Towards an Interlanguage of Biological Evolution

- exploring students’ talk and writings as an arena for sense-making

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The manuscript is divided in two main parts, of which the first part is a background and summary of the whole PhD-project, consisting of the eight chapters above.

The second part is the four papers that report the research, and these papers consist of four separate documents, which are presented on next page.
Papers

Please note that the papers consist of separate documents, which are sent as four attachments.

Paper I  Making Sense of Biological Evolution
- Productive Interaction of Colloquial and School Scientific Language
Olander, C & Ingerman, Å (2009).
Submitted to International Journal of Science Education.

Paper II  Arguing biological evolution in small groups:
The constituents of learning demand in pedagogical context
Olander, C & Ingerman, Å. (2009).
Submitted to Science Education.

Paper III  Teaching biological evolution
– internal and external evaluation of learning outcomes
Accepted for publication in Nordic Studies in Science Education.

Paper IV  Students’ language use when talking about the evolution of life
- negotiating the meaning of key terms and formation of explanation
Olander, C & Ingerman, Å. (2009).
In preparation.
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 of making sense of science. This, my professional background, also directed the choice of general research design, which involves close collaboration with practicing teachers. The work follows one of the main purposes of research in Science Education - developing understanding of the relations between learning and teaching. This thesis contributes to this purpose by exploring students’ mastering of language when making sense of a specific area; biological evolution.

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 argues 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) suggest a ‘mixed method’ approach which, among other things, includes designs which combine qualitative and quantitative research evidence, includes formative and summative evaluation phases, and use several feedback loops in the design. One research approach that aims at embracing 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 both have theoretical orientation and pragmatic aspirations. The aim is developing domain-specific theories about both the process of learning and the scaffolding strategies that are designed to support that learning. Design-based research includes enacting specific learning approaches in authentic practice in an iterative design, thus lending legitimacy both towards academia and practice - the theory must do real work (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003).

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

The recognition of two spheres, mostly labelled the *everyday* and the *scientific*, is a point of concern for many studies in science education, emanating from different theoretical views. There seems to be consensus that the spheres could be analytically identified and separated, for example in relation to social language (Bakhtin, 1981). However, what this implies in
relation to learning and teaching is a matter of discussion. Seeing everyday and scientific as a hard dichotomy, the focus could on the one hand depict the different spheres as incommensurable and regarding the everyday informal language as a source of creating barriers to learning, which has 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 value 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, 2007, p. 67). Certain characteristics are commonly used to describe and differentiate the two spheres, thus also indicating a difference in status (Warren, Ballanger, Ogonowski, Rosebery & Hudicourt-Barnes, 2001). The everyday sphere is often described with words like ‘improvisation, ambiguity, informality, engagement, and subjectivity’ while the scientific side is described with ‘rationality, precision, formality, detachment, and objectivity’ (p. 530). Furthermore, the relations between the different spheres could be regarded as complementary (Vygotsky, 1986), dichotomous (Chi, 2005; Shtulman, 2006), or continuous (Brown & Ryoo, 2008; Warren et al, 2001).

If the idea of different social languages is taken into consideration when teaching it can enhance contextual shifting between everyday and scientific frameworks of understanding and appropriation of scientific language (Reveles & Brown, 2008); with this the students could become bilingual. 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 interlanguge (Barnett, 1992; Lemke, 1990). With this more personal, dynamic, and mixed language the possibility increases of connecting and bridging between informal and formal accounts of phenomena (Brown & Spang, 2008; Gomez, 2007). This mixture of two social languages is taken into analytical use in science education research when, for example, examining teaching and learning about biological adaptation (Ash, 2008) and teaching and learning about evaporation, boiling and condensation (Varelas, Pappas & Rife, 2006).

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 in schools is to introduce the language of the scientific community (Mortimer &
Language provides us with words and terms, grammar, and semantics and it is the combination of conceptual and language components that enhance students' conceptual understanding (Brown & Ryoo, 2008). The school scientific language makes use of numerous technical words/terms (for example beaker, evaporation, and mortality) which are either new for the students or used in unfamiliar contexts, while these terms have become part of the toolkit that teachers use when making sense of science content. Besides that, especially in text books, the language is dense and frequently uses a grammar with nominalisations (Wellington & Osborne, 2001). When combining the terms, they together form thematic patterns (Lemke, 1990) which are a network of semantic relationships which describes the science content; see for example this short and condensed sentence, ‘DNA is located in the nucleus of the cell’. It is the combination of words (the pattern) that is the aim of teaching and learning; the whole (the pattern) becomes more than the parts (the words) – making sense of science involves identifying thematic patterns.

Science dialogue has two patterns, according to Lemke; one is an organisational pattern where people interact with each other in activity structures. Then there is the connection to content, the thematic pattern, which includes constructing complex meanings; semantic relationships in relation to a particular science content area. Since the thematic patterns used in science are, from the beginning, unfamiliar to the students, the teaching must make connections between the scientific expressions and the expressions that students already use when entering the classroom. Here is an interesting intersection between learning, teaching and language. The aim of teaching is, according to Wells (1999) to reach shared semantic patterns, to socialise students into the scientific discourse and at a more general level socialise them into being educated citizens; this is a view well in line with the aspiration that the aim of teaching in school is citizenship and scientific literacy (Roberts, 2007). Learning involves making new meaning of old ones, what we encounter has to fit some familiar thematic pattern, it has to make sense. To talk about phenomena in a new way requires eliciting and bridging your previous understanding, and making sense in the light of what you already have experienced. Thus, learning involves and requires sense-making of relationships; between different social languages as well as the relations to what you have heard before.
Different social languages constitutes 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 specified technical terms, and consequently teaching is suggested to pay attention to these terms, often referred to as concepts. However, the epistemological and ontological aspects have not got the equal amount of attention. Those aspects are part of ‘the nature of science’ and influence students’ understanding and motivation of engaging with science in schools (Brown, Reveles & Kelly, 2005; Warren et al., 2001).

One of the most important implications when it comes to epistemology and ontology are that intentions, purpose and agency has potential as explanations in everyday life and language; furthermore, in everyday life every event is not 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 students’ might not think are in need of explaining, they are ‘natural’ and obvious (Ogborn, Kress, Martins & McGillicuddy, 1996). In science explanations are based strictly on causal links, and ontologically science assumes a worldview where nature 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 and meaning making 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 scientific language, and thus presupposes differences in social language. If the learning demand of specific phenomena is identified, then the teaching could more accurately focus the challenge that students encounter when trying to make sense of this particular science topic. This means that different topics will generate different learning demand, for example learning about electricity will generate one learning demand and learning about photosynthesis will generate another. In general the learning demand may be due to differences in the conceptual tools used, differences which relate to ontological assumptions and epistemological underpinnings of the knowledge used (Leach& Scott, 2003).
When using learning demand as 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 then that the students will arrive to school sharing a common social language. ‘In this respect 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’ (Mortimer & Scott, 2003, p. 123). As a tool for planning teaching, the notion of learning demand has shown potential, when applied to phenomena in school physics and chemistry, as for example ‘electricity’, ‘particle model of matter’, and ‘energy’ (Scott, Leach, Hind & Lewis, 2006). However, since different topics will generate different learning demands, more attention has to be drawn to examples dealing with biological phenomena (Lewis, 2008). Furthermore, more attention has, up to now, been paid to the conceptual dimension 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 the everyday and scientific accounts, connected to the conceptual, epistemological, and ontological dimensions. The conceptual notions that are most important in relation to this thesis are linked to variation, especially its origins and possible consequences. The mere recognition of the variation within populations is identified as a key factor when explaining biological evolution (Bishop & Anderson, 1990; Andersson & Wallin, 2006). Furthermore, students have difficulties to pay 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 change in frequencies of traits (genes) in populations over time, as contrast students often view the process of change as if every individual in a population gradually change (Greene, 1990). Selection is a consequence of the meeting between the variance within a population and the environment. The process of selection 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 these components with different merits.

Epistemologically, the assumption that events have a purpose or goal, is a rationale for teleological 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 & Kattman, 2001; Jiménez-Aleixandre, 1992; Kampourakis & Zogza, in press) and stands in contrast to the accepted explanation model in science, the causal explanation. However, there seems no way to escape reasoning with teleological terms; these formulations are an integral part of our language. The rich occurrence and heuristic value of anthropomorphic and teleological expressions guides Zohar and Ginosar (1998) when suggesting that the instruction in school bring up teleological expressions on 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; ‘the non-rational foundation for thought, emotion, and behaviour’ (Cobern, 1996, p. 584). Religious beliefs are the cultural factor and fundamental idea that is most frequently discussed in relation to biological evolution (Reiss, 2009), and specifically studied in an U.S. context (Smith & Siegel, 2004). In a Swedish context a more prominent issue is whether the world has a purpose or not; if agency matters or if the mechanistic explanations in science are valid (Irzik & Nola, 2009). In everyday life agency do matter and taking on a mechanistic worldview, even for short moments in the classroom, might cause difficulties and conflict to students.

**Relations between school science and science**

Perhaps it is obvious, as Mortimer and Scott (2003) concludes, that science and school science differs; however the relations have implications and the relation is explored by Chevallard (1989), when discussing the idea of *didactic transposition*. The transposition is seen as the steps that has to be taken when science (where knowledge is produced and put to
use), is transformed to school science (where knowledge is learnt and taught). The process undergo four steps (Bosch, Chevallard & Gascón, 2005) starting in science settings where the scientific knowledge are produced and used by scientists; then this body of scientific knowledge is transformed to 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 special focus on the use of models in textbooks. Albeit I question the idea that the purpose of didactics is to ‘make science teachable’, I welcome the effort of reflecting on the relation between science and school science. The notion of didactic transposition points towards that science and school science differs on crucial points, not the least in 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 in 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 was generated during two design-based research projects, which had similar approaches, both towards the intended learning outcome and 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 situations. Since science teaching often connects everyday experiences to models, theories, or concepts it is important whether these are seen as product (goal) or process (means). To ‘learn’ a model, theory, or concept could be a goal to attain, but then you open up for the possibility to learn more or less by heart; students repeat the right words. A model, theory, or concept could also be put into use as theoretical leverage, tool or means in the process of sense-making. This use of tool is expressed by Brown, Collins and Duguid (1989) as: ‘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’ (p. 33). The aspiration, when designing teaching in the projects, was to regard theory as means in the process of sense-making; hence the expression *theory as a tool*.  

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The teaching aim was to weave a scientific story around a specific scientific theory; using a product of science as guideline to 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 using the notion of learning demand as design tool. The strategy was enacted through extensive use of communicative activities where the theory was to be talked into existence (Ogborn et al. 1996). Learning outcome and teaching strategy are influenced and framed by normative considerations, for example the school curricula. 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 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 and trends in science education**

What are then 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 follows the teacher-lead triadic exchange of initiation-response-evaluation, IRE (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).

