation to religious beliefs that ontological issues are most frequently discussed, especially in the United States. For example, when gallup.com (February, 2009) asked the question: "Do you personally believe in the theory of evolution, do you not believe in evolution, or don't you have an opinion either way?" the answers were: Believe in evolution: 39%; Do not believe in evolution: 25%; No opinion either way: 36%. Acceptance of the theory increases with the amount of education the respondents have, but when Bishop and Anderson (1990) surveyed undergraduates, 41% of the students were unsure or did not believe the theory of evolution as truthful.

The situation in U.S. has not changed much since 1990, and Anderson (2007) concludes that a substantial majority of the students believe in God and are sceptical of the theory of evolution. However, believing and accepting are two different things and Smith, Siegel and McInerney's (1995) recommendation for teaching evolution is to be clear about the fact that scientists accept theories - they do not believe, "it is therefore imperative in both teaching and research to use terms accept and reject, belief and disbelief with special care" (p. 33). Smith, Siegel and McInerney also recommend that teaching should not try to change students' beliefs, and in fact, students do not abandon their religious beliefs as a result of being taught evolution (Bishop & Anderson, 1990). There are studies that show little correlation between understanding of evolution and religious belief (Brem, Ranney & Schindel, 2003) as well as studies that show sound understanding without acceptance (Dagher & BouJaoude, 1997). Furthermore, Meadows, Doster and Jackson (2000) has shown that explicit discussion of different views enhanced students' understanding, despite students' religious or non-religious beliefs.

There are four main approaches, according to Barbour (2000), to meet the issue of the relation between science and religion: conflict, independence, dialogue, and integration:

- conflict; the two are held apart and placed in opposition

- independence; the two are different projects when it comes to language and epistemology. They are not in conflict, they are compartmentalised. Science deals with 'how questions' and religion deals with 'why questions'.

- dialogue; the two are respected as different fields but both could gain from a discussion of the foundations of the two.

- integration; a kind of partnership that perhaps causes your religious beliefs be reformulated or even to use Nature when searching for the existence of God.

Most science educators agree with the 'independence' approach, for example, Smith and Siegel (2004): "we maintain that an appropriate goal is for the student to recognize the scientific status of the theory in question, i.e. *believe (in the non-religious sense) that the theory affords the best current scientific* *account of the relevant phenomena based on the available empirical evidence*" (p. 565, italics in original). Others, like Meadows, Doster and Jackson (2000) and Reiss (2009), argue that "teaching about aspects of religion in science classes could potentially help students better understand the strengths and limitations of the ways in which science is undertaken, the nature of truth claims in science, and the importance of social contexts for science" (p. 793). However, religion is only one of the components that form our *worldview*, and the next section will broaden the perspective.

A worldview is composed of cultural factors and fundamental ideas that are taken for granted; "the non-rational foundation for thought, emotion, and behaviour" (Cobern, 1996, p. 584). These cultural factors and fundamental ideas are, for example, gender, religion, ethnicity, and ideology but could also include ideas about science, especially if we consider scientific literacy; the ideas build a framework within which we make decisions. In the science community there is a tendency, according to Gauch (2009), to depict science as independent of worldview, for example, that the used methods are objective and no presuppositions exists in science. This claim is rejected by Irzik and Nola (2009) when arguing that science aims to explain the world, assuming that the world is possible to explain with scientific methods. Scientist often shares presuppositions of causality and Cobern (2000) cites a story (from Collingwood) about this:

> (I)f you were talking to a pathologist about a certain disease and asked him 'what is the cause of the event E which you say sometimes happens in this disease?' he will reply 'The cause of E is C'; and if he were in a communicative mood he might go on to say 'that was established by So-and-so, in a piece of research that is now regarded as classical.' You might go on and ask: 'I suppose before so-and-so found out what the cause of E was, he was quite sure it had a cause?' the answer would be 'Quite sure, of course. 'If you say, 'Why?' he will probably answer 'Because everything that happens has a cause.' If you are importunate enough to ask 'But how do you know that everything that happens has a cause?' he will probably blow up in your face, because you have put your finger on one of his absolute presuppositions … But if he keeps his temper and gives you a civil and candid answer, it will be the following effect. 'That is a thing we take for granted in my job. We don't question it.' (p. 235)

The point of quoting this story is that I suggest that within a group in society, for example, a profession, members share more or less the same worldview. The pathologist and scientist in the story above whose epistemology, what he holds for true, is grounded in a chain of empirical evidence – but in the end it points to a kind of belief. These, often tacit assumptions form part of the social language of the group and frame the sense-making within that specific group. "Everyone has a worldview that includes their sense of what constitutes reality and how one comes to know something" (Anderson, 2007, p. 670) – these worldviews are the epistemological and ontological framing of our ways of making meaning of the world.

The formulations in the Swedish curricula indicate that science rests on specific worldviews, for example, that the world *is* understandable and principally explainable: "Science uses specific assumptions to make nature understandable. The world view this creates differs from those that are obtained through means other than describing nature" (National Agency of Education, 2000, p. 39-40). This has pedagogical implications, for example, the students' willingness to engage in school science may be due to their acceptance of this worldview. This issue will be further developed in ”Discussion and implications”.

## Design-based research

The purpose of this chapter is to give a general picture of the design-based research approach, mainly because the data in this thesis were generated in line with this approach. Another reason for focusing on this research approach is that it is a strategy that aims to bridge a supposed gap between research in science education and practice (The Design-Based Research Collective 2003; Hiebert, Gallimore & Stigler, 2002; Ziechner & Noffke, 2001).

### American approaches to design-based research

In the US, design-based research is discussed in thematic issues of Educational Researcher (Kelly, 2003), the Journal of the Learning Sciences (Barab & Squire, 2004), and Educational Psychologist (Sandoval & Bell, 2004). All three of these special issues, in their introductory papers, trace the origin of design-based research to Allan Collins and Ann Brown. Collins (1992), at the time, advocated a change in educational research more towards 'technical design research'. He also emphasised the role of the teachers as "co-inventors helping to formulate the questions to be addressed and the designs to be tested, making refinements in the design as the experiment progresses, evaluating the effects of the different aspects of the experiment, and reporting the results of the experiment to other teachers and researchers" (p. 17). Brown, (1992) focused on the idea of changing the research environment and methodology in educational research, from laboratory classes to the messy world of authentic classrooms.

Design-based research includes some kind of intervention or experiment and one of the methodological problems inherent in intervention studies is that the respondents, due to the intervention, may perform differently. Specifically, in teaching interventions the students often get ‘better’ results in some sense. This is often explained as the *Hawthorne effect*, which refers to an experiment conducted by psychologists at the Hawthorne plant of Western Electrics, Chicago, in the 1920s. The anecdote from the experiment is that whatever changes the psychologists made, for example, increased or dimmed lighting, the employees’ productivity rose. Brown re-examined the data and found that, on the one hand, not all manipulations did result in improvements in production and, on the other, when they led to improvements, three conditions were met: the workers perceived that there were real improvements in the conditions, the workers perceived that the changes were in their interest and the workers perceived that they were in control of their own conditions. Taking these three conditions into account, Brown reversed the problem with the Hawthorne effect – to a desired effect; she wanted the students to understand that the improvements are in their own interest and that students take charge of their own learning.

Design-based research advocates a different research methodology compared to laboratory studies of learning and Collins (1999) concludes that his and Brown’s methodological development concerns seven areas. These areas are summarised by Barab and Squire (2004), quoted in Table 3:

> … designs-based research focuses on understanding the messiness of real-world practice, with context being a core part of the story and not an extraneous variable to be trivialized. Further, design-based research involves flexible design revisions, multiple dependent variables, and capturing social interaction. In addition, participants are not ‘subjects’ assigned to treatments but instead are treated as co-participants in both the design and even the analysis. Last, given the focus on characterizing situations (as opposed to controlling variables), the focus of design-based research may be on developing a profile or theory that characterizes the design in practice (as opposed to simply testing hypotheses) (p. 3-4)

**Table 3**. Comparing Psychological Experimentation and Design-Based Research Methods (adapted from Collins, 1999)

| Category | Psychological Experimentation | Design-Based Research |
|---|---|---|
| Location of research | Conducted in laboratory settings | Occurs in the buzzing, blooming confusion of real-life settings where most learning actually occurs |
| Complexity of variables | Frequently involves a single or a couple of dependent variables | Involves multiple dependent variables, including climate variables (e.g., collaboration among learners, available resources), outcome variables (e.g., learning of content, transfer), and system variables (e.g., dissemination, sustainability) |
| Focus of research | Focuses on identifying a few variables and holding them constant | Focuses on characterizing the situation in all its complexity, much of which is not now a priori |
| Unfolding of procedures | Uses fixed procedures | Involves flexible design revision in which there is a tentative initial set that are revised depending on their success in practice |
| Amount of social interaction | Isolates learners to control interaction | Frequently involves complex social interactions with participants sharing ideas, distracting each other, and so on |
| Characterizing the findings | Focuses on testing hypothesis | Involves looking at multiple aspects of the design and developing a profile that characterizes the design in practice |
| Role of participants | Treats participants as subjects | Involves different participants in the design so as to bring their differing expertise into producing and analyzing the design |

A similar research methodology guides The Design-Based Research Collective (2003) when they propose that good design-based research should follow five characteristics:

> First, the central goals of designing learning environments and developing theories or 'prototheories' of learning are intertwined. Second, development and research take place through continuous cycles of design, enactment, analysis, and redesign /…/. Third, research on designs must lead to sharable theories that help communicate relevant implications to practitioners and other educational designers /…/. Fourth, research must account for how designs function in authentic settings. It must not only document success or failure but also focus on interactions that refine our understanding of the learning issues involved. Fifth, the development of such accounts relies on methods that can document and connect processes of enactment to outcomes of interest (p. 5).

**European approaches to design-based research**

The design-based research approach has also been presented in a thematic issue of the International Journal of Science Education (Méheut & Psillos, 2004), where European research is presented, mainly under the label of *Teaching Learning Sequences* (TLS). Below, I have listed six, mainly European, research groups that work with developing teaching-learning sequences or designs-based research.

1) *Development research* (Linjse, 1995) has its origins in the Netherlands, especially at the University of Utrecht. The approach involves testing research-based learning and teaching strategies in practice. This is done in the form of scenarios, which are content-specific and detailed descriptions of the expected teaching and learning process (Knippels, 2002). The theoretical outcomes are *didactical structures*, for example, 'problem-posing approach' (Kortland, 2001) where the focus is on students' motivation or the previously mentioned 'yo-yo strategy' (Knippels, 2002) where biological organisation levels are focused.

2) *Educational reconstruction* (Kattmann, Duit & Gropengießer, 1998) has its origins in Germany, especially at the Liebnitz Institute for Science and Mathematics Education (IPN) in Kiel. The approach is based on interplay between a clarification of the science subject matter and an investigation of students' perspectives. The first step includes a literature review and student interviews and the second step of tryouts in classroom. The outcome is a *content structure* for specific science topics, for example, 'non-linear systems' (Komorek & Duit, 2004), such as chaos or fractal structures in physics education or 'cell division' (Riemeier & Gropengießer, 2008) in biology education.

3) *Ingeniere Didactique* (Tiberghien, 2000) has its origins in France and is especially associated with researchers from Paris and Lyon. The root of the approach is a metaphor that draws on the resemblance of the activity of an engineer and a developer of teaching-learning sequences. The approach often includes *didactical transposition* (Chevallard, 1989), which is a description of the steps that are included when science knowledge is transferred to school science settings (cf. the introductory part of this thesis). For example, Tiberghien (2000) builds up teaching sequences about electricity around simplified versions, labelled 'seeds', of science models and theories.

4) *Evidence-informed interventions* (Scott, Leach, Hind & Lewis, 2006) have their origins in the UK, especially at the University of Leeds. The approach is often labelled as teaching-learning sequences and it makes use of two design

tools, *learning demand* (Leach & Scott, 1995, 2002) and *communicative approach* (Mortimer & Scott, 2003). Possible outcomes are 'design briefs' (principles) and 'worked examples' (suggestions for activities) (cf. Ametller, Leach & Scott, 2007). This 'Leeds approach' is more thoroughly discussed in other parts of this thesis.

5) *Learning studies* (Lo, Marton, Pang & Pong, 2004) has its origins in Sweden and Hong Kong, especially researchers in Gothenburg, Kristianstad and Hong Kong. Learning study is related to lesson study (Stigler & Hiebert, 1999) but informed by theory. Most frequently, this theory is the variation theory (Marton, Runesson & Tsui, 2004). The school content focused on is specific and delimited, for example, 'telling time', 'tj sound', and 'have/has' (Holmqvist, Gustavsson & Wernberg, 2007), and 'decimal numbers' (Kullberg, 2007). Apart from the research application, learning studies have a strong position in in-service teacher training.

6) *Design and validation of topic-oriented teaching-learning sequences* (Andersson, Bach, Hagman, Olander & Wallin, 2005), has its origins in Sweden, especially the University of Gothenburg, where teachers and researchers collaborate in continuous cycles of design, teaching, evaluation, and redesign. Possible outcomes are 'guides for further knowledge building', for example, about teaching and learning geometrical optics (Andersson & Bach, 2005). Another outcome is 'content-oriented theories', for example, about teaching and learning biological evolution (Andersson & Wallin, 2006). The research conducted in this thesis generates data from projects guided by this approach.

In spite of the differences between the approaches, Lindwall (2008) concludes that the American approaches share two commonalities. They aim at doing real work in practical educational settings and the working process includes separable parts of ”design, enactment, analysis and redesign” (p. 26). Sandoval and Bell (2004) summarise the design-based approach claiming that "it is theoretically framed empirical research of learning and teaching based on particular designs for instruction" (p. 199-200). These statements from Lindwall (2008) and Sandoval and Bell (2004) are valid for the European approaches as well, perhaps with a stronger focus on the relationship between students and scientific perspectives (Méheut & Psillos, 2004). European and American researchers are brought together in the book *Educational Design Research* and van den Akker, Gravemeijer, McKenney and Nieveen (2006) conclude that design research may be characterised as:

- Interventionist: the research aims at designing an intervention in the real world;
- Iterative: the research incorporates a cyclic approach of design, evaluation and revision;
- Process-oriented: a black box model of input-output measurement is avoided, the focus is on understanding and improving interventions;
- Utility-oriented: the merit of a design is measured, in part, by its practicality for users in real contexts; and
- Theory-oriented: the design is (at least partly) based on theoretical propositions, and field testing of the design contributes to theory building (p. 5).

The outcomes of teaching-learning sequences can result in two directions, according to (Méheut & Psillos, 2004), "results in terms of pragmatic value (feasibility, effectiveness, etc.) and/or results in terms of scientific validity (understanding learning processes, testing learning theories, etc.)" (p. 528). This reflects an aim of both making contributions to the practice of teaching in classrooms and contributing to the development of educational research. The possibility of achieving these both aims increases if the working process includes true collaboration between practitioners and researchers, and the issue of validity and legitimacy in particular are central. The scientific validity and the legitimacy as regards practice would increase if research questions, methodology and results are continuously validated in authentic practice.

Validation of a teaching intervention is most frequently performed, according to Méheut and Psillos (2004), as a validation of learning outcomes in relation to the specific learning objectives. The validations focus on estimations, on the one hand, within interventions (internal validation) or, on the other, on comparisons with other teaching approaches (external validation) (Leach, Scott, Ametller, Hind & Lewis, 2006). Validation of this makes sense and is useful in order to enhance the legitimacy of the research, especially if working together with practicing teachers (Ratcliffe, Bartholomew, Hames, Hind, Leach, Millar & Osborne, 2005). The crucial issue is that however 'good' results you get in such validation, it is only the start; as a teacher and researcher you are pleased that the intervention as a whole made learning gains, but we need to know more, which Andersson and Bach (1996) express as: "There is, however, one question that the improved design does not answer. Which aspects of the teaching were particularly important, and which were less important, with reference to achieving the observed result?" (p. 18).

# 3. Empirical context

This chapter presents the context in which the data were generated; the schools, students and teachers but also the activities where the data were generated and the relations of these activities to the rest of the enacted teaching intervention. However, since the Swedish school system has specific features, this chapter will commence with a short summary of relevant issues stated in the national steering documents (education act, curricula and syllabuses). These issues are the *hierarchy of responsibility* between national authorities and individual schools/teachers, the ways the documents describe the aim of schooling, and the ways the documents pay attention to two areas important to the content in this thesis: *model/theory* and *biological evolution.* (For a more thorough analysis, see appendix A).

## Settings

Since the national documents do not prescribe detailed directions, only general goals to attain, the local schools and teachers have the privilege and the responsibility to plan their teaching accordingly. That also means that the system relies on the local teachers' coherent interpretation of all documents, for example, the choice of a particular content is only justified by its contribution to the goals in the curricula.

> The curriculum and syllabuses are connected to each other and should be regarded as a whole. Both the curriculum and the syllabuses shall provide the foundation for teaching. The syllabuses are a concrete transformation of the goals in the curriculum. /…/ The structure of the syllabuses reflects the division of responsibility between the state and the professionals in the school. By means of setting up the goals, as well as the results to be expected, the state imposes demands on the quality and equivalence of the education. How the goals are to be attained, namely choice of content and method, is determined by the teacher (National Agency of Education, 2004, p. 16).