The aim of teaching is to reach shared semantic patterns, socialise students into the scientific discourse and at a more general level socialise them into being educated citizens (Wells, 1999). This means to depict knowledge as socially constructed (Driver, Newton & Osborne, 2000) and view learning as mastering cultural tools and practices (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 within the science education community is an increasing attention on an aim for science education in line with scientific literacy (Brown, Reveles & Kelly, 2005; Laugksch, 2003: Roberts, 2007) and students ability to ‘talk science’ (Ash, 2008; Lemke, 1990; Mortimer & Scott, 2003; Ogborn et al, 1996; Varelas et al, 2007), which includes argumentative skills (Erduran, Simon & Osborne, 2004; Zohar & Nemet, 2002). Theoretically most of these trends emanate from the idea of Vygotsky (1978) that the development of higher mental functioning in the individual is originating from social life; thus involving a passage from social contexts to personal sense-making. This implies that both individual and sociocultural views on learning have to be considered (Leach & Scott, 2003), 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 use of peer group discussions seems to be supporting, especially if the discussion includes different explanatory models (Jimenez- 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 students’ mastering of the school science language; specifically how it manifests in classrooms that focus teaching and learning of biological evolution. In these classrooms there are differences in, for example, the age of the students, school forms, and school context; differences that are assumed to be an asset in the aspiration of making a contribution to the description of the learning demand for biological evolution.

The research questions relate both to an anticipated product, the learning outcome of the teaching, and to the process of sense-making when students participate in learning activities. These activities were, by the teachers, supposed to enhance students’ understanding of biological evolution. A strategy for empirically reach what is involved when students’ make sense of biological evolution would include examination of instances in the classroom where meaning of words and thematic patterns are externalised in writing and talking. Consequently, the analysis will focus the talk around the activities, which also is in line with a view that potential learning is a consequence of participation in activities.

The first set of questions is dealing with design-based interventions and evaluating such interventions.
In what ways are students’ written language developing? To what extent do students appropriate scientific ways of reasoning about biological evolution?

The second set of questions is dealing with students’ talk when working in peer groups.
In what ways are students’ oral language developing? To what extent do students discern and make use of different social languages? What words and thematic patterns are negotiated and focused in the students talk?

The third set of questions is dealing with the learning demand for biological evolution.
How can a learning demand for biological evolution be formulated that includes both oral and written aspects of scientific language? How do students focus their talk in relation to conceptual, epistemological, and ontological aspects of biological evolution?
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 topic area of science in formal settings. Part of the answer lies in the assumption from Lemke (1990) that learning science involves mastering the language of science; learning to use a specialised conceptual language in relation to specific phenomena. You learn this, like you learn every 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 technical terms, specific grammar, and most of all another thematic pattern; a pattern which combine significant concepts into meaningful relationships which are to be understood in terms of language use within a specific field, in this case school science. We will come back to Lemke and conceptual issues as well as epistemological and ontological considerations that are linked to learning the particular topic area that is focused in this thesis. However, first I will present some more general outline concerning learning and development, where the start of the discussion is ideas from Vygotsky and these ideas implications for this thesis.

Passage from social to individual plane

The most central idea in the writings of Vygotsky is that in the child’s development and learning there is always a passage from social contexts to personal understanding (Vygotsky, 1978). It means that we first encounter, to us, new ideas in a social context; these ideas are communicated in various ways, for example by 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 violation. 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, by this claiming that ‘(I)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 specific mechanism at issue is the mastery of external sign forms’ (Wertsch, 1985, p. 66 - 67). In order not to signify some kind of passive transferral in relation to the notion of internalisation Wertsch (1998) suggest 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 always are 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). 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). Those three functions or notions are important not only in relation to educational research in general, they have also implications for the design and the analysis of data in this thesis. These implications will be discussed below, mainly focussing their connection with students’ use of language.

The link between *thinking* and language is viewed by Vygotsky as a relation between outer verbal speech and inner non-verbal speech and he concludes that ‘(A)ll 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 for researchers; on the other hand externalisations could be a source of information: ‘To study an internal process it is necessary to externalize it
experimentally, by connecting it with some outer activity; only then is objective functional analysis possible’ (p. 227). The discussion above is a reason that this thesis generates its data from externalisations, when students write or talk.

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 origin in encounters on the social plane, however 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). A scientific concept’s characteristics is that they are conscious and deliberate, and they are products of school instruction; ‘school learning is concerned with the assimilation of the fundamentals of scientific knowledge’ (Vygotsky, 1978, p. 84). A scientific concept development starts with its verbal specification, while the spontaneous concepts are first known as objects and then verbalised as concept. In this way spontaneous concepts grew upwards and scientific downwards (Vygotsky, 1986). The consequences of the identification of different ways of the formation of concepts, not the least the bridging of those, are a major part of this thesis and will be elaborated throughout the text.

Another higher mental function that Vygotsky refer to is memory; whether memory is totally an individual feature is questioned by Tharp and Gallimore (1986) with the help of a story; 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 co-constructing explanations from smaller bits of information is part of analysis in this thesis. Such co-constructing, I assume, will have most potential if the students’ are offered to act and discuss within a ‘dialogic space’ (Wegerif, 2008), where different opposing views of understanding a topic are held together in tension.
Zone of proximal development

This idea of the potential development between the child’s actual level and the assisted higher level is introduced as a ‘general developmental law for the higher mental functions’ (Vygotsky, 1978, p. 90) labelled ‘the zone of proximal development. It is 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 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 capabilities and the evaluation of instructional practices’ (p. 165).

The points above made by Wertsch and Addison Stone are related to evaluation and assessment of instruction, in terms of cognitive development. In paper III it is argued that a possible implication of the reported study is that it gives examples of students’ ways of reasoning, which 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 bound of the child’s zone – the level of potential development. This connects to instruction where the notion of proximal development also is 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 enhances the child to internalise is labelled ‘scaffolding’ by Bruner (1985) and includes that the tutor directs the child’s attention, reduces degrees of freedom, indicates critical features, and demonstrates possible solutions. It is kind of gradual handover of responsibility, from assisted to unassisted performance (Wood, Bruner & Ross, 1976). The handover is governed by language acquisition and the language could be introduced by teacher or peers and Bruner (1985) express 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-bound 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)

In relation to my thesis there are another three major implications of Vygotsky idea of 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 the development and learning (p. 86); however, according to Forman and Cazden (1985), the role of peer interaction do not get much attention by Vygotsky. In this thesis the intersection of these two claims, the use of language in peer group discussions, is explored in three papers (I, II and IV) - from different analytical starting points (see meaning/sense in 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 formal discipline, that is, to the significance of each particular subject from the view point 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 that is 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 out by researchers how 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 a distinction between *meaning*
and *sense* of a word. Meaning is the stable zone of a word, pointing towards the collective, generalised, and lexical meaning; while sense is more situated and depending 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 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 (p. 244-245).

In Vygotsky’s use of meaning and sense Wertsch (1985) trace two possibly opposing ideas, on the one hand language use as decontextualisation of the meaning of a word. On the other hand language could be used to contextualise, meaning of a word, which is a words 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 brought to use when analysing students’ talk around activities. Furthermore, as Wertsch suggest, the two perspectives, decontextualisation and contextualisation are considered. On the one hand students’ decontextualisations of the, teacher introduced, scientific terms are analysed (paper IV), as well as students’ contextualisation of colloquial/scientific terms used when talking around activities (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 the two. The everyday sphere is often described with words like ‘improvisation, ambiguity, informality, engagement, and subjectivity’ while the scientific side is described with ‘rationality, precision, formality, detachment, and objectivity’ (Warren, Ballanger, Ogonowski, Rosebery & Hudicourt-Barnes, 2001, p. 530). On the other hand, what the existence of these spheres implies to learning and teaching is a dividing line between research approaches (Anderson, 2007), for example the relations between the spheres are depicted as complementary, dichotomous, or continuous.

The variety in labelling everyday concepts or knowledge are evident when looking at the 8400 entries in Reinders Duit’s (2009) bibliography Students’ and Teachers’ Conceptions and Science Education (STSCE). These conceptions are, according to Roth (2005) labelled as: mis-, pre instructional-, informal-, naïve-, non standard-, canonical-, or alternative conceptions. Other labels are ‘folk theory’ (Windschitl, 2004), ‘folkbiology’ (Medin & Atran, 1999), ‘traditional’ or ‘indigenous knowledge’ (Snively & Corsiglia, 2001), ‘intuitive’ or ‘commonsense’ (Sherin, 2006), ‘spontaneous/informal’ (Vygotsky, 1978), ‘vernacular’ (Brown & Spang, 2008), ‘lifeworld languages’ (Varelas, Pappas, Kane and Arsenault, 2007), or ‘colloquial’ (Lemke, 1990). The scientific accounts and language could also be labelled in different ways (significatively, there are less diversity in labelling these), for example ‘formal’ (Vygotsky, 1978), ‘academic’ (Varelas et al, 2007), ‘schooled’ (Tharp & Gallimore, 1988), or ‘institutionalised’ (Bruna, Vann, & Perales Escudero, 2007).

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, p. 158) argues when stating ‘the strong side of one indicates the weak side of the other, and vice versa”; what differs is the origin and the aim of the concepts. In 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 counts 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, transformed to the individual level. Noteworthy is that
Vygotsky’s framework includes all sciences (not exclusively natural sciences), and he often use of the notion formal concepts/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 misconceptions (Chi, 2005; Ingram & Nelson, 2006) or naïve theories (Shtulman, 2006; Vosniadou, 2007). When these are brought to school they are apprehended as making students’ learning more difficult. In studies that draw on the conceptual change model (first introduced by Posner, Strike, Hewson & Hertzog, 1982 and thoroughly elaborated in Vosniadou, 2008) the everyday and scientific spheres 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 to further learning. Consequently, the starting point when designing teaching for conceptual change (Duit & Treagust, 2003) often is to regard students’ everyday knowledge as an alternative knowledge that has to be changed (or exchanged) to the 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.

**Continuous relations**

Instead of viewing everyday views as incompatible with scientific views and, thus, in need of replacement, the everyday language could be seen as an asset when learning the scientific language (Varelas, Pappas, Kane & Arsenault, 2007). 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 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 benefit of all students (p. 548).

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

Students’ efforts of making sense of the scientific language, through the use of everyday language, may result in a new, personal, and dynamic language; an *interlanguge* (Barnett, 1992; Gomez, 2007). This mixture of two social languages is described as ‘hybridisation’ by Bakhtin (1981) and Lemke (1990) calls this mixing and bridging an ‘interlanguage, a sort of hybrid between colloquial and technical 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 mastering of language and learning to talk science the idea of a hybrid language or interlanguage becomes useful in analysing the use of language in school science settings.

The use of a hybrid language could also be noticed 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). A core point, according to Warren *et al.* (2001) and Varelas *et al.* (2007), is allowing everyday reasoning to become an intellectual resource and asset in sense-making. True recognition of both languages is shown by Gomez (2007) when students made use of multiple discourses when doing a science fair presentation. The interplay between everyday and scientific resources enhanced students’ understanding of science. Another way of expressing hybrid mode of communication is coined ‘double talk’ by Brown and Spang (2008). Both the teacher and the students used vernacular and scientific language when performing a task about classification of organisms. Another example is when Ash (2008) focused on the interplay between everyday and scientific discourses when analysing a successful learning episode about biological adaptation. Also Varelas, Pappas and Rife (2006) found learning gains when making an intervention about evaporation, boiling and condensation. The outcome, students’ ability to talk and reason like scientists, is attributed to a switch back and forth between scientific and everyday discourses. This is in line with the advice from Lemke (1990) to let ‘students translate back and forth between scientific and colloquial statements and questions’ (p. 172). Students will start with their colloquial language and along the way their version of scientific language will be an interlanguage.
The language of science

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

The language of science makes use of words that are specialised technical 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/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 needed to be ‘talked into existence for students’ (p. 14). According to Wellington and Osborne (2001) the words of science belong to different categories in relation to how the words require meaning; naming words, process words, and concept words. Naming words are denoted to familiar and often observable objects, like ‘vertebra’ and ‘pollen’ or related to unfamiliar or unobservable objects, for example ‘cell’ and ‘Bunsen burner’. Likewise are the process words both observable, like ‘evaporation’ and ‘combustion’ while others are more abstract, for example ‘evolution’. The concept words, for example ‘heat’ and ‘fruit’ are especially difficult since them, according to Wellington and Osborne cannot be understood in isolation, they are part of networks with other words and depending 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.

Introduction of scientific words and interpretations between 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 like ‘weight’ and ‘hang straight down from one finger’, while the teacher bit by bit introduce 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 to induct the pupils into a shared scientific
A quite different assumption guide Brown and Ryoo (2008) when making an intervention study in grade 5 of minority students about teaching and learning photosynthesis. In this study is firstly conceptual understanding of the terms in everyday language established; only after that the scientific terms are introduced as alternative. For example they encourage and allow the use of expression like ‘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 from the beginning introduced to the scientific terms, but the experimental group performed significantly better estimated with a pre- and post-test design. The outcome is explained by Brown and Ryoo by the ‘content-first’ strategy; first teaching scientific concepts in everyday language and then provide instructional scaffolds into scientific language. The teaching approach built a conceptual continuity between students’ everyday and scientific communication, which seemed to ease these minority students’ feelings of anxiety and cultural conflict.

The grammar of scientific language makes it different and unfamiliar in comparison with everyday language. The preference of making grammatical metaphors, especially nominalisations in scientific language is a field of research put forward by principally social linguistics like Halliday (2004). In the introduction part of The Language of Science Halliday is stressing that the approach is not dealing with words but with grammatical classes. Grammatical metaphor is exemplified with the words length and motion:

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

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<table>
<thead>
<tr>
<th>'quality'</th>
<th>'entity'</th>
<th>'process'</th>
<th>'entity'</th>
</tr>
</thead>
<tbody>
<tr>
<td>adjective</td>
<td>noun</td>
<td>verb</td>
<td>noun</td>
</tr>
</tbody>
</table>
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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 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). However 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 ‘(T)he 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).

In summary, the analysis of language in this thesis focus words and thematic patterns, this in its turn means successive changes of domain in the analytical attention, back and forth between the students’ sense-making of single words to their combinations in specific contexts. The relations between (and significance for learning) the single words/terms and coherent explanations, like the theory of evolution, are expressed 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).

The aim of teaching is expressed by Wells (1999) as a socialisation into the scientific discourse which involves reaching shared understanding of thematic patterns. Since the thematic patterns used in science are, from the beginning, unfamiliar to the students the teaching must make connections between the scientific thematic and the thematic that students already use when talking about a topic. Learning means to make new meaning of old ones, for example how to connect what you hear now to what you heard before; what we hear must fit some familiar thematic pattern, it must make sense. To talk about phenomena in a new way requires eliciting your previous understanding, and making sense in the light of what you already have experienced. Thus, learning science involves indentifying and making sense of patterns; ‘identifying the semantic relationships between the words, that is interpreting them in the context of a thematic pattern; we connect what we hear to something else that we heard before’ (Lemke, 1990, p. 92).
**Argumentation in science education**

The role of argumentation in science education is underplayed, concluded Driver, Newton and Osborne (2000) when they argued for a teaching about science and not only in science. Since then argumentation in school science settings has meet 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) points at four areas where increased argumentation skills has potential of 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 becomes reasoning and knowing accessible, both to the learners themselves and to others and then it could enhance the possibilities to perform 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). Backing is used to strengthen the warrant and rebuttal refers to circumstances where the claim is valid or not. Toulmin’s Argumentation pattern, TAP (summarized in the 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. Toulmins’ Argumentation Pattern (from Erduran, Simon & Osborne, 2004, p. 918)](image-url)
Several reviews have been made (cf. Bennett, Lubben, Hogarth, Campbell & Robinson, 2005) investigating small group discussions effect on students’ understanding in science, including understanding of evidence, attitudes to science and effects of different stimuli. Improvements are visible when interventions use specific programmes fostering collaborative reasoning and argumentation, however in ordinary settings improvements, according to Bennett et al. depends on the stimulus: ‘(b)Based on 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 mentioned ‘diversified or conflicting views’ relates rather well to the before mentioned notion of dialogic space (see for example Introduction, p. 17).
Learning demand

The previous sections survey of renderings of the everyday and scientific spheres has pointed at several interpretations and approaches to the 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 around this topic, and the researchers’ analytical focus when exploring what is involved in these activities.

In the introduction part of this thesis a recent approach that operationalises the recognition of the supposed gap was introduced: the notion of learning demand (Leach & Scott, 1995, 2002). In summary, the notion of learning demand pay 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 the intellectual challenge that students face when trying to make sense of this particular science topic. Generally speaking, the learning demand is constituted of differences in the conceptual tools used, and these differences in their turn relate to epistemological and ontological assumptions.

Apart from the above mentioned issues, the notion of learning demand theoretically primarily rest on the idea of social language (Bakhtin, 1981) and the recognition of two such languages: everyday/spontaneous respectively scientific/formal language. A social language is here 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 taken into use as design tool it is possible to identify the learning demand for a group of learners, according to Mortimer and Scott (2003) because the students will arrive to school sharing a common social language. This relies on the assumption that students’ have shared much of the day to day experiences which forms 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 that are taught in schools have been investigated from the point of ‘students’ alternative ideas’. The previous mentioned bibliography Students’ and Teachers’ Conceptions
and Science Education (Duit, 2009) with 8400 research papers about students’ and teachers’ conceptions of various concepts in biology, chemistry, physics, and earth science are a good starting point when searching typical student views of scientific topics.

In order to exemplify learning demand I take two examples from the research that has been undertaken at the University of Leeds, both from learning physics. The first, about air pressure, is fairly short and only hints what could be the differences between everyday and scientific accounts in the three dimensions: 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 everyday explanations (‘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 make 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 rather unproblematic for teachers in England, 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. The authors summarize 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 (Scott et al. 2006, p. 66)
As comparison, the Swedish syllabuses state as goals to attain for compulsory school at school year 9, in connection to 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 the Swedish teachers has the responsibility and freedom to choose which principles, in what depth and with what teaching methods this goal is to be attained.

Next step, when identifying the learning demand, is to review the literature on teaching and learning about simple electric circuits. Here Scott et al. (2006) refer to two articles about conceptual issues, for example students’ prevalence for reasoning about electricity in terms of source-consumer and that the current differs 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 to combine the ‘theoretical world’ of models and the ‘real world’ of observation and measurements. The second epistemological issue is that students will have difficulties to apply scientific models generally and in a wide range of contexts.

With this the authors have identified the learning demand; it is more or less a comparison of the earlier steps and results in five conceptual issues to focus and one epistemological. These issues that teaching need to explicitly address is 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 I identify 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. The activity addresses battery as a source and what actually happens within a circuit.
Making sense of biological evolution

In this section the three constituents (conceptual, epistemological, and ontological) of the learning demand will be discussed and the text builds on the presentation in the introduction of this thesis (see ‘students’ sense-making of biological evolution’, p. 9).

Conceptual aspects when 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 with scientific language the following quote from Stearns and Hoekstra (2000, p. 9) is relevant (although condensed): ‘individuals must vary in reproductive success; some variation in the trait must be heritable; the trait must be correlated with reproductive success’.

In biology as science all terms could be understood 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 and with regard to genetics in school science Knippels (2002) suggest that the levels of molecule, cell, organism, and population are more important than others. If selection is understood as ‘variable reproductive success’ (fitness) it includes and prerequisite both variation and heredity. Thus selection becomes the ‘goal’ term and we have to start with defining the other two, especially in relation to the levels of organisation.

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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 (variance within a population) is in opposition of a typological focus where a group is defined as an ‘average individual’. When the typological group changes it is a gradual change, in every member of the group (Greene, 1990). A typological focus is close to essentialism, an idea from Plato about “true essence “which is unfolded in a specie, inherent to a causal power; this way of reasoning do 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 focused. The ultimate origin of variation is mutations, but whether it is a random process is a matter of discussion. Indeed there are different mutation rates, for example
depending on environmental reasons and different part 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 judge afterwards and the effect depends on relations to the environment that the mutations enact with.

Heredity is the process that shape likeness and unlikeness between generations; offspring resemble their parents but are not entirely identical. This interpretation of heredity applies mainly to sexual reproduction where the parental generation contributes with half the genome each. The amount of genetic unlikeness (difference) originates from mutations and then recombination and cross-over reinforce the effect. The possibility of likeness increases if the rate is low of three processes (mutation, recombination, and cross-over). These processes shape the organisms’ genotype, while the phenotype (genotype and environmental influences) are the expressed variation. The process of selection works on the phenotypic variation, however 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 both as passive or active phenomena (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 likeness are passive in the sense that the genetic information is unchanged and the active part would then be the shaping of differences of which mutations are the core part. In connection to teaching and learning likeness/unlikeness was starting point in Knippels (2002) teaching strategy. Furthermore, Banet and Ayuso (2003) emphasise that ‘to explain 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* (1859), and still it is, especially if the notions of variation and selection is tied together. However, natural (adaptive) selection is only one among other types of selection, for instance is sexual selection a notion that perhaps better represent the word selection; in the sense that in sexual selection individuals are selected (sorted) during the period of reproduction, while natural selection is more a process of 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 core words are less and better (not least and best), in relation to others in the population and the environment (Mayr, 2004).