Formulations like the ones above are firm motivations for enacting design-based research since there is room for local initiatives, especially when it comes to choice of content and method. Of course, this responsibility also calls for collaboration and mutual agreements in the local schools.

The overall aim of schooling is expressed, in the education act and curricula, as *citizenship*, which is articulated in line with *scientific literacy* in syllabuses for the natural sciences; for example, the role of natural sciences is emphasised as a way of enhancing active participation in daily debate and the role of the natural sciences in cultural tradition and heritage. The recommendations in connection with content emphasise "developing an ability to see patterns and structures" and to "use concepts, models, and theories … to describe and explain the world around". These concepts, models, and theories are to be apprehended as *tools*, for example, "learn to listen, discuss, reason and use their knowledge as a tool"; one of the theories explicitly mentioned is the theory of evolution.

The groups that participated in this research came from two school forms in the Swedish secondary school system; one from upper secondary school (17 years old, grade 11) which is a non-compulsory school form, and the other from lower secondary school (11 – 16 years old, grades 5 to 9), which is compulsory in Sweden. To some extent, the projects together resemble what Brown (1992) labelled α-phase and β-phase when she made an analogy between software development and design experiments. In Brown's vocabulary, the first project in upper secondary school was α-phase as the researchers had rather firm control over the process, since it was a small group of researchers who planned, taught, and evaluated. The β-phase, which was enacted in lower secondary school, invited practicing teachers to participate and they had a significant influence in planning, teaching and evaluation.

In spite of the differences between the projects, it is important to point out two similarities, one in relation to learning and teaching and the other in relation to the research design. Both projects aimed at a learning goal and teaching strategy in line with: *using the theory of evolution as theoretical leverage in students' sense-making process. The teaching strategy aimed to engage the students in numerous situations where they could communicate their understanding of different accounts*. The research design included documentation that could illuminate to what extent the students appropriated the scientific language, for example, pre- and delayed post tests. Furthermore, the research design included video documentation of several activities, both those that were supervised by the teacher and those that took place without the presence of the teacher. The students who participated gave their written consent to participate, and in the case of the youngest students (in compulsory school) also the parents gave a written consent.

**The project in upper secondary, school year 11 (project A)**

The first project was carried out in an upper secondary school and included one teacher and 48 students from two school classes attending the natural science program. The school is situated in a middleclass suburb with some rural features and most statistical figures follow the average of similar communities in the rest of Sweden. The school is a municipal (public) school and the only secondary school in the municipality and offers all the national study programmes and attracts most of the students in the vicinity. Here, the natural science program is chosen by around twenty percent of the students, which is a little above the average in Sweden. The program is the only one with a substantial number of science-related topics and is considered to be a demanding choice. The students were at the time seventeen years old and it was their second year at the school but their first course in biology. The teacher taught both groups in this study, had formal qualifications for teaching biology and extensive experience as a teacher.

The project was the first cycle in a design-based research project and was rather tentative both when it comes to research design and teaching design. A didactic analysis of the syllabuses resulted in a formulation of a learning goal, which was broadly stated as: the students should be able to use the theory of evolution as a tool when explaining evolution of life on earth. Theory as a tool was supposed to imply that the theory should be used as theoretical leverage and scaffold the students when making sense of biological evolution. Besides identifying the learning goal, an identification of the nature of students' everyday articulation of biological evolution was made; this analysis was mainly based on a literature review of science education research. Three issues that many students had difficulties with were identified: the role of variation within populations, selection as differential reproductive rates and that students often use terms like need, wish, or strive as conceptual tools when explaining biological change.

The students were given diagnostic questions about a week before the beginning of the teaching and these questions were also given to the students a year later as a delayed post test. Additionally, some of these questions also became part of students' activities during teaching, for example, the group discussion of a multiple choice question that later became a main research interest in this thesis. This specific group discussion was focused on in papers I and II, and was held during the third lesson of a sequence that was totally eight lessons long (each lasting 90 minutes). The two introductory lessons, mainly orchestrated by the teacher, concerned fundamental genetics, including heredity, cell division, mutation and the idea of a common descent of life on earth. The actual lesson that provides us with data took the form of laboratory work organised around three activities: an examination of fossils, an exploration of the evolution of humans, and a small group discussion about the origin of intra-species variation. Both the format of the practical work and the use of small group discussions were fairly well known to the students.

The students belonged to two school classes, totalling 48 students, and in this laboratory work they were divided by the teacher into 12 groups, which moved from one activity to another in the order that was most convenient. In all, 29 students in 7 groups gave permission to be video-taped, and for the discussion they went into an adjacent room, started a video camera, discussed, turned off the camera and continued with the next activity; the remaining 19 students in 5 groups held their discussion in another room. Discussions lasted between 6 and 19 minutes with an average of about 11 minutes. The students were informed that the teacher would not see the tape until the course had ended and grades had been awarded.

The multiple choice task was used in a pre test, and three weeks later it was the core part of the small group discussion task during the laboratory work. It was introduced by the teacher as follows: ”Discuss task number four from the pre test. Comment on the alternatives one by one and argue for and against. Then, if you can, come to a mutual agreement. We will follow up the discussion in the next whole class lesson”. The formulation of the task to discuss was:

> “Throughout the course of evolution, living organisms have developed a lot of different traits. What is the origin of this enormous variation?
>
> · The traits arose when they where needed
>
> · Random changes in the gene pool of the organisms
>
> · Living organisms strive to develop
>
> · Great variation is needed in order to achieve balance in nature”

The question was ‘seeded’ with frequently occurring student expressions such as need and strive, thus the alternatives in the multiple-choice question were supposed to illustrate common ideas about the origin of variation; in this way, the evidence-based alternatives are a reflection of the initial view of the conceptual aspects of the learning demand. The formulation of the task structure and frame the students’ discussion, the wording presupposes that evolution has taken place and that there is a variation in traits. With these delimitations in mind, the students can focus on defending or refuting the given alternatives as the (best) explanation of the origin of intra-species variation – a dialogic space (Wegerif, 2008) is opened up and students are offered the opportunity to explore their understanding of the topic.

**The project in compulsory school, school year 5 – 9 (project B)**

This project builds on experiences from the previous project but was carried out in compulsory school, indicating that the students are more likely to represent a cross-section of Swedish children. The project was funded by the Swedish research council and labelled "Teachers and researchers as knowledge-builders for better school science". This made it possible to invite practicing teachers to participate and after an invitation letter to schools, four teachers volunteered to participate. The teachers were all qualified to teach biology at this school level; in addition, they represented various levels teaching experience, both genders, and different ages. The schools were situated in different surroundings: one school was situated in the centre of town, two in multicultural suburbs, and one a bit outside town but still within commuting distance. All four teachers taught the sequence twice to different groups during one school year (Figure 2). This means that about 180 students in eight groups, 11 – 16 years old, were involved.

| May/Aug/Sep/Oct | Nov/Dec | January | Feb/March | May/June |
|---|---|---|---|---|
| Design meetings | Teaching 1 | Evaluation 1 / new design | Teaching 2 | Evaluation 2 |

**Figure 2**. Working process during the two cycles

During the first phase, the teachers and the researchers had four meetings and made a didactical analysis (Andersson *et al.* 2005), partly in line with the notion of learning demand, which lead to a formulation of a learning goal and a teaching strategy. This analysis was grounded in educational research literature, steering documents, and our own teaching experience, which all informed our planning of the teaching intervention.

Early on in this period, the teachers gave some written questions about evolution to their own students, who they knew had participated in teaching about evolution. When discussing the students' answers, the teachers were at first dumbfounded, "how on earth could my students write like this". However, soon a rewarding conversation started about reasons for students' reasoning; retrospectively, this is seen as a turning point, from now on the teachers' involvement in and ownership of the process increased and they made increasingly valuable contributions.

Everybody involved in a project like this does not contribute equally throughout the process, a process that can be described as ”design, teaching, evaluation, and redesign"; these phases are interlinked but the contribution of the different actors, the teachers and researchers varies. In the design phase, the researchers were more active at the beginning, for example, in choosing the literature and preparing the diagnostic instrument. The result of the design phase (the intended learning goal and the teaching strategy) was achieved through collaborative work and could be regarded as guidelines for the intended teaching. The teaching was solely the teachers' responsibility, but both teachers and researchers were involved in evaluations and redesign.

As the intended learning goal, we agreed that the students should be able to use a scientific theory as a tool when encountering new situations; in this case, that students should be able to use the theory of evolution by means of natural selection as a tool when explaining the development of life on earth. The rationale for expressing *theory as a tool* was discussed in the introduction to this thesis, meaning that it may have pedagogical implications if an introduced theory is regarded as goal (product) or means in students' sense-making (process). In this project, we made use of theory in both ways. When evaluating the learning outcome, we assessed students' written answers in relation to goals to be attained in the actual syllabuses and the project interpretation of these goals. However, in the actual teaching, we intended to make use of theory as means in the process of sense-making.

One of the mutual conclusions from the literature about students' reasoning about evolution is that students often explain biological change by referring to terms such as *need, wish, and/or effort*. These terms along with terms that are scientifically central (we labelled them key terms), namely *heredity, variation, and selection,* were to be elaborated and made sense of in the teaching intervention. The intended strategy for the teaching was to present the theory of evolution as a scientific story and to engage students in different communicative settings; a sense-making process in relation to the key terms. We made suggestions for activities that should point to the use of the key terms, and, in particular, depict the theory of evolution as a two-part process: firstly, the origin of variation, and secondly, when this variation meets the environment (selection).

# 4. Analytical procedure

This chapter focuses on the steps taken when proceeding from empirical data to analysis of the students' appropriation of the scientific language and the text is organised in two sections, one for each of the two research questions. The analysis of the two questions is associated with different theoretical underpinnings and makes use of different kinds of analytical tools and different kinds of data. The analysis of the first question employs a macro perspective and aims at validating a whole teaching intervention by means of a pre and post test design, which is a kind of 'product evaluation'. The analysis of the second question employs a micro perspective when analysing processes, focusing on spoken language and relations between content-oriented aspects and more generic patterns. However, the aspiration is that the answers to the two questions together will make a contribution to what it takes to make sense of biological evolution in secondary science classrooms.

The first part of this chapter concerns the students' written answers and the analysis is based on relations between learning goals of the teaching and the students' learning outcome. This kind of analysis is (more) thoroughly performed in the second project and is reported in paper III (*Teaching biological evolution …*). Accordingly, the specific examples refer to this paper III and project B.

The second part of this chapter concerns the students' talk, and the basic structuring tool in the analysis is informed by differentiating meaning and sense of terms (Vygotsky, 1968). The first two papers, I and II, (*Making sense of biological evolution…* and *Arguing biological evolution in small group…)* take students' personal sense of the terms as their analytical starting point. Whereas in paper IV (*Students' language use when talking about the evolution of life …)* the starting point in the analysis is the collective meaning of terms.

## Students' writing (first set of research questions)

When validating a teaching intervention, for example, a teaching-learning sequence, the most frequent type is a validation in relation to specific learning objectives (Méheut & Psillos, 2004). Such validation could be either *internal validation*, which is within the intervention, or *external*, meaning comparisons with other teaching approaches (Leach, Scott, Ametller, Hind & Lewis, 2006). An internal validation seeks to establish whether the aims of the specific intervention were met, for example, if the intervention has a specific learning goal, diagnostic questions could be used in a pre- and post test design. The methodological problems when choosing questions could, according to Millar and Hames (2006), partly be solved by using validated questions from previous studies, but keeping in mind that a validation is made in relation to specific student groups, cultures, and social contexts. Estimations with single questions are also problematic and Millar and Hames suggest the use of several questions and estimating consistency among the answers. External validations make use of some kind of control groups, for example, another group at the school where the intervention takes place, perhaps with the same teacher involved. The point is often to resemble the medical 'placebo design', assuming that that the only difference between the control group and experimental group is the specific intervention.

Using this quasi-experimental design is an intriguing temptation, not least to science teachers and educators who often have a background in natural science research or have studied natural science for several years (Juuti & Lavonen, 2006). However, there are several difficulties when it comes to isolating dependent and independent variables, for example, students' motivations, classroom contexts, and gender and ethnicity differences (Andersson & Bach, 2006; Juuti & Lavonen, 2006). Another external validation approach is to use the same questions as in randomised surveys such as TIMSS, PISA, ROSE or national evaluations. The advantages are greater reliability in relation to the questions as such and the fact that the control groups are truly randomised samples. However, there are still differences in the context in which the students answer the questions; for example, motivational aspects such as the influence of grading must be considered.

Most frequently, both internal and external validations make use of diagnostic questions that students answer individually in writing. When developing questions, the aim is often to assess students' ability to use similar reasoning in a variety of contexts. However, since students' answers are dependent on context, the ways that context is changed is important, especially what is kept as invariant and what is allowed to vary. In this study, the species varied, for example, seals and cheetahs, while what was kept invariant was the type of trait, namely a typical and conspicuous trait that is frequently associated with that species. A similar shift in what is variant and invariant is made by Asterhan and Schwarz (2007), who also found that the suggested approach did not alter the validity of the questions.

Validations are often, as mentioned above, performed in relation to set learning goals and in this study, the formulation of learning goals was carried out by means of a didactical analysis of the steering documents, the educational research literature, and the teachers' and researchers' professional experience. In the first project, the learning goal was articulated as: "*the students should be able to use the theory of evolution as a tool when explaining evolution of life on earth*", which was specified and complemented in the second project as: "*after the teaching intervention the students should be able to explain the evolution of life on earth using the meaning of the terms heredity, variation, and selection*". It was in the second project that the most thorough validation of learning outcome was performed and the text from now on refers to project B (some data from the internal validation performed in project A are presented in appendix B).

The diagnostic tests contained several questions, but the three that were similar in both internal and external evaluation are presented here. One of the open-ended questions was formulated like this in the pre test:

> Seals can remain underwater without breathing for nearly 45 minutes as they hunt for fish. How would a biologist explain how the ability to not breathe for long periods of time has evolved, assuming their ancestors could stay underwater for just a couple of minutes? (Settlage, 1994)

The version in the delayed post test (three months after teaching ended) was formulated:

> Cheetahs are able to run fast, around 100 km/h when chasing prey. How would a biologist explain how the ability to run fast evolved in cheetahs, assuming their ancestors could only run 30 km/h? (Bishop & Anderson, 1990)

Students' written answers were grouped in order to reflect qualitatively different ways of reasoning. The system of categories that emerged had students' actual wording in the foreground but was influenced by previous educational research on students' ideas and ways of arguing as well as scientific views of the specific area. The students' answers are categorised as follows, with examples from the 'cheetah answers' in italics.

> a) The answer describes, but does not explain: *They developed and got longer legs, and they became more vigorous.*
>
> b) The answer explains in a teleological way; mainly with words like need, had to, strive: *Cheetahs have to run fast in order to catch their prey.*
>
> c) The answer explains, only using some key terms: A *biologist would explain like this; Mutations in the genes of the cheetah occurred, which made it run faster.*

d) The answer explains in terms of natural selection: *When one cheetah was born it had, for example longer legs, which made it run faster and therefore it got more food, survived longer and then spread its genes.*

e) No answer or irrelevant answer, or repeats the question: *don't know, et*c.

The answers in category a) describe change, either changes in the environment or the anatomical changes an animal might have gone through when evolving the actual trait. Here, it is also a matter of knowing what the acceptable school-scientific vocabulary is, especially the distinction between a description (category a) and an explanation (which is the basis of categories b, c, and d). Teleological or anthropomorphic explanations are placed together in category b), and here the answers focus on purpose (for example, *in order to*). The explanations in category c) and d) rely on the meaning that students make of the key terms heredity, variation, and selection. Explanations in category c) mainly deal with proximate causes and only make use of some of the key terms, often interspersed with some scientific terms (mostly 'genetic words'). It is a mix where students' growing understanding and mimicking of the scientific language is used when formulating answers. Natural selection is the basis of the fourth category (d), but in different steps, from only mentioning differential survival to differential reproduction and further to accumulation of a trait/gene.

The other two questions dealt with the origin of a new hereditary trait and were based on a similar version from Wallin, Hagman and Olander (2001); however, in this study the item was given both as a multiple-choice question and accompanied by a request to justify the choice:

In the future, it is most likely that entirely new hereditary traits will develop among living organisms – traits that never existed before. What is the origin of an entirely new hereditary trait?

Choose the statement that you consider to be the best. Justify your choice.

- The individual's need of the trait
- Random changes in the genes
- The species strive to develop
- In nature, balance is strived for

The alternative most in line with the scientific explanation is "Random changes in the genes". A system of categories was generated in relation to the open-ended task of justification, where two main categories were discerned, one type dealt with descriptions or explanations of *development in general*, and the other was based on *ultimate causes of new traits*. The latter type of answers refers more thoroughly to the heredity part of the task. The first type of answers used terms such as need, wish and/or adaptation, often referring to individual organisms.