On what organisation level does selection work? The most immediate answer is that selection works on the level of individual organisms, while other suggestions often could be derived from or assigned back to the level of individual organisms. Dawkins (1996) proposed gene selection in the book *The Selfish Gene* and several proposals of group selection has been put forward. However, none are fully scientifically accepted (Mayr, 2004), partly because they could be explained by selection of individuals, which also goes for a most frequent expression in colloquial language, ‘for the best of the specie’. Even accepted notions like kin selection (altruistic behaviour of individuals which partly share genotype) and co-evolution (where different species cause evolutionary change in each other) goes back to the level the individuals of which these groups are composed of.

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 at different understanding. The component of differential survival is merely a step towards the most crucial component, which is differential reproduction; however 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 word fitness, for example in relation to physical training, it could in science settings be interpreted as *survival of the fittest* (best fit) or, more appropriate, *survival of the better fit*. 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 has reproduced; however often the expression is distorted to survival of *the strongest*. In biology as science, the notion of fitness is often used in population genetics, and as mathematical measure, and the words best/better refers to absolute respectively relative fitness. Close to the notion of fitness is the component of *accumulation*, which can be seen as the result of repeated selection and it points at a definition of evolution as the *change over time of gene frequencies in populations*. This is a statement that frames selection towards the organisation level of populations, but the level of molecule (gene) is present.
In summary: when it comes to evolution each of the three terms variation, heredity, and selection could be understood on, at least, three organisation levels: molecule, organism, and population; different focus might lead to different views of evolution as a whole process.

- Variations in the DNA molecule (mutations) are the ultimate origin of variation, and this is a random process. Randomness and chance are in itself tricky to define and here it means approximately ‘unpredictable’. Individual organisms are in a genetic sense unique and populations have different degrees of variance. Recombination and crossovers in the process of cell division might enhance variation.

- Heredity is the process that shape likeness and unlikeness, which is strongly connected to the maintenance and origin of variation. Thus, heredity can refer to the organisation level of molecule (DNA), organism (the genotype), and population (accumulation of traits/genes). The latter part is a common definition of biological evolution: change over time of gene frequencies in populations.

- Selection is in a way a consequence of the (hereditary) variation encounters with the environment. The notion of selection is foremost understood as sorting, selecting, and eliminating on the level of individual organisms and with focus on differential reproductive rates. However, the result of selection is observable on the level of populations, where some genotypes become more or less frequent. Selection is a population phenomena dealing with individual organisms and readable as differences in gene frequencies.

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

Epistemology is here understood both in its general philosophical sense, as the nature, origin, and limits of human knowledge (Encyclopaedia Britannica), and specifically 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). Furthermore, epistemological issues are 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 connection to argumentation a learning demand can arise from different
epistemological beliefs, such as **realist**, **absolutist**, **multiplist**, and **evaluativist** (see Table 1, Kuhn, Cheney & Weinstock, 2000).

### Table 1. Levels of epistemological understanding

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

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

When the students’ reasoning is analysed in paper II some of these levels are prominent, for example knowledge claims referring to authorises (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 framing and choice of explanation. Some of these could be traced to the philosophies of Plato and Aristotle (Ariew, 2003). For example, *essentialism* is an idea from Plato where the ‘true’ essence of specie 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, and for example ‘a washing-machine is for cleaning clothes’. Disregarding; adults mainly attribute teleological explanations only to living things but 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’. The prevalence for teleological reasoning is clearly part of every day 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. The everyday language is closely connected to day-to-day 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 escaping them; reasoning with teleological terms are, for example commonly used in the *Origin of Species* by Charles Darwin (Pramling, 2008) and teleological formulations are an integral part of our language. On the contrary, Zohar and Ginosar (1998) suggest that the instruction in school bring up 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 that is favoured in science is the causal explanation; a cause explains an effect. Teleological explanations reverse cause and effect; an effect (webbed feet) could explain 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, proximate and ultimate, according to Mayr (1961) or, as Ariew (2003) rephrased it, proximate or evolutionary explanations. Answers to questions that start with ‘what is the cause’ deals with either short-term (proximate) or long-term (evolutionary/ultimate) perspectives. Responses with short time scales are due to immediate previous events and they are appropriate in medicine and physiology, which also are 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) to conclude that biology consists of two different fields: mechanistic/functional and historical biology (p. 24). To the mechanistic/functional field belongs for example physiology and medicine, which share experimentation as leading method. These are similar to other natural sciences since they can be explained mechanistically by the use of chemistry or physics, for example diffusion in cells or phototropism in plants. On the other hand Mayr view evolutionary biology as mainly a historical branch of biology. Here experimentation is not always possible and instead Mayr suggest that historical narratives (tentative scenarios) become a method. Following this division of biology as science Mayr finds that functional biology often pose the question ‘how’ and in evolutionary biology ‘why’ more often is asked. This is in line with the view of Ariew (2003) who suggests that answers to questions about ‘how’ should refer to proximate causes; while towards ‘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 developed the idea that there are both proximate and ultimate answers to ‘how and why’ questions.

The main pedagogical point in connection to the proximate/ultimate/how/why discussion above is that students often don’t distinguish them from each other (Abrams et al. 2001), and
then students give answers in a context that the teacher did not expect or the students confuse or mix the context. 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. (2001) conclude that if teaching stress 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 here understood 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) within 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). In the area of biological evolution Ferrari and Chi (1998) claim that when it comes to processes students perceive those as either events or equilibration (see Table below from p. 1236). Most biological processes are best understood as equilibriums, and evolution is for sure one of those areas.

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

<table>
<thead>
<tr>
<th>Event</th>
<th>Equilibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distinct actions</td>
<td>Uniform actions</td>
</tr>
<tr>
<td>Bounded (begins and ends)</td>
<td>Unbounded (ongoing)</td>
</tr>
<tr>
<td>Sequential</td>
<td>Simultaneous</td>
</tr>
<tr>
<td>Contingent and causal</td>
<td>Independent and random</td>
</tr>
<tr>
<td>Goal-directed</td>
<td>Net effect</td>
</tr>
<tr>
<td>Terminates</td>
<td>Continuous</td>
</tr>
</tbody>
</table>

It is probably in relation to religious beliefs that ontological issues are most frequently discussed, and 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 %. The acceptance of the theory grows with the amount of education the respondents have been
engaged with, 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, Anderson (2007) concludes that a substantial majority of the students believe in God and show scepticism against the theory of evolution. However, believing and accepting are two different things and Smith, Siegal and McInerney (1995) recommendation for teaching evolution is to be clear about that scientists accept theories, they don’t believe; ‘it is therefore imperative in both teaching and research to use terms accept and reject, belief and disbelief with special care’ (p. 33). This also includes that teaching should not try to change students’ beliefs, and in fact, students do not abandon their religious beliefs as a result of teaching 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). The recognition of different views enhanced students’ understanding (Meadows, Doster & Jackson, 2000) 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 put in opposition
- independence; the two are different projects when it comes to language and epistemology. They are not in conflict, they are put in compartmentalisation. Science deals with “how-questions’ and religion “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 make your religious beliefs be reformulated or even using nature in the seek of the existence of God.

Most science educators take their point of view in accordance to ‘independence’ (Smith & 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 build our worldview, and the next section will broaden the perspective.

A worldview is composed of cultural factors and fundamental ideas that we take for granted; “the non-rational foundation for thought, emotion, and behaviour” (Cobern, 1996, p. 584). These 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. Within the science community there is a tendency to depict science as independent of worldview (Gauch, 2009) for example about its methods and presuppositions. This claim is rejected by Irzik and Nola (2009) since science aim to explain the world, meaning 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.’ (Cobern, 2000, 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 at 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 writings in the Swedish curricula indicate that science lean 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, 2000a, p. 39-40). This has pedagogical implications, for example the students’ willingness to engage with school science may be due to their acceptance of this world view. 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 was generated in line with this approach. Another reason for focusing this research approaches is that it is a strategy that aims at bridging a supposed gap between research in science education and practice (The Design-Based Research Collective 2003; Hiebert, Gallimore & Stigler, 2002; Ziechner & Noffke, 2001). The latter part of this section gives special attention to ways of validating design-based research, mainly students’ conceptual outcomes in written answers.

American approaches to design-based research

In the US, design 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 introducing articles, trace the origin of the design-based research to Allan Collins and Ann Brown. Collins (1992), at the time, advocated for 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 the idea of changing 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 lightening, the employees’ productivity rose. Brown re-examined the data and found that on the one hand not all manipulations did result in improvement of production and on the other hand when it led to improvements three conditions were met: the workers perceived that it was real improvements of the conditions, the workers perceived that the changes was in their interest and the workers perceived that they were in control of their own conditions. Taking these three conditions into
account Brown reverse the problem with Hawthorne effect to a desired effect; she wants the students to perceive that the improvements are in their 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) conclude that his and Brown’s methodological development concerns seven areas. These areas are summarized by Barab and Squire (2004, p.3-4), quoted in Table 1:

… 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>
<thead>
<tr>
<th>Category</th>
<th>Psychological Experimentation</th>
<th>Design-Based Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location of research</td>
<td>Conducted in laboratory settings</td>
<td>Occurs in the buzzing, blooming confusion of real-life settings where most learning actually occurs</td>
</tr>
<tr>
<td>Complexity of variables</td>
<td>Frequently involves a single or a couple of dependent variables</td>
<td>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)</td>
</tr>
<tr>
<td>Focus of research</td>
<td>Focuses on identifying a few variables and holding them constant</td>
<td>Focuses on characterizing the situation in all its complexity, much of which is not now a priori</td>
</tr>
</tbody>
</table>
A similar research methodology is guiding The Design-Based Research Collective (2003) when they propose that good design-based research 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 been presented in a thematic issue of the International Journal of Science Education (Meheut & 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 in line with developing teaching-learning sequences or designs-based research.
1) Development research (Linjse, 1995) has its origins in the Netherlands, especially connected to the University of Utrecht. The approach involves testing of research-based learning and teaching strategies in practice. This is done as scenarios that are content-specific and detailed descriptions of the expected teaching and learning process (Knippels, 2002). The theoretical outputs are didactical structures, for example ‘problem-posing approach’ (Kortland, 2001) where students’ motivation is focused or ‘yo-yo strategy’ (Knippels, 2002) where biological organisation levels are focused.

2) Educational reconstruction (Kattman, Duit & Gropengießer, 1998) has its origins in Germany, especially connected to IPN in Kiel. The approach is building on interplay between a clarification of the science subject matter and an investigation of students’ perspectives. A first step includes literature review and student interviews and a second step 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 (Artigue, 1994) has its origins in France, especially connected to 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 transformed to school science settings. For example, Tiberghien (2000) build teaching sequences about electricity around simplified versions, labelled ‘seeds’, of science models and theories.

4) Evidence-informed interventions (Scott, Leach, Hind & Lewis, 2006) have its origins in England, especially connected to 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 (Scott & Mortimer, 2003). Possible outcomes are ‘design briefs’ (principles) and ‘worked examples’ (suggestions of activities) (cf Ametller, Leach & Scott, 2007). This ‘Leeds-approach’ approach will be more thoroughly discussed in other parts of this thesis.