When the Swedish National Agency for Education carried out the national evaluation in 2003, a random national sample of students in grade 9 was given written questions. The evaluation was carried out in the latter part of the spring, approximately three months before the end of the students' compulsory schooling. In this thesis, the national sample is regarded as a control group in relation to our experimental group, an approach previously employed by Bach (2001), and here the method is also regarded as an example of external validation. In the Science test, the students in the national sample were given 37 tasks to solve (divided into three sections), and in the Biology section, three tasks dealt with evolution (one open question and one multiple choice question accompanied by a request to justify their choice). These three tasks were also given to the experimental group, but only in the delayed post-test. Consequently, they were unfamiliar to the students and could serve as a comparison with the national sample. However, the students' ambitions to answer are probably lower in the national sample, for example, there are around 50% who 'don't answer' the open-ended tasks involving evolution compared to less than 10% in the experimental group. It should be noted that the 'no answers' are not missing values; the students had the opportunity to answer, but preferred not to write anything, or wrote something irrelevant. With these differences in answering rates in mind, a conversion of the results was carried out in order to obtain a more fair comparison, and not overrate the results of the experimental group.

The percentages presented in the findings are recalculated as proportions of students answering the actual question, and the statistical comparisons between groups are calculated with the $\chi^2$-method, with the level of significance set at $p < 0,01$. The $\chi^2$-method is a way of estimating whether the distribution between groups differs significantly, but gives no indication of the reasons for the varying distribution (Edling & Hedström, 2003). Furthermore, the inter coder reliability was checked, in relation to the open-ended questions about seals and cheetahs, by giving the answers and category headings to two educational scientists who were not part of the project, but were familiar with the content area.

In summary, when exploring the students' written answers and the extent to which the students appropriated scientific ways of reasoning about biological evolution (the first set of research questions), answers to three questions were the basis of an internal validation (pre- and delayed post test) and external validation (comparisons with answers given by a randomised national sample). The students' answers were assessed with a system of categories based on qualitative reasoning, and potential differences between groups were calculated with the $\chi^2$-method. The validity of the questions used was strengthened by their use in previous studies and pilot testing, and the reliability in the analysis of written answers was enhanced by the use of inter coders.

## Students' talk (second set of research questions)

A strategy for empirically exploring what is involved when students make sense of biological evolution would include examination of instances in the classroom where meaning and sense of terms and thematic patterns are negotiated orally. Furthermore, if the ambition is to explore the ways that students bridge the colloquial and scientific languages (Ash, 2008; Varelas *et al.* 2008; Warren *et al.* 2001), we must search for instances in the classroom discourse where colloquial language is used. One set of such instances is peer group discussions, which are an arena for negotiations and argumentation in more informal and colloquial language (Driver, Newton & Osborne, 2000; Southerland, Kittleson, Settlage & Lanier 2005; Jiménez-Aleixandre, 1992).

The analysis of students' talk focuses on two levels: term (Brown & Ryoo, 2008; Wellington & Osborne, 2001) and thematic patterns (Lemke, 1990), which means that there will be successive changes of domain in the analytical focus; from the students' sense-making of single terms to the combination of terms in specific contexts.

As mentioned before, the analysis of students' use of single terms, the distinction of meaning and sense (Vygotsky, 1986) was used as an analytical tool in three papers where students' reasoning is analysed from different starting points: in paper IV, the analysis starts out from the 'meaning side' and in papers I and II, the starting point in the analysis is 'sense'. The data are generated from group discussions, which are regarded as an arena for learning as well as an arena for generating research data. This relies on an assumption that reasoning is a way of using language that makes students' use of meaning and sense accessible to others. Earlier in this thesis, *meaning* was defined as the stable, generalised, collective and lexical zone of a term, which in this analysis is close to the scientific language that the key terms (variation, heredity, and selection) were supposed to be understood as. On the other hand, *sense* is the more situated, personal, local and creative part, depending on the context of the talk, which is how the students negotiate, interpret and contextualise the terms in their talk.

The empirical data involved in the analysis in paper IV are two different activities that students in school year 9 participate in. These activities were designed to elicit the key terms and are thus a reflection of one end of the learning demand, the scientific account of the content to be taught. In the analysis, the collective meaning of three terms that construe the theory of evolution (variation, heredity, and selection) is taken as the point of departure: and the analysis focuses on what local meaning (sense) the students made of them. The identification of the relevant terms was the result of a didactical analysis of the language used in the scientific community, hence the collective meaning.

Early in the analysis of the students' talk, it was obvious that the students seldom explicitly verbalised the key terms, instead they reformulated the terms as a part of a contextualisation; consequently, the analysis focused on this contextualisation. The analysis identified and made tentative use of three discursive strategies the students used when contextualising the terms, strategies that served as conceptual links in the students' talk: paralleling, transferring, and delimiting. The contextualisation is articulated in colloquial language, which, in turn, could lead to other interpretations than originally intended. The next step in the analysis focuses on instances where the students construe explanations, which are when the individual terms are put together by the students in a way that makes sense to them. Here, the analysis focused on the thematic pattern in the explanations and it was possible to identify the use of different social languages, as well as different quality in relation in to the essence of the theory of evolution.

The empirical data that papers I and II are based on is more complex, insofar as both scientific and colloquial accounts are seeded into the activity. Here, the analysis focused on social languages and the three aspects in the constitution of the learning demand for biological evolution when students in an upper secondary school took part in a peer group discussion. The discussion dealt with a multiple choice question, where the alternatives were chosen to elicit both colloquial and scientific accounts of the origin of intra-species variation:

Throughout the course of evolution, living organisms have developed a lot of different traits. What is the origin of this enormous variation?

- The traits arose when they where needed
- Random changes in the gene pool of the organisms
- Living organisms strive to develop
- Great variation is needed in order to achieve balance in nature

One reason for choosing this specific peer group discussion was that the question the students discussed was a product of a didactical analysis of both the scientific and colloquial accounts of the origin of intra-species variation. The insights from this analysis of the learning demand were seeded into a multiple choice question, where the alternatives were supposed to reflect different views of the origin of biological variation. The assumption was that the students' discussion would externalise their articulation of the learning demand. In the activity, the 'initial' version of the learning demand was put into practice, thus turning to a 'dynamic' version of the learning demand, which opens up the research agenda. When analysing students' dynamic exchange of ideas, it was possible to identify students' use of language in terms of distinctive aspects of the three constituents – conceptual *notions*, epistemological *patterns*, and ontological *framing* – in authentic practice

After watching the videotapes, transcriptions of students' discussions were made, which were complemented with comments about important pointing, gestures and pauses. As an initial structuring tool in the analysis elements from Toulmin's argumentation pattern was used (Toulmin, 1958). Toulmin suggests that every argumentation involves specific elements – data, claim, and warrant plus backing and rebuttal – which all are field-independent since they can be found in a variety of topics. When judging trustworthiness, the elements are field-dependant in the sense that evaluation is dependent on the specific subject that is argued about; for example, 'what counts' as data, warrant, rebuttal, etc. are field-dependent (Jiménez-Aleixandre & Erduran, 2008, p. 15).

Transcripts of the discussion in the seven individual groups where first analysed as a whole, meaning that all talk from the groups (ranging between 6 and 19 minutes with an average of 11 minutes) was divided into sequences where different conceptual notions were discussed, regardless of whether they originated in colloquial or scientific language. The three most frequent notions present in the discussions (75% of the time) were need, randomness, and development. The next step in the analysis linked these three notions to three types of social languages; colloquial, school scientific, and inter-language. The theoretical basis of these languages is described elsewhere in this thesis, and our hypothesis was thus that these pre-defined social languages could be empirically discerned and distinguished. An explicit definition was formulated and used as an analytical guide, which was based on a synthesis of literature on colloquial and scientific language (principally Lemke, 1990; Warren *et al.* 2001; Wellington & Osborne, 2001), discourse and interlanguage (principally Ash, 2008; Brown & Spang, 2008; Gomez, 2007), and everyday and scientific concepts (principally Roth, 2008; Vygotsky, 1978; Warren *et al.* 2001).

*Colloquial* language is open, allowing the discussion of most topics as well as different ways of reasoning simultaneously. Arguments can be based on personal experiences and there is room for true recognition of values and emotions. A consequence of this openness is that a large degree of specificity in what is said is not required. The colloquial language is oriented towards oral discussions and is informal in nature.

*Inter*language is characterised by bringing together elements of scientific considerations with personal experiences. It involves translations between languages that open up an arena where talk is more freely constituted, for example, not specifically adhering to the standards of scientific communication.

*School science* language is characterised by restrictions on what is discussed and the ways in which it is discussed. It displays specificity with respect to how terms are used and it is productive when it comes to expressing complex causal relationships. Argumentation is based on models or general ideas rather than personal experiences. The school science language is oriented towards written text and displays a degree of formality, also when used in oral discussions.

Student's utterances (sometimes only one 'sentence' or argument) about need, randomness, and development were linked to the three languages. This kind of analysis can be described as intermediate, between term and thematic pattern; the foundation and starting point is 'term' but the term is contextualised and embedded in an utterance, which may be a (diluted) thematic pattern. On the other hand, these utterances are made in all three languages, and as such they contribute to our understanding of the students' sense-making of the notions. In order to discern how thematic patterns were articulated in different languages, it was necessary to return to the whole data set and specifically look for sequences in the discussions where the use of language fluctuated.

In the students' talk, there were moments when the conceptual notions connected to, and made explicit, the epistemological pattern in which the argumentation was made plausible. Similarly, there were moments of epistemological negotiation that unfolded new rules for the argument, where the discussion hinted about aspects of the ontological framings – such as the domains of where causal and teleological explanations are valid or whether agency matters. In these conceptual, epistemological, and ontological aspects, it was possible to distinguish differences, which consequently were interpreted as encompassing different degrees of scientific quality.

# 5. Findings

**Summary of the papers/manuscripts**

The empirical data that form the basis of the four papers were generated within two design-based research projects. Project A, concerns 17 year old students, and is reported in papers I and II, while papers III and IV concerns project B, which was carried out with students aged 11 – 16. Although the projects involved different school forms, teachers, and age groups of students, they had similar approaches, both to the intended learning outcome and to the teaching strategy that would scaffold students' sense-making process. The fact that students' age varied from 11 to 17 and that they participated in both compulsory and non-compulsory schooling was supposed to be an asset when exploring the conceptual, epistemological, and ontological constituents of the learning demand for biological evolution.

**Paper I**
**Making sense of biological evolution**
**- productive interaction of colloquial and school scientific language**

This paper explores the idea from Lemke (1990) that learning science involves appropriation of the language of school science. Specifically, this means addressing three research questions:

- In what ways do students' sense of conceptual notions related to biological evolution manifest in the discussion?
- In what ways do colloquial, inter- and school science language manifest in the discussion?
- In what ways do conceptual notions and social languages in terconnect and mutually support each other?

The data were generated from a peer group discussion about the origin of intra-species variation, a discussion that was based on a multiple-choice task:

> Throughout the course of evolution, living organisms have developed a lot of different traits. What is the origin of this enormous variation?
>
> - The traits arose when they where needed
> - Random changes in the gene pool of the organisms
> - Living organisms strive to develop
> - Great variation is needed in order to achieve balance in nature

The question as such was based on a didactical analysis of the learning demand for the origin of intra-species variation, where the intended learning goal is best represented by alternative two. On the other hand, the research literature dealing with the language that the students enter school with concludes that students are likely to explain the origin of the variation in terms of need or intentions; these ideas are therefore seeded into the other three alternatives and could be regarded as an initial view of the learning demand.

The analysis principally included three steps:

a) Making quantitative and qualitative descriptions of what notions were important in the students' discussion.

b) Analysis of the meaning and sense (Vygotsky, 1986) of the most frequent notions in the students' discussion and thus dividing the students' talk into sequences that could each be attributed to being described as colloquial, inter-, or school science language.

c) Analysis of the interconnections between different social languages in longer parts of the text, specifically looking for sequences in the discussions where the use of language alternated.

The 29 students in 7 groups who were videotaped during their discussion spent half of their talking time on the notions of need and randomness, one quarter of the time on the notion of development and the remaining quarter on other notions. These three most frequent notions (need, randomness, and development) were articulated by means of three different social languages; colloquial, inter-, and school scientific language.

In colloquial language, students mainly rely on an unspecific interpretation of the notion, often the most generally applicable. Explanations have strong flavours of intentionality; this could be explicitly expressed as, for example, 'planned mutation'. However, reasoning with teleological logic, for example, 'need in order to survive' or 'developed accordingly to environment' is most frequent. Often value words reinforce intentionality, for example, development has a direction, for the better. The intended interpretation of the notions and events is often seen as natural and given a taken-for-granted domain of applicability; thus there is no need to explain events.

Interlanguage makes possible negotiations and delimitations of what the notion is and is not, for example, that randomness is not the only process that explains development of traits. Furthermore, students explicitly argue that the individual's need and striving for development are not necessary when explaining the origin of traits. Technical terms are used, although sometimes in a tentative and mimicking style. When value words such as good/bad/right are used, they are not contextualised with clarifications, for example, what constitutes a good or bad trait in a specific environment.

In school scientific language, students specify the meaning of notions and mainly link examples to general models or theories. This is done in congruence with theories or models, for example, need is seen a result of selection and refers to 'groups', not individuals. Furthermore, the difference (and the importance of that difference) between somatic and sex cells is articulated, and random changes plus environment may lead to selection. Development is seen as a two-step process, starting with an existing variation and followed by selection. Value words are appropriately contextualised, for example, 'better trait' is delimited to mean resistance to penicillin in an environment with penicillin.

In the students' discussion, the use of language alternates between the three social languages. The presence of the colloquial language is not problematic in itself. On the contrary, the conclusion is that during the students' discussion, the scientific quality of the explanations is improved. The differences between the three notions (need, randomness, and development) are discursive delimitations; it is a matter of specifications of the meaning of the three notions. For example, specifications are made step by step in negotiations, and the student groups interpret the notions more and more in line with school scientific language.

All notions are potentially productive, and the more colloquial notions – such as need – are an intellectual resource when explaining the origin of variation. Without delimitations and negotiations of the notion of need, the school scientific explanation would have been less nuanced and accurate. Colloquial expressions such as 'need in order to' trigger refinements in line with scientific language; as one of the students puts it: *not originated because it was needed, but remained when it was needed in that case*.

## Paper II
## Arguing biological evolution in small groups: The constituents of learning demand in pedagogical context

The aim of this paper is to contribute to the description of the learning demand for biological evolution, and its conceptual, epistemological, and ontological constituents. The analysis focused on how students in a particular pedagogical context, small group argumentation, deal with these constituents. Since this paper is based on data from the same setting as the previous paper, this summary will not repeat those issues. In the analysis, the same transcripts as in paper I were used, but the steps in the analysis were different.

In the analysis, the first structuring tool was Toulmin's argumentation pattern, TAP (Toulmin, 1958), where Toulmin argues that all argumentation follows the pattern of referring to data when making a claim. TAP has earlier been used in studies of argumentation in science education mainly because it offers a conceptualisation of important elements in an argument, their relations and how they are linked in patterns of reasoning (Erduran, 2008; Simon, 2008). Since Toulmin's elements have been discussed earlier in this thesis, the following is only a brief repetition: 'warrant' is what justifies the connection between data and claim: *given* (the data) *so* (the claim) *since* (the warrant). Other terms are 'backing', which is used to strengthen the warrant, and 'rebuttal', which refers to circumstances where the claim is valid.

Inspired by previous research on microanalysis of conversation (cf. Ingerman, Linder & Marshall, 2009; Wickman & Östman, 2002), the aim was to explore patterns of reasoning and how they develop; accordingly, sequences of argumentation were the unit of analysis. A typical sequence starts with a warranted claim by one student and continues with a number of warrants, counterclaims, rebuttals, etc. The end of a sequence was defined as the point where some kind of settlement was reached, although temporary, and the discussion briefly halted. In these sequences of argumentation, the analytical focus was on how the constituents of the learning demand of biological evolution (conceptual notions, epistemological patterns, and ontological framings) showed themselves.

The conceptual, epistemological and ontological aspects were layered in the students' discussion but were possible to separate. One conclusion in paper I was that students focused their discussion on three conceptual notions: need, randomness, and development. The meaning of the notions and the context where they should be understood was negotiated, and they were contrasted with their opposites. The students' use of epistemological patterns became discernable when they made claims in relation to conceptual issues. There were three primary dimensions of epistemological patterns made visible in the students' argumentation by:

- referring to resources – 'sources of knowledge' – for example, by naming resources or by linking
- generating explanations – primarily teleological or causal
- linking general accounts and specific examples

In each of these dimensions, the argumentation can be of different quality. In particular, it can have more or less scientific quality (scientific or colloquial nature). Links between the general and specific can be systematic rather than sporadic, explanations can be causal rather than teleological, and resources can be theories rather than names, which can be linked and integrated rather than named. The weakest quality in terms of scientific reasoning is when argumentation is solely in the form of naming references (for example, a single name like *Darwin*) while the strongest argumentation integrates theoretical resources with causal explanations, and also link the general theoretical resource to how it is manifested in several specific situations.

In some instances, the students' ontological framing become important for their interaction. In particular, discussions concerning epistemological differences can be understood as implicit discussions about how the world (and knowledge about it) is constituted. This could concern how general a scientific explanation is, or whether a teleological or causal explanation is acceptable to use in the students' discussion.

## Paper III
## Teaching biological evolution – internal and external evaluation of learning outcomes

This paper aims at evaluating the students' learning outcome in relation to set learning goals in an enacted teaching intervention in 8 school classes and 4 schools. The project that generated the data has been described earlier in this thesis as a cyclic knowledge-building process, in which both teachers and researchers contribute. In this project, there were four teachers who taught the sequence twice with different groups during one school year, which means that about 180 students, 11 – 16 years old, were involved.

The intended learning goal was that the students should be able to use a scientific theory as a tool when encountering new situations; in this case, that students should be able to use the theory of evolution by means of natural selection as a tool when explaining the development of life on earth. The theoretical tools, labelled key terms here, were variation, heredity, and selection. In order to assess the students' attainment of the learning goal, a pre and post test design was used, meaning that the students answered questions in writing before the teaching and that some of these questions were also given to the students in the post test. These post tests, carried out at least three months after the teaching ended, were also answered written.

The internal evaluation made use of mainly three questions, one multiple choice question and two open-ended questions. The open-ended questions were assessed with a system of categories that made qualitatively different reasoning visible. On the whole, the internal evaluation showed significant changes in the ways students responded to written questions. This tendency to answer more in accordance with learning goals was most pronounced among the older students, the 15-year olds. However, also the youngest (11-13 years old) showed significant improvements and on some questions they even performed significantly better than the older students in the national sample used as a kind of control group.

For external validation, an approach previously used by Bach (2001) was applied, meaning that questions from the national evaluation of the compulsory school (National Agency of Education, 2004) were used as points of reference. In the national evaluation, a random national sample of students in school year nine were given (among 12 questions assessing goals to attain in Biology) three questions about biological evolution. The same questions were given as post test questions to the year nine students who participated in the teaching intervention. Both groups answered the questions at the end of their compulsory schooling and the students in the intervention group were given the post test at least three months after the teaching intervention. When the students in the national sample were taught evolution is harder to estimate, according to the national syllabuses it could have been anytime during school year 6 and 9. Both groups answered anonymously, the questions were given in writing with the same wording, and assessed with the same coding scheme.

The result, shown in Table 4, are a summary of the aggregated analysis of all three questions (two open-ended and one multiple choice with four alternatives), which were formulated and assessed in the same way in both groups.

**Table 4.** Consistency among three written answers; national sample and grade nine experimental group. Differences between the groups are significant ($p < 0.01$).

| | No answer in line with learning goal | One or two answers in line with learning goal | Three answers in line with learning goal |
|---|---|---|---|
| National sample (n = 335) | 59% | 32% | 9% |
| Experimental group (n = 85) | 16% | 41% | 43% |

The general methodological difficulties when performing nationwide evaluations as well as the difficulties when comparing specific groups are discussed in the paper. For example, there is an assumed difference in the students' motivation to make an effort to give reasonable answers; a difference that would favour the experimental group. The figures shown in Table 4 are the result of a recalculation made in order not to overestimate the answers of the experimental group. However, after these re-calculations there is still a significant gap (calculated with the $\chi^2$-method) between the answers of the two groups.

This study indicates that there were gains in learning outcome within the intervention and also in comparison with a randomised sample. The evaluating design (especially the external), as Bach (2001) has shown, is a methodological contribution when assessing intervention studies. The approach, with qualitative categorising of reasoning, has the potential of informing teachers' scaffolding of students' sense-making process in relation to scientific reasoning, for example, the students' answers exemplify and point towards the upper part of the zone of proximal development - *the potential zone of development*.

## Paper IV
## Students' language use when talking about the evolution of life – negotiating the meaning of key terms and their semantic relationships

This paper reports on the same project as paper III, however, the analytical focus was quite different. The aim was to explore how the students made sense of the scientific language that was introduced in the teaching-learning sequence, especially the key terms that the scientific story was supposed to refer to. The analysis focused on two levels: on the term level it focused on students' meaning making of the terms one by one (cf. Brown & Ryoo, 2008). The other level is when the terms are used together in the formation of explanations, for example, the students' use of thematic patterns (cf. Lemke, 1990).

In order to reach the aim, recordings of students' talk during classrooms activities were made. In these activities the ambition was that the students, in their reasoning, should make use of the introduced key terms: *variation, heredity, and selection*. Of the two activities that were documented, one, *predict population*, was web-based and the students worked together in pairs predicting the result of an existing variation among a population of reindeers. In the other activity, *selection game*, the students actively played the role of predators and hunted a population of paper clips.

The analysis was performed in relation to the talk around the activities and first of all it was obvious that the students seldom explicitly verbalised the key terms, variation, heredity, and selection; instead, they made several reformulations. Consequently, the interest turned towards these reformulations and the emerging structures of how the students addressed the key terms linguistically. When generating structuring tools, the first source of inspiration was Vygotsky's (1986) distinction between *meaning* and *sense* of a term.

The analytical focus was on the students' statements, the 'sense' that the students made of the key terms; instances where the students contextualise (reformulate) the key terms or important aspects of meaning making. The function in the students' talk (sense as situated meaning) of the reformulation in this way becomes the main interest in relation to meaning (collective). The analysis showed that the students do not actively articulate the terms, instead they make conceptual links using three contextualising strategies: paralleling, transferring, and delimiting. Variation was always reformulated with paralleling, a word parallel – difference, while selection was mainly reformulated with delimitations. Heredity was reformulated with all three strategies.

These kinds of reformulations made by the students often dilute the meaning of the scientific terms, since scientific terms add conceptual depth and are productive as resources for understanding with more finely grained specificity (Brown & Ryoo, 2008). However, when students combine the (reformulated) terms into more coherent explanations, the thematic patterns become closer connected to the scientific language. A good explanation of evolution should include, according to Ferrari & Chi (1998), five components: individual variation, heredity, differential survival, differential reproduction, and accumulation. This is exemplified by students in this paper – without explicit articulation of the components. Below, is one example from the web-based activity, *predict population* (group 3):

| | | |
|---|---|---|
| 84 | Emma: | I first thought that it was like mutations and that was surely true as well, but then it was also like this ... that those with longer legs survived better and then it were those who reproduced |
| 85 | Eva: | exactly, then we write like this ... let us take the example that all reindeers are chased by wolves ... the fastest survives |
| 86 | Emma: | which is the one with longest legs |
| 87 | Eva: | because it runs fastest, has a good mutation |
| 88 | Emma: | well |
| 89 | Eva: | first of all, it is a mutation that makes you get longer legs |
| 90 | Emma: | mm |
| 91 | Eva: | and since they would rather take your friend who doesn't have your mutation |
| 92 | Emma: | mm |
| 93 | Eva: | because they more easily get hold of your friend therefore you survive and your children get your dominant mutation (predict population, group 3) |

Emma mentions the aspect of heredity at the beginning (technical term mutations), and so does Eva both in the middle (technical term mutations), and at the end (your children get your dominant mutation). Variation is discerned (some had longer legs). This variation confronts the environment (all reindeers are chased by wolves), thus resulting in selection (the fastest survives). With the introduction of wolves in this example, the students touch upon the notion of *selection pressure*. The result of this pressure (reindeers hunted by wolves) is formulated by Eva in a rather personalised style: would rather take your friend who doesn't have your mutation /…/ more easily get hold of your friend therefore you survive.

This is possibly a contradictory finding – poor articulation of the parts (meaning of the key terms) and acceptable articulation of the whole (thematic pattern). In this paper, it is suggested that one reason for this is that terms have to be contextualised in order to be comprehensible. Furthermore, similar to what Brown and Ryoo (2008) conclude, that these students' articulated their understanding with their own colloquial expressions might have helped them to articulate an explanation in scientific language in the delayed post test.

## Conclusions and summary of findings

This summary is structured in accordance with the research questions in the thesis and therefore the aim and questions are repeated. The aim of this thesis is to explore what is involved when making sense of biological evolution by focusing on students' appropriation of the school science language. The specific research questions concerns, on the one hand, the students' appropriation of scientific ways of reasoning as externalised when the students write answers individually, and on the other, what happens when the students talk with peers in group discussions.

**To what extent do the students appropriate school science ways of reasoning about biological evolution, as it is externalised in writing answers individually?**

The overall pattern, explored with a pre and post test design, is that the students answer more in line with set learning goals after the teaching than before. However, there is an age gradient with respect to how the answering rates change towards the set learning goals. The oldest, the 15- and 17-year old, students answers differ approximately 60 percent between pre and post test, while the answers from the students aged 11 -13 differ approximately 30 percent.

When the written answers from the experimental group are compared with the answers from the randomised national sample (15-year old students), the experimental group aged 11 -13 gives answers in line with set learning goals with the same frequency as the older students in the national sample. On the other hand, when analysing answers from comparable age groups (the 15-year old students), there are significant differences in favour of the experimental group, especially when judged by merging several answers, thus pointing to the students' consistency in reasoning.

Looking at the types of answers, there are two main differences between the answers of the experimental group and the national sample, and both concern epistemological aspects. The first concerns the explanatory mode, in this case *teleological* or *causal* explanation. The experimental group (after teaching) mentioned 'purpose' and 'intention' to a lesser extent in their answers, while the national sample favoured answers with a flavour of teleological reasoning. Secondly, there is a difference in the relation to how the questions are apprehended concerning 'what counts as an answer': in this case, *description* or *explanation*. The questions are always formulated in such a way that they explicitly ask for an explanation and a scientific explanation is emphasised (typically formulated as "how would a biologist explain …"). However, discerning whether the answer should be an explanation or a description seems to be complicated for the students. The students in the national sample more frequently give answers with descriptions, and not explanations; an explanation includes reasoning with the help of a mechanism, for example, natural selection. Likewise, the students in the experimental group answered with descriptions in the pre test, but in the post test the majority of the students answered with explanations and reasons with reference to mechanisms.

Apparently, a change in language use, when writing answers, has taken place in the experimental group. However, it is another question whether this is established in more general language use, for example, concerning the choice of explaining instead of describing, and to what extent it is used in more informal contexts. Put in another way: to what extent have these students made sense of and appropriated a general thematic pattern in science (causal explanations referring to mechanisms), exemplified by the thematic pattern of explaining biological evolution in school science (natural selection, resting on the terms variation and heredity). This is an issue explored in the next section when analysing students' talk in peer groups.

**What happens when the students are offered the opportunity to discuss with peers?**

The overall conclusion is that the students take the opportunity to discuss with peers earnestly - the students focus their discussion mainly on the supposed task, they seriously consider the opinions of their peers, and they are not afraid to express their own lack of knowledge. The students mainly focus their talk on conceptual issues. At the same time, they make use of several epistemological patterns. Furthermore, their use of social language alternates between colloquial and scientific accounts.

The students most frequently start their talk as a negotiation concerning conceptual notions (what does this mean?) that is linked to a discussion about epistemology (what counts as explanation?) and sometimes the talk also is linked to ontology (what constitutes the world?). A typical example of this type of discussion, analysed in paper II, (*Arguing biological evolution* …), deals with all three constituting aspects of the origin of biological variation. The students make connections between one set of conceptual notions (need, randomness, and development) and another set (variation and selection) resulting in two distinctively different epistemological patterns. These patterns are teleological reasoning versus causal reasoning, and underlying the whole discussion is the ontological framing of whether things in nature happen because of agency or mechanisms.

The analysis of students' language mainly deals with terms and the combination of terms into thematic patterns. Concerning the students' use of single terms, one conclusion is that the students seldom explicitly verbalise the scientific terms as such, instead the students contextualised them as reformulations using three strategies: paralleling, transferring, and delimiting. All three of these strategies have merits and drawbacks in connection with the (Vygotskyan) meaning of single terms, since the strategies do not encompass all nuances, components, and specificity of the scientific meaning of the term. For example, if selection is delimited to 'survival rate', there is a lack of certain components that is inherent in the scientific meaning of, for example, 'reproduction rate'.

However, when the students use the terms mentioned above in combination as a thematic pattern when formulating coherent explanations, the pattern get closer to the scientific accounts. The two main ways in which the students negotiated explanations were on the one hand, *discernment of differences* between terms and, on the other, *linking and coherence* among terms. The students discern differences by negotiating about delicate but important nuances (differences) in wording connected to understanding *variation and selection*. For example, from paper IV (*Students language use* …) in a discussion in school year 9: "the wolves got better sense of smell ... no that the wolves who had a good sense of smell"; here, the students discern the difference between whether some of the wolves already *had* different abilities or if it was a result of selection (*got* better). Another similar example is when the students negotiate whether to use *are* or *become* when explaining the ability to run fast; *are* points to the existing variation, while *become* points to the result of selection.

When the students employed the other strategy 'linking and coherence of terms', it was also possible to explore different qualities in the students' ways of explaining. The structuring tool was informed by the components that, according Ferrari and Chi (1998), should be included in a qualitatively rich answer: *individual variation, heredity, differential survival, differential reproduction,* and *accumulation of changes*. The estimation of quality relies on the links and relations of the components, for example, whether they are articulated with a causal character or not. As the data show, the students often assist each other in coordinating scientifically sound and coherent explanations.

The students' talk show a common pattern when they are discussing a multiple choice concerning the origin of intra-species variation, a question that is seeded with alternatives pointing to both scientific and colloquial language. The students focus on three notions (need, randomness, and development) and the meaning of these notions and the context in which they should be understood are negotiated and contrasted with their opposites. This is expressed in three types of social languages (colloquial, inter, and scientific language), which means that each of the three notions are, according to the students, possible to express in different social languages. However, need and development were more frequently used in the colloquial language than in scientific language (in interlanguage somewhere in between). The opposite applied in the frequency distribution of the notion of randomness, as well as in the case of more technical terms such as mutation and sex cells. Discussions using the notions of need and development seemed to evoke less use of technical terms.

When analysing longer sequences of the students' discussions, it was obvious that the talk alternated between different social languages in a productive way. The notions with more of a colloquial origin, like need and development, served as a resource in the discussion in mainly two ways.

Firstly as a trigger, this is forcing the students to refine their argumentation. One example of this is shown in paper I (*Making sense of biological evolution* …), when one student, Diana, claims that random changes have an "underlying thought" (the expression has a pointer towards teleology, thus colloquial language). Another student, Dee, then argues against this first by giving an answer in interlanguage:

> "or not exactly thought but ... of course random changes happen ... but the changes that survive are the good ones" .

This is defined as interlanguage because it is an interplay between languages: the scientific language when claiming: "of course random changes happen" and the colloquial language when labelling a change as 'good', without contextualising what good relates to. However, Dee continues her argumentation with:

> "If, among the cheetahs, there was someone who could run faster and someone slower, then ... those who were big and strong would get a lot of food and then more and more of these came about".

Then she moves closer to scientific language, because 'good' is contextualised and a mechanism is proposed in order to explain the issue.

Secondly, terms with a colloquial origin could be contextualised in the scientific language, for example, regarding the term 'need': "not originated because it was needed but remained when it was needed" or regarding the term development: "all those who had a certain trait managed better in one part of the lake, and then they developed there". Thus, the colloquial language serves as a resource and leverage in the students' process of making meaning.

In relation to the aspiration of this thesis - contributing to the formulation of the learning demand for biological evolution - this summary has so far pointed to several conceptual notions that are important in the students' discussion, irrespective of their origin in scientific or colloquial language: variation, heredity, selection, need, randomness, and development. The interpretations of these notions are dealt with, the context in which they should be understood is negotiated, and they are contrasted with their opposites.

In terms of epistemological aspects, two patterns have already been mentioned: teleological reasoning and causal reasoning. Other epistemological issues discussed by the students refer to resources for knowing and linking between general accounts and specific examples. Together with the above-mentioned teleological and causal aspect, it was also possible to distinguish other indicators of quality in reasoning. The weakest quality in terms of scientific reasoning is when argumentation is solely by means of naming references, for example, with a single name like *Darwin* or with an isolated expression like *survival of the fittest*, while the strongest integrates theoretical resources with causal explanations that also link the general theoretical resource to how it is manifested in several specific situations.

Ontological aspects mainly concerned the previously mentioned issue of whether agency and mechanisms are potential explanations of how the world is constituted or 'works'. The assumption that religious beliefs would play a minor role seems to be confirmed, at least there are no indications of religious concerns in the students' discussion. However, other ontological aspects raised concerns what is possible to discuss in relation to biological evolution. For example, in one group, the students chose to discuss evolution only with reference to animals, and then animals do not necessarily include humans (sic!). This is, of course, strictly scientifically, highly arguable but, or perhaps because of this, it eased the tension in the group and this kind of ontological neutralisation enabled the students to stick to their discussion.

# 6. Discussion and implications

Here, the main findings from the previous section will be discussed in the light of an overarching theme: relations between content-oriented aspects and more generic patterns, which might contribute to both practice and further research. However, the chapter will commence with reflections on some of the methodological considerations that arose during the empirical work and analysis reported in this thesis.

**Methodological considerations**

Methodologically, the analysis focuses on the appropriation of the school science language, which is both an indication of what kind of theoretical contribution could be expected, and an epistemological stance concerning what is involved in learning and how to explore the issue. However, since the methodology follows a tradition in science education by making fine-grained analyses, certain delimitations are unavoidable. In this case, the focus is on a specific situation (formal schooling), age group (11-17 years old), and content area (biological evolution). With these delimitations in mind, two issues will be discussed. Firstly, the consequences of adopting the perspectives of macro and microanalysis of learning are discussed. These perspectives point to a product or process orientation that may entail different contributions to the fields of practice and research. Secondly, different modes and accompanying consequences are discussed in terms of what the notion of learning demand can contribute. The modes include, and again, reflect macro and micro approaches; an initial macro approach where the focus is on a literature review of endpoints versus a micro analysis of what happens when this initial version is brought into play in the classroom.