5) Learning studies (Lo, Marton, Pang & Pong, 2004) have its origins in Sweden and Hong Kong, especially connected to 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 that are in focus are specific and delimited, for example ‘pricing’ (Pong, 2000), ‘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 connected to the University of Gothenburg. The approach 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.

Albeit the differences among the approaches, Lindwall (2008) conclude 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) summarize the design-based approach claiming that ‘it is theoretically framed empirical research of learning and teaching based on particular designs for instruction’ (pp. 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). In the book Educational Design Research (2006) European and American researchers are brought together and van den Akker, Gravemeijer, McKenney and Nieveen (2006) conclude that design research may be characterized 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 upon theoretical propositions, and field testing of the design contributes to theory building (p. 5).

**Internal and external evaluations of learning outcome**

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

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*, that 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. If the intervention has a specific learning goal diagnostic questions could be used in a pre- and post test design. The methodological problems with choosing questions could partly be solved by using validated questions from previous studies, although we have to keep 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 (2006) suggests the use of several questions and estimate consistency among the answers. External validations make use of some kind of control groups, for example another group at the school where the intervention take place, perhaps with the same teacher involved. The point is often to resemble the medical ‘placebo-design’, supposing 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 the least to science teacher and educators which often have a background in natural science research or anyway studies natural science for several years (Juuti & Lavonen, 2006). However there are several difficulties with 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 randomised surveys like TIMSS, PISA, ROSE or national evaluations. The gains are a greater reliability in relation to the questions as such and the control groups are truly randomised samples. However, there are still differences in the context where the students answer the questions, for example you have to consider motivational aspects like the influence of grading.

These kinds of validations make sense and are 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 these validations it is only the start; as 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, p. 18) 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?’
Empirical design

This chapter presents the context where the data was generated; the schools, students and teachers but also the documented activities and their relation to the rest of the enacted teaching intervention. However, since the Swedish school system has peculiarities the 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; 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 please see appendix, for example are all quotes below properly cited in the appendix.)

The national documents

Since the national documents do not prescribe detailed directions, only general goals to attain, the local schools and teachers have the privilege and responsibility to plan their teaching accordingly. That means also 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 on the local schools.
The overall aim of schooling is, in education act and curricula, expressed as *citizenship* which is articulated in line with *scientific literacy* in syllabuses for natural science; for example, is the role of natural science emphasised as active participation in public debate and its role in cultural tradition and heritage.

The recommendations in connection to 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* and another tool explicitly mentioned is *language*, for example ‘learn to listen, discuss, reason and use their knowledge as a tool’. One of the theories that are explicitly mentioned is the theory of evolution.

**Settings**

The groups that participated in this research came from two school forms in the Swedish secondary school system; one came from upper secondary (17 years old, grade 11) which is a non-compulsory school from and one came from lower secondary (11 – 16 years old, grades 4 to 9) which is compulsory in Sweden. To some extent the projects together resembles what Brown (1992) labels 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 since the researchers had rather firm control of 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 significant influence in planning, teaching and evaluation.

Albeit the differences between the projects, two similarities are important to point out already, one in relation to teaching and learning and one in relation to research design. Both projects aimed at a learning goal formulated as: *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 who took place without the presence of the teacher.
The project in upper secondary, in school year 11 (project A)

The first enacted project was in the upper secondary 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 public school; the only secondary school in the municipal and the school 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 with a substantial amount 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 qualification in 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 formulated 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 emanated mainly from 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 pursue’ 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 the students a year later as a delayed post test. Apart from this use, 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 is the focus in paper 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 was a practical organised around three activities: an examination of fossils, an exploration of the evolution of humans, and a small group discussion about the origin of variation. Both the format of the practical and the use of small group discussions were rather well known to the students.

The students belonged to two school classes, totally 48 students, and in this practical they formed three groups. They were divided by the teacher into 12 groups and 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. When performing the discussion they went to an adjacent room, started a video camera, discussed, turned off the camera and continued to the next activity. Discussions lasted between 6 and 19 minutes with an average of about 11 minutes. The remaining 19 students in 5 groups had their discussion in another room. The students were informed that the teacher would not see the tape until the course was ended and the grading finished.

The multiple choice task was used in a pre test, and three weeks later it formed the core part of a small group discussion task. It was introduced by the teacher thus: ‘Discuss task number four from the pre test. Comment the alternatives one by one and argue against and for. Then if you are able, come to a mutual agreement. We will follow up the discussion in the next whole class lesson’. The task to discuss was formulated as:

“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 pursue development
- Great variation is needed in order to get balance in nature”

The alternatives in the multiple-choice question were supposed to illustrate common ideas about the origin of variation, they were ‘seeded’ with frequently occurring student expressions like need and pursue. The evidence-based alternatives are in this way a reflection of the teacher’s 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 variation. A dialogic space (Wegerif, 2008) is opened up and students are offered to explore their understanding of the topic. Doing this, the students’ talk has the potential of being an arena for learning, which is the pedagogical idea. Furthermore, the talk in the discussion could become a research resource, because the talk might illustrate the conceptual notions students rely on and how these are part of epistemological patterns and are ontologically framed.

The project compulsory school, in school year 5 – 9 (project B)
This project builds on experiences from the previous but was enacted 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 announcement-letter to schools, four teachers volunteered to participate. The teachers were all qualified to teach biology at this school level; beside that, they represent various teaching experience, gender, and age. The students were all part of the Swedish compulsory school system and came from different environments; one school was situated in the centre of town, two in multicultural suburbs, and one a bit outside town but still at commuting distance. All four teachers taught the sequence twice with different groups during one school year (Figure 2). This means that about 180 students in eight groups, 11 – 16 years old, were involved.

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<tr>
<th>May/Aug/Sep/Oct</th>
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<th>January</th>
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<tr>
<td>Design meetings</td>
<td>Teaching 1</td>
<td>Evaluation 1 / new design</td>
<td>Teaching 2</td>
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**Figure 2.** Working process during the two cycles

During the first design phase, the teachers and the researcher had four meetings where we made a didactical analysis 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 in this period the teachers gave some written questions about evolution to their own students, which they knew had participated in teaching about evolution. When we later discussed the students’ answers, the teachers were at first dumbfounded about, ‘how on earth could my students write like this’. However, soon we started a rewarding conversation about reasons for students’ reasoning. Retrospectively, this is seen as a turning point. From now on the teachers’ engagement and ownership of the process increased and they made increasingly valuable contributions.

All involved in a project like this do not contribute equally throughout the process. Earlier in this paper the process is described as ‘design, teaching, evaluation, and redesign’; these phases are interlinked but the different actors’ – the teachers’ and researchers’ – contribution varies. In the design phase the researchers were more active in 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 in evaluations and redesign both teachers and researchers were involved.

As 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 expression *theory as a tool* was discussed in the introduction of this thesis, meaning that it may have pedagogical implications if an introduced theory is regarded as goal to attain (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 goal to attain 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 referring to terms like *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 use of, and “invented”, activities that should point at using the key terms and, in particular depict the theory of evolution as a two-part process; the origin of variation and this variation meeting with environment (selection).
Analytic procedure

This chapter is focusing on the considerations made when proceeding from empirical data to analysis of the students’ mastering of the scientific language. The first part will deal with the analysis of the students’ written answers which was (more) thoroughly analysed in the second project (see paper III), therefore the specific examples refer to this project B. The second part of this chapter concerns the analysis of the students’ talk, whose overall design is informed by the differentiation from Vygotsky (1968) about a word’s meaning and sense. The first two papers, I and II, take students sense of the words as analytical starting point, whereas paper IV starts out with the lexical meaning of words and their combination in thematic patterns.

Students’ written answers

In science education research one of the most frequent methods of validating a teaching intervention is to validate in relation to students’ learning outcome of specific learning objectives (Meheut & Psillos, 2004). Such validation could be either internal or external, (Leach, Scott, Ametller, Hind & Lewis, 2006). An internal validation seeks to establish, within the intervention, whether the aims of the specific intervention were met, for example in a pre- and post test design. The purpose of an external validation is to make comparisons with some kind of randomised sample, thus facilitating the possibility of making generalisations.

Most frequently, both internal and external validations make use of diagnostic questions that students answer in individual writing. The construction of specific questions is a field of research of its own (Millar & Hames, 2006), and often researchers make use of previously developed and in that way validated diagnostic questions. When developing questions the aim is often to assess students’ ability to use similar reasoning in a variety of contexts. 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 specie varied, for example seals and cheetahs, while the evolution of a typical trait of that specie was kept as invariant, namely the ability of prolonged diving, and fast running, respectively. A similar shift in what is variant/invariant is made by Asterhan and Schwarz (2007), who also found that the suggested approach did not alter the questions’ validity.

Validations are also made in relation to set learning goals and in this study the formulation of learning goals was done as a didactical analysis of the steering documents, the educational
research literature and the teachers/researchers professional experience. In the first project this 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 the second project that the most thorough validation of leaning outcome was performed and the text from now on refers to this.

The diagnostic tests had several questions but the three which were similar in both internal and external evaluation are focused here. One of the open ended questions were formulated like this at 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 at 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 about 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 do 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 with some key terms: A biologist would explain like this; it occurred mutations in the genes of the cheetah, 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 gets more food, survive longer and then spread its genes.

e) No answer or irrelevant answer, or repeats the question: don’t know etc.

The system of categories reflects qualitatively different ways of reasoning. The answers in the 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 for category b, c, and d). Teleological or anthropomorphic explanations are put together in category b), and here the answers focus purpose (for example in order to). The explanations in category c) and d) rely on the sense 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 various steps, from only mentioning differential survival to differential reproduction and further to accumulation of a trait/gene.

The two other questions dealt with the origin of a new hereditary trait and emanated from 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 with a request to give a reason for 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 is the best. Justify your choice.

- The individual’s need of the trait
- Random changes in the genes
- The specie’s pursue development
- In nature balance is pursued
The alternative that is 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. Two main categories was 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 answer refers more thoroughly to the heredity part of the task. The first type of answers used words like need, wish and/or adaptation, often referring to individual organisms.

When the Swedish National Agency for Education performed the national evaluation in 2003, a random national sample of students in grade 9 was given written questions. The evaluation was performed in the latter part of the spring, approximately three months before the end of the students’ compulsory schooling. In this study we regard this national sample as control group in relation to our experimental group. In Science, students in the national sample were given 37 tasks to solve (divided into three tests), and in the Biology part, three tasks dealt with evolution (one open question and one multiple choice question accompanied with a request to justify their choice). These three tasks were also given to the experimental group, but only at the delayed post-test. In that way they were unfamiliar to the students and could serve as a point of comparison with the national sample. However, the students’ ambition to answer is probably lower in the national sample, for example there are around 50 % who “don’t answer” the open-ended tasks about evolution compared to less than 10 % in the experimental group. It should be noted that it is 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 made in order to get a more fair comparison, and not overrate the results of the experimental group.