The data in this thesis were generated during experimental settings, teaching interventions that were part of an exploration of new design when teaching biological evolution. The analysis focused on students' appropriation of the language of school science. Such a focus can have at least two perspectives: a macro perspective focusing on products of the interventions or a micro perspective, which focuses more on processes within the interventions. In this thesis, both perspectives are considered, although the process is the main interest. It is not evident that the two perspectives could be combined, for example, they often differ in theoretical underpinning, time framing and type of data, and they contribute to different knowledge claims, which may attract different audiences. In the Introduction part of this thesis the differences between macro and micro was described like this: macro perspective involves longer time frames and analysis often use quantitative methods judged on written data. The knowledge claims that macro analysis report is often expressed as generalisations, while the micro analysis points more to situated and contextual knowledge claims. Furthermore, micro analysis typically focuses on shorter episodes and oral communication, and analysis is mostly done with qualitative methods.

In this thesis, the macro perspective involved a pre and post test design aimed at estimating students' learning outcome in relation to set learning goals. Findings from such an analysis inform the designers, in this case, the researcher and the teachers involved, if the intervention as a whole 'works' in relation to set learning goals; goals that were articulated based on actual curricula and syllabuses. In approaches like PISA and TIMSS, which also use test items in order to estimate learning outcome, the main purpose is to inform the educational system, and form the basis for comparisons over time and between countries. The approach used in this thesis is to present qualitatively different ways of reasoning rather than absolute numbers of correct or incorrect answers. Detailed descriptions of different ways of reasoning have the potential to make contributions to classroom practice. Andersson (2000) expresses this idea as that a description "has good developmental validity if it stimulates the thinking and actions of the teachers and other actors concerned in such a way that it results in attempts to improve teaching" (p. 66). Thus, could these descriptions contribute to school development, for example, as a tool for formative assessment? The discernment of teleological and causal explanations or different connotations of terms, such as development, could inform and enhance teachers' use of formative assessment (cf. Black, Harrison, Lee, Marshall & Wiliam, 2003).

When formulating the learning demand that faces the students in connection with a specific topic, the standard procedure is to establish two endpoints concerning a specific topic in school syllabuses; the knowledge to be taught versus students' typical formulations of the same phenomenon. This working procedure is a useful starting point, which could be derived from, on the one hand, the school curricula and syllabuses, and on the other, literature in educational research – in other words, it is a product of a literature review. In the work reported in this thesis, this *initial* version of the learning demand was brought into play in practice, through teaching activities, and is thus transformed into a more *dynamic* version.

The initial version of learning demand is strong on articulating conceptual aspects and to some extent also epistemological aspects. However, when this version is seeded into teaching activities, it is possible that other aspects will emerge. When analysing student' talk during teaching activities, other conceptual and epistemological aspects also become pertinent, and potentially also aspects relating to worldview or ontology become more visible. In this thesis, this is exemplified by the fact that the meaning of conceptual issues previously described in literature are negotiated (for example, need and randomness) along with more 'under-researched' conceptual notions (for example development). The epistemological patterns of teleological and causal explanations are well described in literature; however, other patterns connected to quality of reasoning are less well described. Such patterns include the students' ways of making use of diverse resources supporting their arguments as well as various links between specific examples and general models and theories. When it comes to ontological and worldview aspects, these surface when the students are engaged in peer group discussions; in this thesis ontological and worldview aspects are negotiated, for example, when the students discuss whether agency matters or what issues science could deal with.

As shown in this thesis, the constituents of the learning demand are *layered* and the relations between aspects might be more evident in a microanalysis of the students' talk, which, for example, Wickman and Östman (2002) and Ingerman, Linder and Marshall (2009) have shown. These findings advocate greater attention to a microanalysis of the ways the learning demand is talked into existence by the students themselves, in other words, it is a research method that has the potential to make more aspects visible.

**Discussion of findings**

One finding, in relation to the first set of research questions, is that there is an improvement in the students' answers, measured in terms of quality, in both internal and external comparisons. This is perhaps not that surprising, interventions often show some improvements in relation to set learning goals (cf. Brown, 1992; Méheut & Psillos, 2004); nevertheless, the differences between the national sample and the experimental groups are significant. Looking at qualitative aspects, the first finding, the decrease in teleological explanations and increase in causal explanations, is not that surprising since the teaching aimed at emphasising the theory of evolution as a coherent explanatory tool. This kind of continuous reference to a coherent theoretical model has, according to Hammer and Elby (2003), the potential to enhance deep learning. The other qualitative aspect, the decrease in descriptions and increase in explanations, was more a novelty, and the change that occurred over time in the students' answers might be understood in a similar way to what

Ogborn, Kress, Martins and McGillicuddy (1996) refers to as "explanations have to be talked into existence" (p. 14). However, in this case, it is rephrased as 'descriptions have to be talked into explanations'.

The recognition of the epistemological aspect of distinguishing between descriptions and explanations might have implications for learning in general – in relation to argumentation. If we use the vocabulary of Toulmin (1958), descriptions are a kind of claim, while an explanation is closer to a warrant, and if the explanation is articulated as a mechanism, it qualifies as backing. With an exemplification from this thesis: "*They* [the reindeers] *developed and got longer legs, and they became more vigorous*" was depicted as a description and it resembles a claim as to what constitutes a fast-running reindeer. The answer could, of course, be an explanation of why a certain reindeer runs fast, but the question concerned reasons for change over generations. Then, the utterance "*the fastest survives*" is more like a warrant that connects the data (in the population of reindeers, the frequency of 'long legged' increased) and the claim (it is better to run fast). While an utterance like: "*first of all it is a mutation that makes you get longer legs /../ and since they* [the wolves] *would rather take your friend who doesn't have your mutation"* also implies a mechanism and thus qualifies as backing. Teaching activities and scaffolding that promote coherent and developed argumentation, like the one above, have the potential to increase the quality of students' reasoning. Reasoning with this kind of developed argumentation is what is required in relation to the higher grades in the Swedish school system; and I would argue that it is a general criterion of quality in relation to most subjects.

Three expressions have been frequently used throughout this thesis: *zone of proximal development*, *appropriation of language*, and the *constituents in the process of making sense of biological evolution*. These three will now be discussed as a relation between content-oriented aspects of learning biological evolution and more generic patterns. The first concerns the understanding of the potential zone of development in relation to a specific topic area. The second concerns appropriation of languages and the identification and exploration of a hybrid language, interlanguage. The third, partly informed by the findings linked to the first two, relates to the constituents in the process of making sense of biological evolution, that is, conceptual, epistemological, and ontological aspects.

Vygotsky's idea about the zone of proximal development is probably one of the most discussed. However, most attention in science education research has been directed towards *the actual zone* of development rather than *the potential* *zone*. By this I mean that the zone of proximal development could be seen as a continuum between two zones, or rather positions: the unassisted and the assisted, respectively. The actual zone is what emerges when performance is unassisted, for example, when students write answers individually; while the potential zone refers to assisted performance, for example, when students discuss with peers who possibly are more competent. The findings in the thesis contribute with descriptions and exemplifications of reasoning that could be included in the potential zone. This is shown, on the one hand, in relation to the content-oriented aspect, where the analysis shows a variety of qualitatively different ways of reasoning about biological evolution. These different ways include conceptual aspects such as the role of the origin of variation and the role of reproductive success. However, most significant are the differences in relation to epistemological aspects, which point to more generalised patterns, for example, related to quality in reasoning. This is exemplified in this thesis by the students' choice of giving descriptions or explanations, and whether to choose a teleological or causal explanation. Also important are the students' different uses of resources, references to naming or theoretical ideas, and linking exemplifications and general patterns.

The different ways of reasoning exemplified in this thesis, with typical student expressions, represent *a pool of potential answers*. The students' expressions might be a starting point when teachers are planning teaching, for example, as an indication of the kind of reasoning to be expected among the students. An approach that may have pedagogical potential is to pose a diagnostic question to a group of students and gather the written answers (anonymously) on a sheet of paper. The range of answers could be an example of the potential zone development in relation to this specific question. By letting the students discuss the different answers, the responsibility for judging the potential of each answer is handed over to the students. This is in line with the idea of handover, which was introduced by Wood, Bruner and Ross (1976) in order to link assisted to unassisted performance. However, I would argue that the discussion that arises (starting out with the pool of answers) is still assisted, but by means of the range of these answers. The answers point to and scaffold the students' reasoning towards one end of the zone of proximal development – the potential zone of making sense of this specific topic.

In the writings of Vygotsky about teaching, most attention is on the individual student's development, with and without assistance. This assistance is assumed to include an adult (often a teacher) assisting a child (often teaching one student); in school practice this one-to-one relationship has to be extended to also deal with peer interaction (Forman & Cazden, 1985). This main choice of analytical focus in this thesis, students' talk in peer groups, was guided by the assumption that talk in peer groups would externalise argumentative discourse in another way (than, for example, writing) and hopefully in a more authentic way; authentic because data was generated in ordinary classroom practice, rather than from questionnaires or interviews. With the results in hand, I would argue that the analysis sheds light on the potential zone of articulating the topic. The reason for this is, first of all, that the students seem to take the opportunity to discuss seriously. This suggests that they see the occasion as an opportunity to make sense of a problematic area. An arena is established where technical terms and scientific models may be introduced, negotiated, and made sense of, in particular in relation to personal and everyday experiences. The pedagogical methodology applied here is to 'seed' results from a didactical analysis into students' activities; these seeds can have both colloquial and scientific origins. It could actually be beneficial with seeds with different origins. According to Wegerif (2008), the chance of opening a 'dialogic space' increases if different views are present and held in tension in an arena where different social languages are brought into contact and contribute to the students' sense-making process.

The expression *appropriation the language of school science* implies that the aim of schooling is to appropriate the scientific language where language is understood as specific terms and their combination into thematic patterns. The analysis of the students' use of terms is informed by Vygotsky's distinction between the meaning and sense of a term. If this distinction is taken together with the notion of learning demand, it gives a rationale for my analysis, both from meaning to sense and sense to meaning. On the one hand, in paper IV, the terms that originate in science language, for example variation, heredity, and selection, are depicted as close to the 'meaning side' of a term (collective, general and lexical 'meaning'). The identification of the importance of these terms comes from using learning demand as a design tool, meaning a didactical analysis of 'the scientific language of the content to be taught'. These terms inform the teacher when planning and are 'seeded into' activities with the hope that the students will make use of the terms when talking –meaning is thus taken as point of departure, and it is students' sense making of the intended meaning that is analysed. On the other hand, in papers I and II the activity (the discussion) that is analysed is informed by a mix of colloquial and scientific accounts and the analysis focuses on the ways the students make sense (local, situated and creative 'meaning') of the content – thus sense making is taken as a point of departure and shared potential meaning is aimed at and often reached, although temporarily.

When the students reformulate terms it might, from a school science perspective, lead to a possible momentary *decrease in the precision*, as this thesis have shown, but not necessarily in the long run, because these reformulations is part of the process of sense-making. It could cause problems for those students who choose further science studies and a career in science. However, if they have grasped the *meaning* of the terms, it would be fairly easy to 'copy' the accurate terms for the phenomena; the meaning of the term in that specific scientific community (cf. Brown & Ryoo, 2008). The reformulations *increase the relevance* in the sense that the verbalisation of an explanation in an interlanguage is advantageous when communicating in social life outside the science classroom and thus the possibility of further sense-making is enhanced, an ongoing sense-making process that Hammer and Elby (2003) express as "reconstructing and refining one's current understanding" (p. 54).

The negotiations about terms lead to formation of thematic patterns, patterns that borrow characteristics from both colloquial and scientific language. When the discussion alternates back and forth between the endpoints, as shown in all three papers mentioned above, a new hybrid language is established – an interlanguage. The mere identification of such a hybrid language support the idea that the relations between colloquial and scientific languages are best viewed as continuous. If we for a second accept that one of the normative aims of school science is to appropriate the scientific language, which is in line with what Vygotsky (1978) and the Swedish curricula express, I would argue that this is hard to achieve without continuous shifting and linking between colloquial and scientific accounts. The colloquial expression has to be taken as a resource in the sense-making of the scientific language. Single terms have to be contextualised in order to be comprehensible, for example, terms that on the surface have primarily colloquial pointers, like need, can be contextualised in a sound scientific pattern: *not originated because it was needed but remained when it was needed* (Amy, paper II)

The formulation of *the learning demand for biological evolution* is constituted by conceptual, epistemological, and ontological aspects. These aspects can be derived from a literature review of school curricula and educational research papers. This standard procedure is useful as a design tool for teaching (Leach & Scott, 2002). However, what is analysed in this thesis is the students' talk around activities; activities that were seeded with insights from the initial version of learning demand. This methodology has a pedagogical function (as an arena for learning), but it also contributes with a research resource; the students' interpretations of the initial learning demand develops into a new and more dynamic version of the learning demand.

Important conceptual notions that previous research has pointed to, for example, variation, need, and randomness, are discussed by the students. However, I would argue that the kind of analysis performed in this thesis gives a more nuanced picture of how the students make sense of these notions. For example, variation is contextualised with a parallel word (difference), and both need and randomness are discussed in alternating social languages, thus connecting colloquial and scientific understanding. The fact that a notion like development was prominent in the discussion is a rather novel insight and will have implications for future teaching.

Teleological reasoning as a prominent epistemological pattern in the students' explanations is thoroughly described in literature. What this thesis contributes is exemplifications of how students negotiate and assist each other in coordinating explanations that often become more and more in line with a causal explanation. References to authoritative sources (names or isolated phrases) or theoretical resources (the theory of evolution) also point to a different quality in reasoning. One of the ontological concerns that the students mention and I would like to emphasise is the core assumption in science that the natural world is explainable in terms of mechanisms and only mechanisms; there is no room for purpose, wishes, and intentions – this is a perspective so odd and unfamiliar to many students that it must be discussed explicitly. For example, that scientists accept (not *believe*) scientific theories and that science aims at answering how (not *why*) the world is constituted. By discussing epistemological and ontological issues, more students would relax and hopefully consider making the effort that is required in order to make sense of school science.

# 7. Summary in Swedish

Mellanspråklighet som en möjlighet för att tala om biologisk evolution: En utforskning av elevers samtal och skrivande som en arena för meningsskapande

## Inledning

Bakgrunden till denna avhandling är en nyfikenhet om lärande av naturvetenskap, en nyfikenhet som växt under arbetet som lärare på grundskola och gymnasieskola. En viktig del av läraryrket är att stötta elevers försök att tillägna sig och skapa mening av det som presenteras i undervisningen, och denna avhandling följer en tradition inom ämnesdidaktisk forskning genom att undersöka vad denna meningsskapande process innebär i relation till specifika ämnesområden. Ambitionen är att ge ett kunskapsbidrag genom att fokusera elevernas språkanvändning när de försöker göra ämnesområdet biologisk evolution begripligt för andra. Analysen som genomförs fokuserar relationer mellan innehållsspecifika aspekter av elevers tillägnande av ämnesområdet biologisk evolution och mer generiska mönster, exempelvis sociala språk (Bakhtin, 1981) och begreppsliga, epistemologiska och ontologiska aspekter (Bruner, 1985) av att lära sig något.

Avhandlingen är skriven inom ramen för en forskarutbildning på institutionen för pedagogik och didaktik och forskarutbildningsämnet är ämnesdidaktik; inom detta ämne refereras ofta till en internationell arena där forskningsintresset rör 'science education'. Det ges regelbundet ut handböcker inom området och i den senaste *Handbook of Research in Science Education* (Abell & Lederman, 2007) anges syftet med forskningen vara ”förbättring av undervisning och lärande av naturvetenskap över hela världen[1]” (s. xiii). Detta ambitiösa syfte ska uppnås genom att forskningen dels grundas i elevers och lärare faktiska praktik och dels är öppen för nya teoretiska perspektiv, forskningsmetodologier och -strategier, samtidigt som forskningen omfattar redan prövade och verifierade metoder. Chatterji (2004) föreslår en blandad metodologisk ansats med en forskningsdesign som kombinerar exempelvis kvantitativa och kvalitativa metoder samt summativa och formativa utvärderingar och innehåller flera cykler av återkoppling. En forskningsansats som omfattar de ovan nämnda kriterierna – iterativ design, grundad i autentisk praktik och nyttjande av blandad metodologi – är *designbaserad forskning*. Ansatsen är ett slags hybrid mellan en renodlad akademisk forskningstradition och en mer utvecklingsorienterad tradition. Designbaserad forskning har både en

1 Citaten i denna sammanfattning är (om inget annat sägs) översatta till svenska av mig.

teoretisk och en pragmatisk orientering, och en strävan att öka legitimiteten gentemot både akademin och praktiken. Ambitionen är att i autentisk praktik utveckla innehållsrelaterade teorier om lärandeprocess samt strategier som stöttar denna process (jmf. Brown, 1992; Cobb, Confrey, diSessa, Lehrer & Shauble, 2003; The Design-Based Research Collective, 2003).