The percentages presented in findings are recalculated as proportions of students answering the actual question. The statistical comparisons between groups are calculated with the \( \chi^2 \)-method, with the level of significance set as \( p < 0,001 \). The \( \chi^2 \)-method is way of estimate whether two the distribution between groups differs significantly, but give no indications of the reasons why they are distributed this way (Edling & Hedström, 2003).

The intercoder reliability was checked, in relation to the open ended questions about seals/cheetahs, by giving the answers and category headings to two educational scientists who not were part of the project, but familiar with the content area. They independently
categorised answers; at first the three of us agreed in 77 % of the cases, and after a discussion about interpretation of headings we reached 90 % agreement.

In summary, three questions were the basis of making an internal validation (pre- and delayed post test) and external validation (compared to answers given by a randomised national sample). The students’ answers were assessed with a qualitatively based system of categories, rather than quantitative numeric system. The validity of the used questions were strengthened by their use in previous studies and own pilot testing, and the reliability was enhanced by the use of inter coders. Potential differences between groups were calculated with the \( \chi^2 \)-method.

**Students’ talk**

A strategy for empirically reach what is involved when students’ make sense of biological evolution would include examination of instances in the classroom where meaning of words and thematic patterns are negotiated orally. Furthermore, if the ambition is to explore the ways that students’ bridge between the colloquial and scientific languages (Ash, 2008; Varelas, Pappas, Kane & Arsenault, 2007; Warren, Ballanger, Ogonowski, Rosebery & Hudicourt-Barnes, 2001) we have to seek moments in the classroom discourse where colloquial language is expressed. One set of such moments are 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; Jimenez-Aleixandre, 1992).

The analysis of students’ talk focus two levels, word/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 attention; from meaning of single words to their combinations in specific contexts.

Starting out with word/term, the definition of meaning and sense from Vygotsky (1986) was taken as 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 paper I and II the starting point is ‘sense’. The data is generated from group discussions, which is 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 is defined as the stable, generalised, collective and lexical zone of a word; 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 reformulate the terms in their talk.

What is done in paper IV is to start out with the collective meaning of three terms that construe the theory of evolution (variation, heredity, and selection) and analyse what local meaning (sense) the students made of them. The identification of the terms was a result of a didactical analysis of the language used in the scientific community, hence the collective meaning. Early in the analysis it was obvious that the students rarely articulated the terms in verbatim, instead they reformulated them; consequently, the analysis focused these reformulations. The analysis identified and made tentative use of three discursive strategies that served as conceptual links in the students’ talk: paralleling, transferring, and delimiting. The reformulations are articulated in colloquial language which in its turn could lead to other interpretations than was originally meant. Next step in the analysis focus instances where the students construe explanations, which are when the individual terms are put together by the students in a way that make sense to themselves. Here the analysis focussed the thematic pattern in the explanations and it was possible to identify use of different social languages and different quality in relation in to the essence of the theory of evolution.

The empirical data that the analysis builds on in paper IV is two different activities that students in school year 9 take part in. These activities were designed to elicit the key terms and are in this way a reflection of the teachers’ view of one end of the learning demand; that is the scientific account (social language) of the content to be taught.

The empirical data that paper I and II builds on is more complex, insofar that both scientific and colloquial account is seeded into the activity. Here the analysis focussed social languages and the three dimensions in the constitution of learning demand for biological evolution when students in an upper secondary school performed 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 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 were needed
- Random changes in the gene pool of the organisms
- Living organisms pursue development
- Great variation is needed in order to get 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 biological 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 the students’ articulation of the learning demand. In the activity the ‘initial’ version of the learning demand was put into play, thus turning to a ‘dynamic’ version of the learning demand which opens up a new research agenda. When analysing students’ dynamic exchange of ideas we were able 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 we used elements from Toulmin’s argumentation pattern, TAP (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 could be found in a variety of topics. When judging the trustworthiness, the elements are field-dependant in the sense that evaluation is dependent of the specific topic that is argued about; for example ‘what counts’ as data, warrant, rebuttal etc are field-dependent (Jimenez-Aleixandre & Erduran, 2008, p. 15). Toulmin argues that 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). Backing is used to strengthen the warrant and rebuttal refers to circumstances where the claim is valid or not.
Transcripts from the groups’ discussion where first analysed as a whole, meaning that all talk from seven groups (ranging between 6 and 19 minutes with an average of 11 minutes) were divided in sequences where different conceptual notions were discussed, no matter if they originated in colloquial or scientific language. The three most frequent notions present in the discussion (75 % of the time) were need, randomness, and development. The next step in the analysis connected these three notions with three types of social languages; colloquial, school scientific, and inter-language. The theoretical basis for 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. We made an explicit definition to use as analytical guide based on a synthesis of literature on everyday 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, allows the discussion of most topics, as well as different ways of reasoning side by side. Arguments can be based on person and personal experiences. There is room for true recognition of values and emotions. A consequence of this openness is that great 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 an arena where talk is more freely constituted, for example not specifically adherent 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 of how terms are used and it is productive in 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 production 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 is kind of intermediate between word/term and thematic pattern; the foundation and starting point is
‘term’ but the term is embedded in an utterance that may be a rather diluted thematic pattern. On the other hand these utterances are made within 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 within different languages it was necessary to go back 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 where the conceptual notions hitched into, and made explicit, the epistemological pattern in which the argumentation was made plausible. Similarly, there were moments of epistemological negotiation unfolded new rules for the argument, in which the discussion hitched into ontological framings – such as the domains of where causal and teleological explanations are valid or whether agency matters. In these conceptual, epistemological, and ontological dimensions, it was possible to distinguish differences, which consequently were interpreted as encompassing different degrees of scientific quality.
Findings

Summary of the papers

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

Project A (upper secondary, in school year 11)

Since no evaluation of students’ conceptual learning outcome is done in this project, at least not with the same rigour as in project B, this section starts with a brief evaluation made especially for this thesis.

The project was documented by a pre- and post design and these tests are here used as an internal validation, and I will present data 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 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 to estimate with the use of Likert scales:

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<tr>
<th>Throughout the course of evolution living organisms have developed a lot of different traits. What is the origin of this enormous variation?</th>
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<tbody>
<tr>
<td>▪ The traits arose when they where needed</td>
</tr>
<tr>
<td>▪ Random changes in the gene pool of the organisms</td>
</tr>
<tr>
<td>▪ Living organisms pursue development</td>
</tr>
<tr>
<td>▪ Great variation is needed in order to get balance in nature.</td>
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Figure 3. Multiple choice question about origin of a trait.
Ducks are water living animals. 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

We can use a Likert scale to gauge how students perceive the origin of webbed feet. Figure 5 shows the distribution of responses with a five-point scale, where 1 indicates a strong belief in need, and 5 indicates a strong belief in mutation. The distribution is skewed towards the need category, with a clear majority preferring the need explanation.

The project involved totally 48 students, however it was 41 of those who participated in both the pre- and post test, thus is the analysis based on these students answers (n = 41). These
students chose alternatives significantly more in line with the set learning goal in the delayed post test, calculated with $\chi^2$-method, p<=0,001.

The results is a validation of the teaching interventions as a whole, seen as the learning outcome in conceptual learning estimated through 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). This is a part of the answer to the first research question - students do develop towards set learning goals in their written language.

The sequences as a whole are evaluated, as a product, with the help of students’ written language use; that means more focus on language as goal/ends. This is a more generally accepted evaluation form; it is for example possible to make quantitative estimations and comparisons before and after teaching (internal evaluation) or compared to randomly chosen control groups (external evaluation). However, it is harder to articulate reasons for the change and it are these explorations that are the challenge to find (Méheut & Psillos, 2004). My main aim is therefore to explore the parts of the sequence that consist of the students’ group discussions. The rationale for this is that it was a central part of the teaching strategy to engage students in discussions where reasoning could be exposed, challenged and argued for and against. This means that what is explored is the process of meaning making, an exploration of students’ oral language use; that means more focus on language as means/tools.

**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 mastering the language of school science, specifically the intersection between conceptual aspects of biological evolution and social languages (Bakhtin, 1981). The data was generated from a peer group discussion about the origin of biological variation, a discussion that was based on the same multiple choice question that was used in the earlier mentioned pre test:
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 pursue development
- Great variation is needed in order to get balance in nature

The question as such emanated from a didactical analysis of the learning demand for the origin of biological variation, where the intended learning goal is best represented by alternative two. On the other hand, the research literature that deal with the language that the students enter teaching with concludes that students are likely to explain the origin of variation in terms of need or intentions. These notions are therefore seeded into the other three alternatives and could be regarded as an initial view of the learning demand that face the students.

The analysis principally included three steps:

a) Making quantitative and qualitative descriptions of what notions/words 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 divide the students’ talk into sequences that each could 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 look for sequences in the discussions where the use of language fluctuated.

The 29 students in 7 groups that 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 were spread on other notions. These three most frequent notions (need, randomness, and development) were articulated with the use 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 articulated as for example ‘planned mutation’. However, most frequent are
reasoning with teleological logic, for example ‘need in order to survive’ or ‘developed accordingly to environment’. Often value words reinforce intentionality, for example development has a direction, for the better. The standing of the notions and events are often seen as natural and given a taken for granted domain of applicability; thus there is no need for explaining events.

Interlanguage opens up for 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 strive for development is not necessary in explaining traits. Technical terms are used, however sometimes in a tentative and mimicking style. When value words, like 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 theory or model, for example need is seen a result of selection and refers to ‘group’, not individuals. Random changes plus environment may lead to selection. Furthermore, the difference (and the importance of that difference) between somatic and sex cells are articulated. Development is seen as a two-step process, starting with an existing variation and then selection. Value words are appropriately contextualised, for example ‘better trait’ is delimited to mean resistance of 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 along the students’ discussion the scientific quality of their explanations are improved. The differences between the three notions (need, randomness, and development) are discursive delimitations; it is a matter of specifications of 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 expression such as ‘need in order to’ triggers refinements in
line with scientific language as one of the students articulate as: not originated because it was needed, but remained when it was needed in that case.

The actual process of constructing explanations could be described as learning; anyhow it is hard to separate articulation from learning since they ‘go hand in hand, in a mutually reinforcing feedback loop’ (Sawyer, 2002, p.12). In the discussion, that is reported in this paper, 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. This interlanguage discourse, as seen in the empirical data, is an arena for learning. On this arena for learning, elements of colloquial origin and school science origin are brought in contact with each other, and the meaning of terms and notions can be explored, detailed, and negotiated.

**Paper II**

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


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

In analysis, first structuring tool was Toulmin’s Argumentation Pattern (TAP (Toulmin, 1958). Toulmin argues that 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). Backing is used to strengthen the warrant and rebuttal refers to circumstances where the claim is valid or not. 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). Micro-analysis of conversation (Wickman & Östman, 2002; Ingerman, Linder & Marshall, 2009) could reveal patterns of reasoning and how they develop. Therefore we took sequences of argumentation as our unit of analysis. A typical sequence starts with a warranted claim from one student and continues with a number of questions, counterclaims, rebuttals etc. End of a sequence was defined as the point where some kind of settlement was reached, although temporary, and the discussion took a brief halt. In these sequences of argumentation we searched for how the constituents of the learning demand of biological evolution (conceptual notions, epistemological patterns, and ontological framings) showed themselves.

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

- referring to resources – “sources of knowledge” – for example through naming resources or through linking
- generating explanations – primarily teleological or causal
- linking between general accounts and specific examples

In each of these dimensions, the argumentation can have different qualities. In particular, it can have more or less scientific qualities (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 by naming references (for example, a single name like Darwin) 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.

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.

In summary, when analysing students’ dynamic exchange of ideas we were able 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. The constituents are layered but analytically separable, for example students negotiate the meaning of the conceptual notions: need, randomness, and development. Epistemologically the students make their argumentation plausible by referring to authoritative resources, for example names or theories. They structure their explanations both with internal logic, for example causality or teleological reasoning, and external linking between examples and general ideas. Ontological framing is mainly done as negotiations about what is allowed to talk about or whether agency matters in a school science discourse.

**Project B (lower secondary, school years 5 – 9)**

**Paper III**

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


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

The intended learning goal was formulated thus, 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, here labelled key terms were variation, heredity, and selection. In order to asses 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 some of these questions were also given to the students as post test. These
post tests, performed at least three months after the teaching ended, were also answered in
writing.

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 written questions. This tendency
to answer more in accordance with learning goals was most pronounced among the older
students, the 15 years old. However, also the youngest (10-11 years old) showed significant
improvements and on some questions they even performed significantly better than the older
students in the national sample that was used as a kind of control group.

As external validation three questions from the national evaluation of the compulsory school
(National Agency of Education, 2004) were used as point 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 that 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 had their
teaching in 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, emanates from the aggregated analysis of all three questions
(two open ended and one multiple choice with four alternatives) that were equally formulated
and assessed in both groups. The harsh division in two parts (in line respectively not in line
with learning goal) perhaps violates the earlier mentioned intention of categorising different
qualities in reasoning, but for the sake of clarity in this summary it might be excused.
Table 4. Consistency among three written answers; national sample and grade nine experimental group. Differences between the groups are significant (p < 0.001).

<table>
<thead>
<tr>
<th></th>
<th>No answer in line with learning goal</th>
<th>One or two answers in line with learning goal</th>
<th>Three answers in line with learning goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>National sample (n = 335)</td>
<td>59 %</td>
<td>32 %</td>
<td>9 %</td>
</tr>
<tr>
<td>Experimental group (n = 85)</td>
<td>16 %</td>
<td>41 %</td>
<td>43 %</td>
</tr>
</tbody>
</table>

The general methodological difficulties when performing nation wide 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 efforts of providing reasonable answers; a difference that would favour the experimental group. The figures shown in Table 4 are recalculated in order not to overestimate the answers of the experimental group. However, after these re-calculations there is still a significant gap (calculated with $\chi^2$-method) between the answers of the two groups.

This study indicates that there were gains in accordance to learning goals within the intervention and also in comparison with a randomised sample. The evaluating design, especially the external, could be a methodological contribution when performing intervention studies. The approach with qualitative categorising of reasoning, have the potential of informing teachers scaffolding of students sense-making process towards scientific reasoning; for example it indicates and exemplifies the potential zone of development. However, what is evaluated here is the sequence as a whole and as a product; it does not give many answers to how the students engaged with the process of learning.
Students’ language use when talking about the evolution of life
- negotiating the meaning of key terms and formation of explanation

This paper reports from the same project as paper III, however the analytical attention 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 lean on. The analytical attention focussed two levels, on the one hand the word/term level, meaning students’ meaning making of the terms one by one (Brown & Ryoo, 2008). The other level is when the terms are used together in formation of explanations, meaning the students’ use of thematic patterns (Lemke, 1990).

In order to reach the aim, recordings of students’ talk during classrooms activities were made. In these activities the teacher’s ambition was that the students should make use of the introduced key terms: variation, heredity, and selection. Of the two activities that was documented the first one, predict population, was web-based and the students worked together in pairs predicting the result of existing variation. They got information about a population of reindeers, specifically about the variation in length of legs of these reindeers and the students were to speculate about the length of legs in the future. First the students discussed and then wrote answers which were sent to a data base and an answer was auto generated with new information that the students responded to, for example a population of wolves was introduced. In the other activity, selection game the students actively played the role of predators and hunted paper clips. The population of the prey, the paper clips, was from the beginning represented by one hundred individuals in ten colours (ten of each), but after a hunting session they were decimated to 25 individuals. These remaining clips/preys “reproduced”, and the result was a distribution of colours that no longer were ten of each, some colours would even become extinct after a few hunting sessions while others would increase in numbers.

The analysis was performed in relation to the talk that surrounded the activities and first of all it was obvious that the students seldom explicitly verbalised the key terms, variation, heredity, and selection; instead the students 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 word. Meaning is the stable (generalised, collective and lexical meaning) zone of a word, while sense is more situated and depending on the context of the talk (personal, local and creative meaning).

The analytical focus was on 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 their meaning. 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 identified that the students do not actively articulate the terms, instead they make conceptual links with three strategies; they contextualise as parallel reformulation, with metaphorical or transferring, and reformulation that delimit the meaning. Variation was always reformulated as parallel, a word parallel – difference, while selection was mainly reformulated with delimitations. Heredity was reformulated with all three strategies.

These kinds of reformulations that the students make often dilutes the meaning of the scientific words, since scientific words add conceptual depth and are productive as resource for understanding with more fine 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 wording of the components. I will give one example from the web based activity, predict population:

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 was those who reproduced
85 Eva: exactly, then we write like this ... let us take the example that all reindeers are chased by wolfs ... the fastest survives
86 Emma: which is that with longest legs
87 Eva: because it runs fastest, have a good mutation
Emma: well

Eva: first of all it is a mutation that makes you getting longer legs

Emma: mm

Eva: and since they rather take your friend who don’t have your mutation

Emma: mm

Eva: because they easier get hold of your friend therefore you survive and your children get your dominant mutation (predict population, group 3)

Emma mention 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 is facing the environment (all reindeers are chased by wolfs), thus resulting in selection (the fastest survives). With the introduction of wolfs in this example the students touch upon the notion of selection pressure. The result of this pressure (reindeers hunted by wolfs) is formulated by Eva in a rather personalised stile: rather take your friend who don’t have your mutation /.../ easier get hold of your friend therefore you survive.

This is possibly a contradictive 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 has to be contextualised in order to be comprehensible. Furthermore, as Brown and Ryoo (2008) also conclude, these students’ understanding articulated with their own colloquial expressions might have helped them to articulate an explanation in scientific language in the delayed post test.
Summary of findings

The aim of this thesis is to explore students’ mastering of the language of school science and how a potential mastering is developing. The specific research questions, in summary, concerns the students’ appropriation of scientific ways of reasoning; mastering of language, especially the use and awareness of different social languages; and framing of the learning demand seen as constituted by conceptual, epistemological, and ontological aspects.

To what extent do the students appropriate scientific ways of reasoning about biological evolution? The overall pattern, estimated with a pre- and delayed post test design, is that the students’ answer more in line with set learning goals after the teaching than before. With the precaution that the questions differ a bit between the groups, there is an age gradient in how the answering rates change towards the set learning goal. The oldest students, the 15 and 17 year old, answers differs with approximately 60 percentage units between pre- and post test, while the answers from the students aged 11 -13, differed approximately 30 percentage units.

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

Looking at the types of answers there are two main differences; the first one is that the experimental group to a lesser extent put forward ‘intention’ in their answers, while the national sample favours answers with a flavour of teleological reasoning. Secondly, there is difference in relation to how the questions are apprehended that concerns epistemology. The questions that are used are always articulated in such a way that they explicitly ask for an explanation and a scientific explanation is emphasised (typically articulated as ‘how would a biologist explain …’). To discern, whether the answer should be an explanation or a description, seems to be a complication for the students. The students in the national sample give more frequently answers with descriptions, and not explanations, for example they do not
include reasoning with mechanisms. The majority of the students in the experimental group do reason with reference to mechanisms at the post test, which they did not at the pre test.

Apparently a change in language use when writing answers has taken place, however it is another question whether this, for example the choice of explaining instead of describing, is established in a more general language use, and to what extent it is used in more informal contexts. Putting the question in another way: to what extent have these students seen through, made sense of and appropriated the general thematic pattern in science (causal explanations referring to mechanisms), exemplified with the thematic pattern of explaining biological evolution in school science (natural selection, leaning on the terms variation and heredity). This is a question explored when analysing students’ talk in peer groups.

What happens when the students are offered the opportunity to discuss with peers? The overall impression is that the students take this affordance with earnestness; they focus their discussion mainly on the supposed task, they engage seriously with the opinions of their peers, and take an unafraid attitude in relation to expressing their own lack of knowledge. The students mainly focus their talk on conceptual issues, and simultaneously they are making use of several epistemological patterns; furthermore their use of social language alternate back and forth between colloquial and scientific accounts.

The analysis of students’ language mainly deals with words/terms and their combination into thematic patterns. The first conclusion is that the students very seldom explicitly verbalise the scientific words as such, instead the students make use of three strategies as contextualisation of the terms – paralleling, transferring, and delimiting. These strategies do not encompass all nuances and specificity of the scientific meaning of the word; if, for example, selection is delimited to ‘survival rate’ there is a lack of nuances that is inherent in the scientific meaning, for example ‘reproduction rate’. However, when the words are used in combination (thematic pattern) they get closer to scientific accounts.

Secondly, words that the students explicitly choose to negotiate are need, randomness, and development. While randomness has mainly scientific origins the words need and development have potential as explanation in more colloquial settings; however, in spite of origin, the students found it necessary to discuss what the words implies in relation to biological evolution. When discussing they contextualise the words in colloquial, inter-, and
scientific language. This indicates, on the one hand that it is possible to contextualise ‘colloquial’ words in a scientific language and vice versa. Furthermore, when analysing larger sequences of the discussion the use of colloquial language seems to trigger specifications that are more in line with the scientific accounts – the colloquial language serves as leverage in the students’ talk.

In what ways do the students’ talk inform the formulation of the learning demand for biological evolution? Firstly I argue that this thesis makes a methodological contribution to the operationalisation of the notion of the learning demand, from an initial version leaning on literature reviews to a more dynamic version leaning on authentic classroom discourse. This will be further elaborated in the discussion; here are some results from the analysis of talk.