Lärande av naturvetenskap innebär bland annat att tillägna sig skolans språkbruk inom naturvetenskap, ett språkbruk med specifika termer och framförallt specifika tematiska mönster. Detta nya språkbruk lär man sig (i likhet med lärande av andra nya språk) genom att använda det tillsammans med andra som redan behärskar språket (jmf. Bakhtin, 1981; Lemke, 1990; Vygotsky 1978). Språk, i allmänhet, förser oss med ord och termer, grammatik och semantik (betydelse) och, enligt Brown och Ryoo (2008), genom att kombinera begreppsliga och språkliga komponenter ökar elevernas möjlighet att nå förståelse av innehållet. Det naturvetenskapliga språket använder specifika termer, exempelvis bägare, sublimering och konsument som antingen är nya för eleverna eller används i nya sammanhang. Dessa termer har, å andra sidan, blivit en del av den ”verktygslåda” som elevernas lärare använder sig av för att skapa mening om det naturvetenskapliga innehållet. Att skapa mening innebär bland annat att skapa sammanhang och inga enskilda termer har fixerad betydelse utan betydelsen beror av sammanhanget. Sammanhanget kan uttryckas av de *tematiska mönster* som termerna ingår i (Lemke, 1990): ”ett mönster av samband mellan ords betydelser inom ett specifikt vetenskapligt fält kallar jag tematiskt mönster. Det är ett mönster av betydelsebärande relationer[2] som beskriver det tematiska innehållet, det vetenskapliga innehållet, av ett specifikt innehållsområde” (s. 12).

Eftersom de tematiska mönster som används inom skolans naturvetenskap, i vart fall till en början, är obekanta för eleverna bör undervisningen, enligt Lemke, göra kopplingar mellan det vetenskapliga språket och det språk som eleverna redan använder. Lärande innebär att koppla till något vi redan mött förut, det nya ska passa in i ett tidigare känt tematiskt mönster - för att vara meningsfullt ska det nya vara begripligt i ljuset av något vi redan mött. De betydelsebärande mönster som beskriver det naturvetenskapliga innehållet är uppbyggda av ord, men: ”meningars betydelse utgörs inte av ordens betydelse. Vi måste nå bägge samtidigt genom att passa in orden och deras betydelsebärande relationer inom meningen till olika tematiska mönster och relationer mellan tematiska enheter” (s. 35). Med andra ord, det är kombinationen av termer (mönstret) som är syftet med lärande och

2 Min översättning av ’semantic relationships’ (Lemke, 1990)

undervisning, helheten (mönstret) blir mer än delarna (termerna).

**Syfte och frågor**

Syftet i denna avhandling är att undersöka hur elever tillägnar sig skolans naturvetenskapliga språkbruk. En strategi för att närma sig frågan är att studera tillfällen i klassrummet då betydelse och innebörd av termer och deras sammansättning till tematiska mönster får sitt uttryck i tal och skrift. Avsikten är också att bidra till en beskrivning av vad som bygger upp lärandeutmaningen[3] vad gäller lärande av biologisk evolution.

I linje med den tidigare diskussionen om blandad metodologi kan man anlägga åtminstone två perspektiv för att uppnå syftet: makro- respektive mikroanalys. Framställer man skillnaden som en dikotomi kan den beskrivas som att makroanalys oftast innebär längre tidsspann och skriftlig data, samt att analysen ofta använder kvantitativ metod och kunskapsanspråket är generalisering. Mikroanalys fokuserar processer och innebär analys av kortare episoder och ofta muntlig diskurs. Analysen använder ofta kvalitativa metoder och syftar mot mer sammanhangsbundna kunskapsanspråk. I denna avhandling har bägge perspektiven använts, även om det senare kommit att dominera genom mikroanalys av elevers tal när de deltar i undervisningsaktiviteter. Detta kan också ses som antagande om lärande: lärande är en konsekvens av deltagande i aktiviteter och inbegriper successiv appropriering av vetenskaplig diskurs.

**Den första typen av frågor** rör en värdering av lärandets utfall i relation till lärandemålen, och är närmare ett makroperspektiv; en analys av före/efter undervisning.

I vilken utsträckning tillägnar sig eleverna ett naturvetenskapligt språkbruk om biologisk evolution, som det externaliseras i elevers individuellt skrivna svar? På vilka sätt utvecklas elevernas skrivna svar från före till efter undervisning?

**Den andra typen av frågor** är mer i linje med ett mikroperspektiv och fokuserar elevers tal i gruppdiskussioner; en analys av en meningsskapande process.

I vilken utsträckning tillägnar sig eleverna ett naturvetenskapligt språkbruk om biologisk evolution, som det externaliseras i elevers tal i gruppdiskussioner? Vilka termer och tematiska mönster fokuseras och förhandlas i elevernas diskussion? På vilka sätt konstitueras konceptuella, epistemologiska och ontologiska aspekter av biologisk evolution i elevernas diskussion? På vilka

3 Min översättning av uttrycket 'learning demand' (Leach & Scott, 1995,2002)

sätt är sociala språk kopplade till dessa aspekter i elevernas diskussion?

## Bakgrund

En central utgångspunkt i denna avhandling är Vygotskys (1978) resonemang om att utveckling och lärande innebär en övergång från social till individuell kontext. Det betyder bland annat att vi möter (för oss) nya idéer i ett socialt sammanhang, idéer introduceras av andra, och individer tolkar genom internalisering, ett slags personligt meningsskapande[4]. Den omvända processen, externalisering är enligt Vygotsky (1986) när resonemang återinträder på en social arena. Det är alltså en tvåvägstransformation; å ena sidan, det vi möter i vårt sociala liv blir verktyg i en internaliseringsprocess; å andra sidan är det externalisering (exempelvis i denna avhandling är det elevers tal och skrift) som gör individers resonemang tillgängligt på en gemensam arena. Denna reflexiva relation uttrycker Sfard (2007) som en ”pågående tranformering av mänsklig verksamhet som ett resultat av två komplementära processer, dels *indivualisering av det kollektiva* och dels *kollektivisering av det individuella* (s. 569, kursivering i orginal). Transformationen är inte en passiv kopiering av andras språk, vilket får Bakhtin (1981) och Wertsch (1998) att föreslå termen appropriering i stället för internalisering. Det är en process av att ” ta över någonting som tillhör någon annan och göra det till sitt eget” (s. 53), vilket enligt Sfard (2007) oundvikligen medför individuell variation.

En central fråga inom naturvetenskapernas didaktik är idén om två sfärer, oftast benämnda som den *vardagliga* och den *vetenskapliga*, exempelvis i förhållande till begrepp, kunskap eller språk (Warren, Ballenger, Ogonowski, Rosebery & Hudicourt-Barnes, 2001). Det verkar råda konsensus om att sfärerna är analytiskt separerbara, till exempel med hjälp av Bakhtins begrepp *sociala språk*. Dock råder det inte konsensus om vad identifieringen av sfärerna betyder för lärande och undervisning. Om man ser vardagligt och vetenskapligt som skarp dikotomi kan fokus, enligt Warren *m.fl.*, vara att se de olika sfärerna som oförenliga och betrakta det vardagliga informella språket som något som skapar hinder för fortsatt lärande, ett hinder som måste övervinnas, exempelvis genom en process av ’conceptual change’ (Anderson, 2007; Duit & Treagust, 2003). Å andra sidan kan fokus vara att överbrygga de två sfärerna (inte se dem som ”antingen eller”) och värdera det vardagliga[5] språket som ”en tillgång som kontinuerligt kan användas i klassrum och i lärande, men också studeras, undersökas och analyseras i termer av dess möjligheter

4 I engelskt språkbruk är ’sense-making’ ett ord som mer fångar den personliga och kontextuella aspekten.

5 Termen för vardagligt är ofta ‘everyday’ på engelska, exempelvis ’everyday language’. I avhandlingen har oftast termen ’colloquial’ (vardagsspråklighet) använts eftersom detta mer specifikt pekar mot språkanvändning.

och begränsningar ” (Varelas, Pappas, Kane, Arsenault, Hankes, & Marnotes Cowan, 2008, s. 67).

Idén om kontinuum mellan vardagliga och vetenskapliga sfärer, speciellt i relation till scientific literacy och språk, exemplifieras av Wallace (2004) inom områdena ”autencitet, multipla diskurser och ’tredje rummet[6]’”. Områdena inbegriper växlingar mellan vardagligt och vetenskapligt språk, exempelvis refererar autencitet till ett kontinuum av uttryckssätt. Multipla diskurser pekar mot ett kontinuum i genre (privata och kollektiva genrer) och ”termen tredje rummet representerar ett kontinuum av mening och poängterar den betydelsebärande delen av språk /…/ detta pekar mot att ett kontinuum kan representera hybrid betydelse av vetenskapliga ord och händelser ” (s. 911). Balgopal och Montplaisir (i tryck) tar de tre områdena från Wallace som analytiskt redskap när de undersöker elevers skrivande om naturligt urval. Enligt författarna når eleverna förståelse av naturligt urval när de går in i ett dialogiskt sammanhang av både vardagliga och vetenskapliga uttryckssätt, genre och mening.

Färdigheten att växla (kodväxla) mellan vardagliga och vetenskapliga uttryckssätt är, enligt Reveles och Brown (2008), en viktig resurs i elevers identitetsskapande, som i sin tur är grundläggande för att utveckla scientific literacy – för alla elever, oavsett social, ekonomisk och etnisk bakgrund. Reveles och Brown föreslår att ett sätt att uppnå kodväxling är att se språk som en resurs i undervisningen genom att ”bygga semantiska relationer. /…/. Explicit undervisning i att använda och bemästra det naturvetenskapliga språket när de [eleverna] lär sig kan göra naturvetenskapen mer inbjudande för eleverna” (s. 1039). Förmågan att använda, översätta och urskilja sociala språk är ett av syftena med undervisning naturvetenskap och ju mer utvecklad denna förmåga är desto mer utvecklad är elevernas förståelse enligt Mortimer och Scott (2003). När eleverna arbetar med att skapa mening av det naturvetenskapliga språket, med hjälp av det vardagsspråkliga, kan de utveckla ett nytt hybridspråk, ett *interlanguage*[7] (Barnett, 1992; Lemke, 1990). Med detta nya, mer personliga och dynamiska språk ökar möjligheten att koppla samman och överbrygga mellan informella och formella beskrivningar av fenomen (Brown & Spang, 2008; Gomez, 2007). Interlanguage kan ses som en väg att överbrygga den tidigare nämnda uppdelningen i sociala språk, vetenskaplighet och vardagsspråklighet. Överbryggningen mellan dessa två

6 ’authenticity, multiple discourses, and third space’ (Wallace, 2004)

7 Översätts som ex. blandspråk, interimspråk, hybridspråk. I denna sammanfattning väljs oftast interlanguage.

sociala språk beskrivs som ”hybridisering” av Bakhtin (1981) och Lemke (1990) benämner interlanguage som ”en sorts hybrid mellan vardagsspråklighet och tekniskt språkbruk” (s. 173).

Begreppet interlanguage används ofta i samband med lärande av ”andraspråk”, men om vi tar utgångspunkten att lärande av naturvetenskap inbegriper lärande av naturvetenskapligt språkbruk kan interlanguage vara ett användbart begrepp för att analysera språkbruket inom undervisning av naturvetenskap. En egenskap hos interlanguage är att det öppnar upp en arena där resonemang kan testas och idéer prövas, exempelvis genom att imitera det naturvetenskapliga språket eller imitera uttryck från lärare och klasskamrater. När Vygotsky (1978) introducerade idén om ’den närmaste utvecklingszonen’[8] argumenterade han för en ”omvärdering av imitationens roll i lärande” (s. 87), och Sfard (2007) har visat att imitation har betydelse för lärande av matematik. Hon anser att reflekterande imitation är ett sätt att ta den andres perspektiv och därmed gå in i en ny diskurs, skolmatematikens diskurs. Växelverkan mellan språken har också visats stötta elevers lärande av biologi, exempelvis klassifikation av organismer (Brown & Spang, 2008), biologisk anpassning (Ash, 2008), naturligt urval (Balgopal & Montplaisir, i tryck) och fotosyntes (Brown & Ryoo, 2008). Förmågan att tala och resonera vetenskapligt (som utvecklats i de ovan nämnda studierna) tillskrivs en växling, fram och tillbaka, mellan vardagligt och vetenskapligt språk.

**Empirisk kontext**

Empirin i denna avhandling har genererats under två designbaserade projekt med likartad ansats vad gäller lärandemål och undervisningsstrategi. Lärandemålet uttrycktes som: eleverna ska kunna använda vetenskaplig teori som verktyg när de förklarar fenomen i omvärlden. Eftersom undervisning i naturvetenskap ofta, enligt Lemke (1990) försöker koppla vardagliga erfarenheter till naturvetenskapliga modeller, teorier eller begrepp är det viktigt om dessa ses som mål (produkt) eller medel (process). Lärande av en modell, teori eller begrepp kan ses som ändpunkt (mål att uppnå), men då öppnar man för möjligheten att eleverna lär sig mer eller mindre utantill. En modell, teori eller begrepp kan också ses som teoretisk hävstång, verktyg och medel i elevernas meningsskapande. Bakhtin (1981) uttryckte detta som att i skolan finns det ” två grundläggande sätt för appropriering och överföring -samtidigt - av andras ord (en text, en regel, en modell): ’redogöra ordagrant’ eller återberätta med egna ord’” (s. 341). En möjlig arena för återberättande och successiv appropriering av vetenskapligt språkbruk är smågruppsdiskussioner

8 ’The zone of proximal development’ (Vygotsky, 1978).

där interlanguage fungerar som verktyg. Vilket också är i linje med hur Brown, Collins och Duguid (1989) utrycker verktyg: ” verktyg delar flera viktiga drag med kunskap: de kan bara förstås till fullo genom att användas, och användandet medför både förändring av användarens syn på världen och anpassning till värdesystemet hos den kultur där de används” (s. 33). Ambitionen när undervisningen planerades i ovan nämnda projekt var att se teori som medel i en förståelseprocess: därför uttrycket *teori som verktyg*.

Två projekt har som sagt genomförts, ett i gymnasieskolan där 48 elever i två klasser (med samma lärare) på naturvetenskapligt program deltog. Eleverna var alla 17 år och läste sitt andra år på programmet, och det var deras första kurs i biologi. Den lektion som fokuseras i denna avhandlings analys var en laboration där de 48 eleverna delades in i 12 grupper som gick mellan tre stationer: undersökning av fossil, stamträdsövning angående människans ursprung och en gruppdiskussionsuppgift om uppkomsten av inomartsvariation. Det är elevernas gruppdiskussion som analyseras i den här avhandlingen: se artikel I (*Making sense of biological evolution* …) och artikel II (*Arguing biological evolution*…).

I grundskolan genomfördes projektet på fyra skolor, och där deltog fyra lärare och cirka 180 elever. Lärare och forskare planerade tillsammans undervisning om biologisk evolution och lärarna genomförde sedan undervisningen i någon av de klasser de undervisade för tillfället. Undervisningen utvärderades gemensamt och en reviderad planering togs fram som iscensattes i en annan av lärarens klasser. På detta sätt kom ungefär 180 elever i åldrarna 11 till 16 år att delta i lokalt anpassad undervisning om evolution. Två typer av analys har genomförts av data som genererats från detta projekt. Dels en utvärdering av elevers skrivna svar på diagnostiska frågor, som presenteras i artikel III (*Teaching biological evolution* …), samt en analys av elevers tal när de genomför undervisningsaktiviteter, se artikel IV (*Students' language use* …)

**Analytisk procedur**

Analysen siktar mot att undersöka hur och i vilken utsträckning eleverna tillägnar sig ett naturvetenskapligt språkbruk om biologisk evolution. När det gäller den första typen av forskningsfrågor (lärandets utfall i förhållande till lärandemål som det externaliseras i elevers individuellt skrivna svar) användes skriftliga frågor i en för- och eftertestdesign. I den här avhandlingen fokuseras tre frågor: två öppna och en flervalsfråga. Skälet till valet av just dessa tre frågor är att frågorna också var med i den nationella utvärderingen av grundskolan som genomfördes 2003. Det var därmed möjligt att dels göra en *intern validering*, en skattning av elevernas svar före respektive efter experimentundervisning.

Dels kunde en *extern validering* göras, en skattning av experimentgruppens svar jämfört med svaren från ett nationellt urval av elever (jmf. Bach, 2001; Leach, Scott, Ametller, Hind & Lewis, 2006). Svaren från eleverna grupperades efter kvalitativa aspekter av elevernas resonemang (inte med poängsättning), och utgångspunkten var främst konceptuella och epistemologiska aspekter. Exempel på konceptuella aspekter är resonemang kring betydelsebärande komponenter (och kombination av komponenter) för att förklara biologisk evolution: befintlig variation, differentierad reproduktion, ärftlighetens roll etc. Epistemologiska aspekter rörde exempelvis grundläggande aspekter som skillnaden mellan beskrivning och förklaring, men också val av olika förklaringsmönster, exempelvis teleologiskt eller kausalt.

För den andra typen av frågor, elevers meningsskapande process som det externaliseras i elevers tal i gruppdiskussioner, skiftar analysenheten mellan elevernas bruk av enskilda termer till analys av hela sekvenser där termerna kombineras till betydelsebärande mönster. När det gäller ords mening, som verktyg i sociala praktiker, gjorde Vygotsky (1986) en viktig distinktion mellan ett ords betydelse (*meaning*) och dess innebörd (*sense*). Betydelsen är, enligt Vygotsky, den stabila zonen av ett ord och pekar mot den kollektiva, generaliserade och lexikala meningen. Ordets innebörd är däremot mer situerad och beroende av kontext, och pekar därför mot den lokala, personliga och kreativa meningen. För att begripliggöra ett ord måste det kontextualiseras, sättas in i ett sammanhang, och när innebörden av ord förhandlas och argumenteras för och emot ökas möjligheten att nå en överenskommelse om vad ordet betyder. På så sätt närmar man sig, med Vygotskys språkbruk, den generaliserade och kollektiva meningen (betydelsen) via diskussioner av den situerade och personliga meningen (innebörd). De ord som fokuseras i denna avhandling är ord eller termer som har specifik betydelse i naturvetenskapligt språkbruk, därför kommer ordet *term* oftast att användas, exempelvis termerna: variation, ärftlighet och urval. När innebörden av termer kontextualiseras, förhandlas och kontrasteras kan den tolkningen av termen som 'talas fram'[9] komma närmare det som Vygotsky avsåg med betydelsen av en term. Denna överenskomna tolkning av termens betydelse är också nära det som jag förstår som ett begrepp: en mer generaliserad och kollektiv 'delad mening'. Med andra ord, vare sig vi talar om ord, termer, eller begrepp kan de inte förstås som ändpunkter av förståelse eller enheter som talar för sig självt – det är i den meningsskapande processen som termer närmar sig begrepp, det är ett kontinuum.

9 'Talked into existence' (Ogborn, Kress, Martins & McGillicuddy, 1996).

Analys av enskilda termer innebär inte termerna i isolation, utan den kontextualisering som eleverna förhandlar i sin diskussion, vilket har analyserats från olika utgångspunkter. I en studie (rapporterad i artikel IV, *Students Language use …*) utgick analysen från en lexikal betydelse av termerna variation, ärftlighet och urval. Lexikal därför att den betydelse som lärarna och forskarna utgick från när termerna valdes ut var den vetenskapliga betydelsen. Analysen inriktades på de sätt som eleverna 'made sense', dvs. den innebörd eleverna gjorde av termerna. I två andra studier (rapporterade i artikel I, *Making sense of* … och artikel II, *Arguing biological evoloution* …) var utgångspunkten både betydelse och innebörd eftersom uppgiften som diskuterades pekade mot både kollektiv och lokal mening. I dessa studier riktades den analytiska uppmärksamheten mot den (gemensamma/delade) betydelse som eleverna förhandlar fram.

**Resultat**

Den första typen av forskningsfrågor handlar om lärandets utfall i förhållande till lärandemål som det externaliseras i elevers individuellt skrivna svar. Den interna valideringens kvantitativa skattning visar att elevernas svar efter undervisning, jämfört med före, är signifikant mer i linje med lärandemålen. Detta är mest accentuerat för de äldre eleverna (15 – 17 år) där skillnaden mellan för- och eftertest är ungefär 60 %, medan för de yngre eleverna (11-13 år) är skillnaden ungefär 30 %. Den externa valideringen gjorde en jämförelse mellan experimentgruppens svar och svaren från ett nationellt urval av elever. För de grupper som är lika åldersmässigt (15-åringar) är svaren från experimentgruppen signifikant mer i linje med de uppsatta lärandemålen. Detta är också framträdande när svaren från tre frågor aggregerats, vilket tyder på att experimentgruppens svar är konsistenta. När det gäller de yngre eleverna i experimentgruppen (11-13 år) svarar de ungefär på samma sätt som de äldre eleverna i det nationella urvalet.

De kvalitativa skillnader som är mest framträdande är att svaren från eleverna i experimentgruppen (efter undervisning) sällan argumenterar i teleologiska termer (intention, strävan eller ändamål) i stället grundar de svaren på kausalitet. I svaren från eleverna i det nationella urvalet förekommer ändamålsförklaringar (teleologiska) oftare än kausala förklaringar. Eleverna i det nationella urvalet använder också i större utsträckning beskrivningar i sina svar, medan eleverna i experimentgruppen i större utsträckning ger förklaringar, och dessa förklaringar innehåller mekanismer i termer av naturligt urval.

Den andra typen av frågor handlar om elevers tal i gruppdiskussion och analysen av elevernas användande av enskilda termer visar att eleverna sällan uttalar de termer (variation, ärftlighet och urval) som undervisningen avsåg att bygga den vetenskapliga historien kring. I stället använder eleverna olika strategier för att kontextualisera och begripliggöra termerna: eleverna använder synonymer, överföringar och avgränsningar[10]. Exempelvis kontextualiseras termen variation i stort sett alltid med ett synonymt ord: *olikhet* eller *skillnad*, medan urval oftast kontextualiseras på ett avgränsande sätt: som *överlevnad och/eller reproduktion.* Ärftlighet kontextualiseras på alla tre sätten, exempelvis i överförd mening som något som *lever vidare*. Alla tre strategierna har styrkor (bland annat blir termerna möjliga att diskutera), men också svagheter i relation till den (Vygotskianska) generaliserade meningen eftersom kontextualiseringarna oftast inte fångar alla nyanser, komponenter och den specificitet som utmärker den generaliserade meningen. Om exempelvis urval avgränsas till ”skillnad i överlevnad” saknas en viktig komponent, som ingår i den generaliserade meningen av urval, nämligen skillnad i reproduktionsframgång.

När termerna sätts samman av eleverna till längre förklaringar (tematiska mönster) blir resultatet ofta förklaringar som ligger nära den vetenskapliga förklaringen. Eleverna diskuterar dessa mönster på huvudsakligen två sätt, genom *urskiljning av nyanser* och genom *länkning och sammanbindning* mellan termer. När det gäller det första sättet urskiljer eleverna finkorniga men viktiga skillnader i ordval när det gäller kontextualisering av variation och urval; exempelvis från en diskussion angående skäl till att gott luktsinne utvecklats hos vargar: ”vargarna fick bättre luktsinne … nej, de vargar som hade bättre luktsinne”. Urskiljandet och förhandlingen kring ordvalet *fick* eller *hade*, där ”vargarna fick bättre” pekar mot resultatet av urval, medan ”vargar som hade” pekar mot en befintlig variation är viktigt för att tillägna sig det vetenskapliga språkbruket kring biologisk evolution. Elevernas diskussion förs också med ett interlanguage, eftersom få vedertagna skoltermer används och referenser till egna erfarenheter ofta görs. Länkningen och sammanbindningen mellan termer gör eleverna exempelvis genom att länka de komponenter som Ferrari och Chi (1998) förslog skulle ingå i en god förklaring av evolution: individuell variation, ärftlighet, differentierad överlevnad, differentierad reproduktion och ackumulation av förändringar. Det är då också möjligt att skatta kvalité i resonemang, till exempel om länkningen görs med kausal logik.

Oftast tar elevernas diskussion sin start i en förhandling om konceptuella frågor (vad betyder det här?) vilket ofta kopplar till en diskussion om epistemologi

10 ’Paralleling, transferring, and delimiting’ är de termer som används i artikel IV.

(vad räknas som förklarande?) och, ibland, också till en diskussion om ontologi (vad konstituerar världen?). Ett typiskt exempel på detta är den diskussion som analyseras i artikel II (*Arguing biological evolution*…), där förhandlas de tre aspekter som konstituerar förståelsen av biologisk evolution. Eleverna gör kopplingar mellan en grupp av konceptuella begrepp (behov, slumpmässighet och utveckling) och en annan grupp (variation och urval) vilket resulterar i två distinkta epistemologiska mönster. Dessa mönster är teleologisk respektive kausal förklaring, och det som ontologiskt ramar in hela diskussionen är frågan om händelser i naturen sker på grund högre mål eller vetenskapliga mekanismer.

Analysen av längre sekvenser i elevernas diskussion visar att diskussionen växlar mellan olika sociala språk på ett produktivt sätt. Även uttryck med mer vardagsspråkligt ursprung (som exempelvis behov och utveckling) fungerar som en resurs i diskussionen; företrädesvis på två sätt. För det första som en ”igångsättare” som tvingar eleverna att förfina argumenten. Ett sådant exempel analyseras i artikel I (*Making sense of biological evolution* …) när en elev påstår att slumpmässiga mutationer ändå har en ”underliggande tanke” (ett uttryck som indikerar ändamålsförklaring och vardagsspråklighet). Svaret från kamraten visar på interlanguage genom ett växelspel mellan språk: *”kanske inte exakt genomtänkt … givetvis sker det slumpmässiga mutationer ... men de förändringar som är bra överlever”.* Växelspelet är mellan det vetenskapliga (slumpmässiga mutationer sker) och det vardagsspråkliga där ”bra” inte kontextualiseras. För det andra kan termer med vardagsspråkligt ursprung kontextualiseras med vetenskapligt språkbruk, exempelvis termen *behov: ” uppkom inte på grund av behov men stannade kvar när det behövdes” och utveckling: ”alla som hade en speciell egenskap klarade sig bättre i en del av sjön och då utvecklades dom där”.*

## Diskussion

Syftet i denna avhandling är att undersöka hur elever tillägnar sig skolans naturvetenskapliga språkbruk, ett språkbruk som definierats som de termer som används och dessa termers kombination i tematiska mönster. Om vi börjar med de enskilda termerna verifierar avhandlingen att termer i sig inte har fix betydelse, utan eleverna förhandlar hur termerna ska förstås[11]. Denna förhandling görs ofta genom att omformulera termerna med annan ordalydelse, och då *minskar (momentant) den vetenskapliga precisionen*; den betydelse som termerna har i vetenskapligt språkbruk. Sett i ett längre perspektiv verkar dock eleverna ha tillägnat sig det vetenskapliga språkbruket,

11 Jämför ‘explanations are talked into existence’ (Ogborn m. fl, 1996)

detta visas både genom elevers skrivna svar och när de samtalar i grupp. En möjlig förklaring till detta är att trots att precisionen momentant minskat har *relevansen ökat* genom att eleverna har tillägnat sig ett interlanguage för att kommunicera sin förståelse av biologisk evolution. Förmågan att uttrycka sin vetenskapliga förståelse med ett interlanguage ökar möjligheten att diskutera ämnet utanför klassrummet och därför kan en meningsskapande processen fortsätta; en pågående process av lärande som Hammer och Elby beskriver som ”en rekonstruktion och förfining av ens nuvarande förståelse” (s. 54).

Resultatet i avhandlingen pekar också mot att vardagsspråket är en tillgång när eleverna approprierar det vetenskapliga språket. Dels har det visats att enskilda termer, exempelvis behov och utveckling, fungerar som hävstänger i diskussionen och dels har det visats att eleverna växlar på ett produktivt sätt mellan olika språkbruk. Det omvända är inte en framkomlig väg för lärande, det vill säga om vi i skolan *inte* tar hänsyn och hämtar näring i det vardagliga språket försvårar vi lärande. Att värdera elevens språkbruk som en resurs är att ta elevens perspektiv och det har i flera andra studier visat sig ha heuristiskt, emancipatoriskt och pedagogiskt värde (jmf. Ash, 2008; Brown & Ryoo, 2008; Kattman, 2008; Zohar & Ginossar, 1998).

Vygotsky (1978) introducerade begreppet den närmaste utvecklingszonen (ZPD), som skillnaden mellan den problemlösningsförmåga en elev visar, dels enskilt och dels assisterad av en vuxen eller kamrats hjälp. Detta tolkar jag som två zoner eller positioner, en *nuvarande* och en *potentiell* position. Inom science education har forskningsfokus framförallt gällt elevens nuvarande position, vanligen benämnd ”elevers förförståelse”, och mycket av denna forskning finns samlad i en databas[12] (Duit, 2009) med 8 400 artiklar om elevers och lärares uppfattningar (’conceptions’). Dessa undersökningar av elevers förförståelse är givetvis en bra utgångspunkt när undervisning ska planeras, det är en indikation på elevernas språkbruk före undervisning. Den potentiella zonen, språkbruket efter undervisning, har inte fått lika stor uppmärksamhet, men resultaten i denna avhandling pekar mot resonemang som kan ingå i den potentiella zonen och därmed, enligt Brown och Ferrara (1985) resonemang som undervisningen bör sträva mot.

Resonemang som pekar mot den potentiella zonen, har dels ett innehållsspecifikt perspektiv där analysen visar på olika konceptuella komponenter som har betydelse för ett vetenskapligt språkbruk, exempelvis den roll som befintlig variation, slump och olika reproduktionsförmåga har. Analysen visar också

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på skillnader vad avser epistemologiska aspekter som pekar mot mer generella mönster i relation till kvalité i resonemang. I avhandlingen exemplifieras olika kvalité genom elevers val att ge beskrivningar eller förklaringar, och genom elevers val av förklaring i teleologiska eller kausala termer. Elever väljer också att hänvisa till olika resurser för att stärka sina resonemang, här visar referens till namn (exempelvis Darwin) eller uttryck (exempelvis 'survival of the fittest') lägre kvalité än referens till en sammanhängande teorisk resurs (exempelvis evolutionsteorin). Kvalité kan också visas genom att länka flera exempel till samma generella teoretiska idé eller att ge flera exemplifieringar till en generell teoretisk idé.

En av de ontologiska aspekter som eleverna i sin diskussion berör gäller ett grundantagande inom naturvetenskapen: att världen är möjlig att förklara i termer av mekanismer och bara mekanismer. Det innebär att i förklaringar inom naturvetenskap finns det inte utrymme för ändamål, önskningar eller intentioner – detta är ett perspektiv som ter sig udda och långt ifrån elevens värld och därför bör perspektivet diskuteras explicit med eleverna. Till exempel att forskare accepterar (inte *tror* på) teorier som den just nu bästa förklaringsmodellen och att naturvetenskap syftar till att förklara hur (och inte *varför*) den fysiska världen fungerar. Med en öppen diskussion av epistemologiska och ontologiska frågor i klassrummet kommer förhoppningsvis fler elever att ta sig an ansträngningen, som trots allt behövs, för att skapa mening av skolans naturvetenskap.

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# Appendix A

## Swedish national steering documents

The analysis has three aims, firstly to present an overview of the different Swedish steering documents (education act, curricula and syllabuses), and especially their relations with respect to responsibility between national authorities and individual schools/teachers. The second aim is to explore in what ways the steering documents pay attention to, and articulate the notion of *scientific literacy.* Thirdly, the analysis explores the ways the documents describe (prescribe) how two areas, within the domain of science education, are to be treated. These areas are "model/theory" and "biological evolution"; analytical attention is also paid to perspectives and elements that are absent in the official documents.

### Continuity and hierarchy of responsibility

The Swedish compulsory school (lower secondary) includes students in pre-school classes and grades 1 – 9, which means that students that are approximately 6 to 16 years old. Students aged 16 – 19, grade 10 – 12, attend non-compulsory school (upper secondary). Although being voluntarily, more than 90% of the students choose to attend the non-compulsory school. In 1994, both the compulsory and the non-compulsory school system were provided with new steering documents. The two curricula (Lpo 94 and Lpf 94) were (at the time) presented in a single document, thus indicating a vision of continuity in the school system. These curricula are fairly similar in content and structure, and define two types of goals, goals to strive towards and goals to attain.

> **Goals to strive towards** specify the orientation of the work in the school. They specify the qualitative development desired in the school.
>
> **Goals to be attained** express the minimum levels pupils should have attained when (on)[1] leaving school. Both the school and the principal organiser are responsible for ensuring that pupils are given the opportunity of attaining these goals. (National Agency of Education, 1994a and b, p. 8 and 10, respectively)

Both curricula are formulated in line with the Swedish school policy, meaning a goal-based system with a high degree of local responsibility, thus leading to a hierarchy of responsibility in relation to attainment of goals. In brief, this means that the Swedish government formulates the overall goals (to strive towards and to attain) in a document labelled "curriculum". These documents are fairly short, about 15 pages each for the two school forms, with headings such as *norms and values, knowledge*, and *assessment and grades*.

The syllabuses (from 1994, but partly re-worked in 2000) deal with goals for each subject, one at the time, but the overall intention is to "make clear how the subject contributes to fulfilling the goals of the curriculum, as well as the reasons for studying the subject in order to fulfil different societal and civic needs" (National Agency of Education, 2000a, p. 5). The National Agency of Education has the assignment to formulate the syllabuses, with goals to attain in school years five and nine, plus criteria for grading; however the concrete interpretation of all these documents is delegated to the individual school (teachers). In official documents, this hierarchy of responsibility is formulated as:

> The curriculum and syllabuses are connected to each other and should be regarded as a whole. Both the curriculum and the syllabuses shall provide the foundation for teaching. The syllabuses are a concrete transformation of the goals in the curriculum. /…/ The structure of the syllabuses reflects the division of responsibility between the state and the professionals in the school. By means of setting up the goals, as well as the results to be expected, the state imposes demands on the quality and equivalence of the education. How the goals are to be attained, namely choice of content and method, is determined by the teacher (National Agency of Education, 2004, p. 16).

**Scientific literacy in curricula**

In this section, the analysis aims at exploring an issue that Roberts (2007) declares is inherent in all science education: "the role of two legitimate but potentially conflicting curriculum sources: science subject matter itself and situations in which science can legitimately be seen as to play a role in other human affairs" (p. 729). A curriculum can take several positions in relation to the dilemma Roberts refers to: science for its own sake, career versus science for all and citizenship.