The students most frequently start out their talk as a negotiation concerning conceptual notions (what does this mean?) that hitch into a discussion about epistemology (what counts as explanation?) and sometimes the talk also hitch into ontology (what constitutes the world?). A typical example of this is the argumentation, analysed in paper II, (Arguing biological evolution … , p. 8-10), which 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.

Other epistemological aspects that the students are discussing refer to resources for knowing and linking between general accounts and specific examples. Together with the before mentioned teleological/causal aspect it was possible to distinguish different levels of quality in reasoning. The weakest quality in terms of scientific reasoning is when argumentation is solely by naming references, for example, a single name like Darwin or 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 before mentioned agency/mechanism, but also negotiations about what is possible to discuss. For example the students choose to only
discuss evolution with reference to animals, not humans; this is (strictly scientifically) arguable but, or perhaps because of this, it eased a tension in the group and their discussion continued.

**Discussion and implications**

In this discussion three main claims that emanates from this thesis will be put forward, claims which may have implications for practice. The first claim is connected to the understanding of the *potential zone of development*, in relation to a specific topic area. The second claim concerns *mastering languages* and the identification and exploration of a hybrid language, interlanguge. The third claim, partly informed by the findings linked to the first two claims, relates to *the constituents in the process of making sense* of biological evolution, meaning conceptual, epistemological, and ontological aspects.

All these claims follow a tradition in science education by means of making fine grained analysis which makes certain delimitations unavoidable. In this case the focus is on a specific situation (formal schooling), age group (11-17 year old), and content segment (biological evolution). Methodologically the analysis focus the mastering of 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.

The idea from Vygotsky about the zone of proximal development is probably one of the most discussed, however most attention in science education research has been drawn to *the actual zone* of development, rather that *the potential zone*. The findings in thesis contribute on the one hand with descriptions and exemplifications of what could be included in the potential zone, in relation to biological evolution. Furthermore, ‘new’ research methodologies when analysing the potential zone are explored and suggested, along with pedagogical implications of enacting these methodologies.

The analysis shows a variety of qualitatively different ways of reasoning about biological evolution. These different ways includes conceptual aspects like origin of variation and the role of reproductive success. Differences also have epistemological origins, for example the students’ choice of making descriptions or explanations, and whether choosing a teleological or casual explanation. Several ways of reasoning is exemplified in this thesis, with typical
student articulation, and as such they represent a pool of potential answers. The students’ articulations 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 which may have pedagogical potential is to pose a diagnostic question to a group of students and putting together the written answers (anonymously) on a piece 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 of judging the potential of each answer is by this handed over to the students. The idea of handover, which was introduced to link assisted to unassisted performance (Wood, Bruner & Ross, 1976). However, I suggest 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 at and scaffold the students 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 thesis main choice of analytical focus, students’ talk in peer groups, was guided by the assumption that talk in peer groups would externalize argumentative discourse in a more authentic way, than for example interviews. With the results in hand I argue that the analysis shed light on the potential zone of articulations about 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 apprehend 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 in’ results from a didactical analysis into students’ activities; these seeds can have both colloquial and scientific origins. It could actually be beneficial with seeds from different origin, according to Wegerif (2008) the chance of opening a ‘dialogic space’ increases if different views are present and held in tension within an arena where different social languages is brought into contact and contribute to the students’ sense-making process.
An expression often used in this thesis is *mastering the language of school science*, which implies that the aim of schooling is to appropriate the scientific language; language understood as specific words and their combination into thematic patterns. The analysis of the students’ use of words/terms emanates from Vygotsky’s distinction between the meaning and sense of a word. 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) I depict the words that emanates from science language, for example variation, heredity, and selection as close to the ‘meaning-side’ of a word (collective, general and lexical ‘meaning’). The identification of the importance of these words comes from using learning demand as design tool, meaning a didactical analysis of ‘the scientific language of the content to be taught’. These words inform the teacher when planning and are ‘seeded into’ activities with the aspiration that the students will make use the words when talking – thus meaning is taken as point if departure, and it is students’ sense making of the intended meaning that is analysed. On the other hand, in paper I and II the activity (the discussion) that is analysed is informed by a mix of colloquial and scientific accounts and the analysis focus the ways the students make sense (local, situated and creative ‘meaning’) of the content – thus sense making is taken as point of departure and co-constructed potential meaning is (temporary) aimed at and often reached.

The negotiations about words hitch into formation of thematic patterns; patterns that lend characteristics from both colloquial and scientific language. When the discussion alternates, as shown in all three papers mentioned above, back and forth between the endpoints, a new hybrid language is established – an *interlanguge*. The mere identification of such a hybrid language advocates that the relations between colloquial and scientific languages are best seen 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 what Vygotsky and the Swedish curricula express); I 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 resources in the sense-making of the scientific language. Single words have to be contextualised in order to be comprehensible, for example words that on the surface have primarily teleological pointing, 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, p. 10)
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 design tool for teaching (Leach & Scott, 2002), however what is analysed in this thesis is the students’ talk around activities; activities which were seeded with insights from the initial version of learning demand. This methodology has pedagogical function (as arena for learning), but it also gives raise to a research resource; the students’ interpretations of the initial learning demand develops to a new and more dynamic version of the learning demand. Important conceptual notions that previous research has pointed out, for example, variation, need, and randomness are discussed by the students. However, I argue that the kind of analysis that is made in this thesis give a more nuanced picture how the students’ make sense of these notions. For example, variation is contextualised with a word parallel (difference), and both need and randomness are discussed with alternating social languages, thus connecting colloquial and scientific understanding. That a notion like development was prominent in the discussion is a rather novel insight and will have implication for future teaching.

That teleological reasoning is a prominent epistemological pattern in the students’ explanations is thoroughly described in literature, what this thesis contribute with are exemplifications of how students’ negotiate and co-construct explanations that often becomes 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 at a different quality in reasoning. One of the ontological concerns that the students touch upon 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 has to be discussed explicitly; doing so more students would relax and hopefully consider to offer the effort that is required in order to make sense of school science.
References


Swedish 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 on 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 grade 1 – 9, that means students that are approximately 6 to 16 years old. Students at the ages of 16 – 19, grade 10 – 12, attend the non-compulsory school (upper secondary). Albeit being voluntarily, more than 90 % of the students choose to attend the non-compulsory school form. In 1994, both the compulsory and non-compulsory school system got new steering documents. The two curricula (Lpo 94 and Lpf 94) were (at the time) presented in single document, thus indicating a vision of continuity within the school system. These curricula are rather 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) 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 respectively 10)

Both curricula are formulated in line with the Swedish school policy, meaning a goal-based system with high degree of local responsibility, thus leading to a hierarchy of responsibility in relation to attainment of goals. In short, it 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 like
*norms and values, knowledge, and assessment and grades.*

The syllabuses (from 1994, but partly re-worked in 2000) deals 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 assignment to formulate the syllabuses, with goals to attain at school year five and nine, plus criteria for grading, is given to the National Agency of Education; 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 refer to: science for itself and career versus science for all and citizenship.

When arguing the aim of including science in the curricula you could focus two different views, the arguments could be bildnungen/literacy or instrumentalism (Sjøberg, 1997), these relate to the arguments that Millar (1996) coined as: utility, economics, democratic, and cultural/social. Focus on the instrumental part is grounded on arguments leaning on utility and economics. On the one hand in relation to the society, which is claimed to need scientists for
its wellfare and economical growth. On the other hand, 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 at literacy lean on considerations about democratic and cultural issues. The students of today are to be a citizen in a future democratic society, which host a range of decisions that could be informed by insights from science. The cultural arguments mainly point at the impact that science had and have on our society. The impact is, in my view, thoroughly embodied in our everyday life to an extent that it is rarely discernable, separable, or reflected on.

The Swedish Act of Education\(^2\) (1985:1100) points at an aim of the school system well in line with an education for citizenship. For example, in the second paragraph it is stated that “(T)he 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, carry on the vision from 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 valuating statements, for example about requirements for a good environment. Arguments in line with utility or economics are rare, and the few that occurs 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” (ibid, 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 future and citizenship.

In the curricula for the non-compulsory school (grade 10-12) the vision of citizenship is toning 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; 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” (ibid, 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, and afterwards separate texts about physics, chemistry, and biology. The common text (National Agency of Education, 2000a), points at science as project in line with the notion of scientific literacy; for example: “a central part of the Western cultural tradition” (p.39) and “(T)he education thus affects pupils both as individuals and as citizens of society (p. 41). The syllabus is written in the perspective of humans, for example when arguing 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 human beings, “Biology looks at people as biological beings” (p. 45).

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

Criteria for pass: The student uses their knowledge about nature, humans and her activities as argument towards claims in issues about environment, health and social life.

Criteria for pass with distinction: The student uses their knowledge in science in order to examine and value claims towards environment, sustainable resources, health and technology.

Criteria for pass with special distinction: The student uses their knowledge in science in order to examine an argumentation towards 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 world view 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 state that “all epistemologies are grounded in worldview presuppositions (ibid, p. 237). A worldview consists of contributions from cultural factors as gender, religion, ethnicity, ideology etc. and is the fundamental ideas 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 in the students’ worldview should be a scientific one (Cobern, 1996).

The last sentence in the quote above (constitute an important part of our culture) point at 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 form’s curricula and syllabuses emphasise scientific literacy as an aim.
**Writings about theory/model and biological evolution.**

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 historically has gained knowledge about the world (National Agency of Education, 2000a, p. 39-40):

> Science uses specific assumptions to make nature understandable. The worldview 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 inter-relationships 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 gaining knowledge (epistemology) of the world is described as developing generalised theoretical models. These generalised models are then to 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 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 levels in grading (pass, pass with distinction, and pass with special distinction). The National Agency offers grading criteria and state that the basis for assessing is “the student’s ability to describe and explain the world around
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 later, in relation to the criteria of the non-compulsory school.

**Criteria for pass with distinction**

The pupil use 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 use 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 ways of describing reality...

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

In the section above I quoted parts of the aim of 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 with 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 is going to be achieved in the classroom is more sparsely communicated. 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 in 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 reality.

**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 are continuity and similarities. As final conclusion I will point at three: grading, knowledge as tool, and lack of guidance, which have implications for our design-based research projects.

In the guidelines for grading both the syllabuses stress the use of scientific concepts, models, and theories, furthermore the syllabuses point at different qualities 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 qualities as: differentiates respectively identifies differences. Thus the grading system shows similarities, both in respect in areas to asses and in terms of words for quality.

Understanding knowledge as a tool is a goal in both curricula, among others with reference to critically examine and value statements and relationships. The relation between language and tool is in the curricula for compulsory school articulated 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 have also 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; analysing at the curricula and syllabuses it becomes evident that there are very little guidance in relation to teaching methods or specific content to teach. For example, in spite of the fact that the theory of evolution is stated as 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 example organism 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. On one point glimpse an intention, 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 enacted curriculum.

In summary, this analysis conclude 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, throughout all school forms, that could contribute to encompass such an aim is 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 are 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.