When arguing about the aim of including science in the curricula, one can focus on two different views; the arguments could be bildung/literacy or instrumentalism (Sjøberg, 1997). These relate to the arguments that Millar (1996) coined as: utility, economics, democratic, and cultural/social. The focus on the instrumental part is grounded in arguments resting on utility and economics. On the one hand, in relation to society, it is claimed to need scientists for its welfare and economic growth and on the other, in relation to the individual student, meaning the competence of mastering a life in modern society, and a presumed economically rewarding career. The arguments that point to literacy rest on considerations concerning democratic and cultural issues. The students of today will be citizens in a future democratic society, which hosts a range of decisions that could be informed by insights from science. The cultural arguments mainly point to the impact that science has and had on our society. The impact is, in my view, thoroughly embedded in our everyday life to an extent that it is rarely discernable, separable, or even reflected on.

The Swedish Education Act (1985:1100) points to an aim of the school system well in line with an education for citizenship. For example, in the second paragraph it is stated that "the education shall provide the pupils with knowledge and skills and, in co-operation with the homes, promote their harmonious development into responsible human beings and members of the community".

In relation to knowledge, the curriculum for compulsory school, continue the vision of the Education Act towards citizenship and literacy when claiming that school should "take responsibility for ensuring that pupils acquire and develop the knowledge that is necessary for each individual and member of society /…/ acquire good knowledge in school subjects and subject areas, to develop themselves and prepare for the future" (National Agency of Education, 1994a, p. 9). The curricula state that knowledge is a tool when critically examining and evaluating statements, for example, about requirements for a good environment. Arguments in line with utility or economics are rare, and the few that occur could also point in other directions. For example, the goal: "have fundamental knowledge about what is necessary to maintain good health and also understand the importance of lifestyle for health and the environment" (p. 10). This goal indicates a type of knowledge that could be useful for the individual students' mastering of life, however, at the same time it points towards the future and citizenship.

In the curricula for the non-compulsory school (grades 10-12), the vision of citizenship is toned down; instead, goals in relation to future education and working life emerge: "develop the knowledge of pupils as preparation for working life or studies at university and university college etc., and also as preparation for adult life as a member of society taking responsibility for one's own life" (National Agency of Education, 1994b, p. 8). The individual students' use of knowledge is focused on; this is mainly articulated as a need for *life-long-learning* and *preparedness for the future*. For example, students should use their knowledge as a tool to: "critically examine and value statements and relationships /…/ overview large areas of knowledge and develop an analytical ability and thus come closer to an increasingly scientific way of working and thinking/…/ have good insight into central parts of the Swedish, Nordic, and Western cultural heritage" (p. 10-11).

I would like to remind the reader that the idea of *knowledge as a tool* is part of both curricula.

**Scientific literacy in syllabuses**

The syllabuses for compulsory school have a common text concerning science studies along with criteria for grading, followed by separate texts on physics, chemistry, and biology. The common text (National Agency of Education, 2000a), points to science as project in line with the notion of scientific literacy; for example: "a central part of the Western cultural tradition" (p. 39) and "the education thus affects pupils both as individuals and as citizens of society (p. 41). The syllabus is written from the perspective of humans, for example, when arguing for a constructivist view of the formulation of knowledge claims: "develop the insight that science is a specific human activity forming part of our cultural heritage" (p. 40), and in biology, in relation to humanbeings, "Biology looks at people as biological beings" (p. 45).

In the criteria for grading in science studies in compulsory school, the issue of using knowledge in science as a means in relation to participating in an argumentation is expressed like this (National Agency of Education, 2000a, my translation):

> **Criteria for pass**: The students use their knowledge about nature, humans and their activities as argument supporting claims regarding issues about environment, health and social life.
>
> **Criteria for pass with distinction**: The students use their knowledge of science in order to examine and value claims regarding the environment, sustainable resources, health and technology.
>
> **Criteria for pass with special distinction**: The students use their knowledge of science in order to examine an argumentation supporting the environment, sustainable resources, health and everyday technology, along with the interests and values that underpin different claims.

In the syllabuses for the non-compulsory school, each national programme has specific goals (ratified by the government). The description of the structure and nature of the Natural Science programme starts with a worldview assumption (Cobern, 2000), when stating that:

> The basic preconception that nature is understandable is a central assumption of the natural science programme. Developments in mathematics, the natural sciences and technology have radically changed Man's view of the world /…/. The natural sciences thus constitute an important part of our culture (National Agency of Education, 2000b, p. 2).

The nature of science, of the natural sciences, includes, according to Cobern (2000), the presupposition that the world is accessible to our understanding in the dimensions of ontology, epistemology, and axiology. Furthermore, Cobern states that "all epistemologies are grounded in worldview presuppositions" (p. 237). A worldview consists of contributions from cultural factors such as gender, religion, ethnicity, ideology, etc. and is the fundamental idea we take for granted and that has been found viable in daily life. In philosophy, ontology is the nature of being or the nature of nature; worldview is an attempt to describe important components. If the goal of education is scientific literacy, one component of the students´ worldview should be a scientific one (Cobern, 1996).

The last sentence in the quote above (*constitute an important part of our culture*) points to scientific literacy as an aim of the programme. This is further emphasized in the text about Biology:

> Aim of the subject: The subject also aims at providing knowledge which stimulates active participation in public debate on the basis of a biological perspective. This covers a deepening of the knowledge of evolutionary processes which form the basis for the diversity of organisms and their genealogy, as well as a knowledge of what is required for ecologically sustainable development. (National Agency of Education, 2000b, p.12).

Thus, both school forms' curricula and syllabuses emphasise scientific literacy as an aim.

**Theory/model and biological evolution in syllabuses**

In the syllabuses for compulsory school the common text, about science, starts out with a few assumptions about how to understand the world and how we have historically acquired knowledge about the world (National Agency of Education, 2000a, p. 39-40):

> Science uses specific assumptions to make nature understandable. The world view this creates differs from those that are obtained through means other than describing nature. The sciences have often taken their starting point in everyday observations and experiences, but during the

course of history have developed increasingly generalised explanatory models. Science studies deal not only with scientific interpretations of everyday life, but also the study of scientific issues and theories./…/

The school in its teaching of science studies should aim to ensure that pupils: develop their ability to see patterns and structures which make the world understandable, as well as strengthen this ability through oral, written and investigatory activities /…/develop the ability to see interrelationships between their observations and theoretical models,

That the world is understandable is a worldview assumption and furthermore, the syllabuses point out that the worldview expressed in science may differ from other ways of depicting the world. The way of acquiring knowledge (epistemology) of the world is described as developing generalised theoretical models. These generalised models should then be used as patterns and structures when making sense of the world. When it comes to the subject of biology, the evolutionary perspective should encompass both the study of the development of life and the way pupils see themselves … "develop their knowledge of the conditions and development of life and are able to see themselves and other forms of life from an evolutionary perspective" (p. 44). The latter aim (to see themselves … from an evolutionary perspective) is a rather demanding task.

The compulsory school has three grading levels (pass, pass with distinction, and pass with special distinction). The National Agency offers grading criteria and states that the basis for assessing is "the student's ability to describe and explain the world around him or her from a scientific perspective /…/ with the help of concepts, models, and theories from biology, physics, and chemistry" (SKOLFS 2000:141, my translation). These criteria will be further discussed below in relation to the criteria for the non-compulsory school.

**Criteria for pass with  distinction**

The pupil uses concepts, models, and theories from biology, physics, and chemistry in situations that are new for him/her, in order to describe and explain processes and phenomena in the world around.
The pupil differentiates between scientific and other ways of describing reality..

**Criteria for pass with special distinction**

The pupil uses concepts, models, and theories from biology, physics, and chemistry in order to create new questions and hypotheses about phenomena in the world around.
The pupil identifies differences between scientific and other way of describing reality

In the syllabuses for the non-compulsory school, all of the 17 national programmes have eight subjects/courses in common to ensure that every student has the opportunity (if they pass) to qualify for studies at university. In addition, each programme has syllabuses for programme-specific subjects/courses. The students who are focused on in this paper followed the Natural Science programme, the subject Biology, and a course labelled Biology A. Consequently, this analysis of steering documents focuses on the syllabus for this programme, subject, and course.

In the section above, I quoted parts of the aim for the subject Biology, which emphasized the importance of deepening the knowledge of evolutionary processes in order to understand biology. This focus on the theory of evolution is further stressed in the following formulations about the subject Biology and the course Biology A (National Agency of Education, 2000b, p. 13):

> Biology is the science of life, its origins, evolution, forms and conditions.
>
> Life is characterised by a high degree of order. This can be described in a system of different levels ranging from molecules right up to the ecosystem. Each new level creates new relationships and questions. The subject covers not only biological organisation, but also the interaction between and within levels. The theory of evolution is basic to the study of this interaction. /.../
>
> The school in its teaching of biology should aim to ensure that pupils: develop their ability to use biological theories and models, as well as assess their validity and limitations. /…/
>
> Biology is the science of life, its origins, evolution, forms and conditions. The subject covers not only biological organisation, but also the interaction between and within levels. The theory of evolution is basic to the study of this interaction. /…/
>
> Biology A presents natural scientific theories about the origins and development of life. The composition of different species in an ecosystem, as well as the behaviour of organisms is viewed from an evolutionary perspective.

How this will be achieved in the classroom is more sparingly described. One of the goals might give a hint, since students should be "able to communicate their knowledge and experiences in speech and writing, as well as have acquired insights into language as a means of learning and developing concepts" (ibid, p. 10).

The National Agency also offers grading criteria at three levels. For example (ibid, p.15):

**Criteria for Pass:** Pupils describe the main features of some biological theories.
Pupils use biological concepts, models and theories introduced to describe biological phenomena and relationships.
Pupils differentiate between scientific and other ways of describing eality.

**Criteria for Pass with distinction:** Pupils use biological concepts, models and theories to explain biological phenomena and relationships, as well as apply these to situations in everyday life.
Pupils examine and discuss issues and hypotheses concerning phenomena in the surrounding world on the basis of biological theories and models.

**Criteria for Pass with special distinction**: Pupils compare and evaluate the validity of different models and theories, as well as identify differences between scientific and other ways of describing reality.
Pupils integrate knowledge from different sub-areas, and relate this knowledge to overall theories.
Pupils analyse and discuss new issues and hypotheses concerning phenomena in the surrounding world, as well as reflect on their validity on the basis of biological theories and models.

When comparing the two curricula and syllabuses, there is continuity and there are similarities. As a final conclusion, I will point to three: *grading, knowledge as tool, and lack of guidance*, which have implications for the design-based research that has been undertaken.

In the guidelines for grading, both the syllabuses stress the use of scientific concepts, models, and theories; furthermore, the syllabuses point to different quality in their use. In non-compulsory school, the quality is described in the criteria for grading: use … to describe, use … to explain, and analyse and discuss new issues. In compulsory school, the same issue (the increasing ability to use theoretical tools) is described as: use … in situations that are new, use … in order to create questions and hypotheses. Concerning the relation between scientific and other explanations, the syllabuses for both school forms formulate the different quality as: differentiates and identifies differences. Thus the grading system shows similarities, both with respect to areas to assessing and in terms of words for quality.

Understanding knowledge as a tool is a goal in both curricula, among other things, with reference to *critically examine and value statements and relationships*. The relation between language and tool in the curricula for compulsory school is expressed as *learn to listen, discuss, reason and use their* *knowledge as a tool.* In the syllabuses, tool is used with special reference to theoretical models: “In science studies, these models provide tools to clarify and study issues and feelings arising from contact with nature, with the human body and with technology” (p. 41). In the goal for the Natural Science programme, tool is used with special reference to language: “Language is a tool for communication, as well as for reflection and learning (p. 7). These epistemological assumptions of how to understand knowledge also have implications as guidelines for teaching, which will be further discussed in the next section.

The Swedish school policy is to delegate many decisions to the individual schools and teachers; when analysing the curricula and syllabuses, it becomes evident that there is very little guidance when it comes to a teaching methods or specific content to teach. For example, in spite of the fact that the theory of evolution is stated to be a core theory, there are no key concepts mentioned. Should teaching include natural selection, sexual selection, and/or no selection (neutral evolution); should heredity and origin of variation be included, are human beings an example of organisms even when studying evolution, etc. Teaching methods are also an open question; should teaching include lectures, laboratory work, field trips, computer activities, inquiry-based teaching, etc. There is one hint of advice in the curricula, since both curricula emphasize oral and written activities in order to understand; language as means of learning. These formulations indicate that activities that include communication in speech and writing should be part of the teaching.

In summary, this analysis concludes that the steering documents declare that the aim of schooling is to prepare students for citizenship; a conclusion that counts especially for compulsory school. The kind of content, in all school forms, that could contribute to encompassing such an aim, is to focus on the role of theories and models and in Biology, the theory of evolution is pointed out as core aspect. Furthermore, the theories and models should be regarded as tools. What is less articulated is *how* the overall goals and aims are to be achieved, for example, is the choice of teaching method, as well as specific and exemplifying content delegated to local schools and teachers.

Notes:

1. This exchange of words (when/on) is the only difference between the two documents.

# Appendix B

## Pre and post analysis in project A (upper secondary)

The project was documented by means of a pre- and post design and these tests are used here as an internal validation, and data will be presented from two questions that were equal in both tests. The pre test was given two weeks before teaching and the post test ten months after the teaching (both tests were anonymously answered). Both questions concerned the origin of variation; one was a about the origin of new traits in general and the other was about the origin of a particular trait (webbed feet in ducks). The multiple choice question (Figure 3) was formulated as part of the project. The second question (Figure 5) was adapted from Bishop and Anderson (1990) and Jensen and Finley (1995) and the students were asked to estimate with the use of Likert scales.

Throughout the course of evolution, living organisms have developed a lot of different traits. What is the origin of this enormous variation?

- The traits arose when they were needed
- Random changes in the gene pool of the organisms
- Living organisms strive to develop
- Great variation is needed in order to achieve balance in nature.

**Figure 3.** Multiple-choice question about origin of a trait.

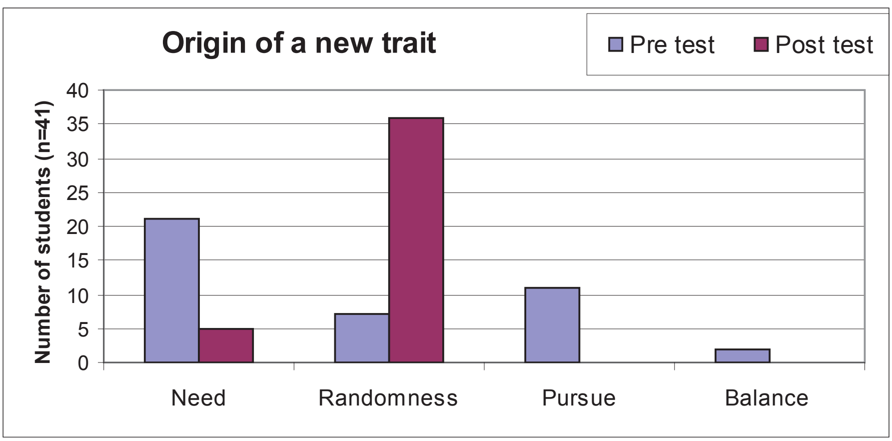


**Figure 4.** Students' pre/post-test choice of the origin of a new trait (n = 41)

| Ducks are animals living in water. Their feet are webbed and this trait makes them good swimmers. The trait of webbed feet in ducks appeared in their ancestors because: | | | | | | |
|---|---|---|---|---|---|---|
| they lived in water and needed webbed feet in order to swim | **1** | **2** | **3** | **4** | **5** | of a chance mutation |

**Figure 5.** Likert question about the origin of webbed feet

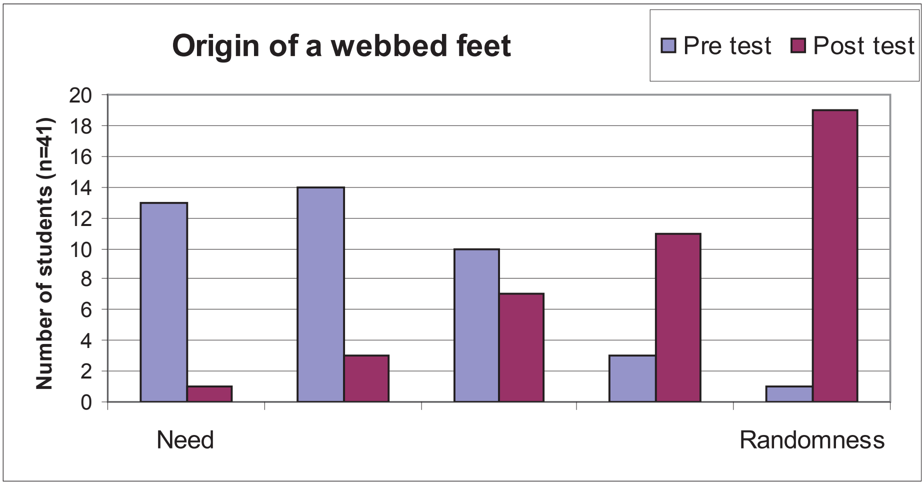


**Figure 6.** Students' pre/post-test choice of the origin of webbed feet (n = 41)

The project involved a total of 48 students; however, only 41 of 48 participated in both the pre and post test. Accordingly, the analysis is based on these 41 students' answers (n = 41). These students chose alternatives significantly more in line with the set learning goal in the delayed post test, calculated with the $\chi^2$-method, $p<0,01$.

The results are a validation of the teaching interventions as a whole; viewed as the learning outcome in conceptual learning estimated by means of written answers to written test questions. This way of making internal and external validation is one way of validating, in general terms, the outcome (Leach, Scott, Ametller, Hind & Lewis, 2006).