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A CONCEPTUAL MATRIX FOR SCIENCE EDUCATION

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Abstract. *A conceptual matrix for science education is presented. It contains nine matrix elements, metaphysics, epistemology, ontology, praxis in classroom, content, theories of learning, teachers teaching, students learning and students preconceptions. These elements are linked to each other and constitute a didactical web. The elements in the matrix are regarded from three aspects, philosophical, operational, and interactive. The elements in the matrix and the aspects are discussed from a point of view in which the sociocultural perspective challenges the scientific paradigm of learning. The resulting standpoint is that it is fruitful in science education to utilize the sociocultural perspective in interaction with a constructivistic way of creating knowledge in order to extend the scientific paradigm for teaching and learning in science.*
Key words: science education, didactical matrix.

Background

Science education is a field in which the content of science and the process of science learning no longer is obvious but has to be given justification. A watershed was created with the publication by Kuhn (1962, 1970) of his famous book *"The Structure of Scientific Revolution"*. This book gave a carte blanche for social constructivists from different schools of social studies to express their opinions about the content and development of science. A paradigmatic fight about the nature of science has raged ever since. A reinterpretation of Francis Bacons famous expression: "*Knowledge is power"* has led to the slogan "*Power is knowledge"* which might signify this dicotomy in opinions.

Kuhn (1992) expressed however in his Rotschield lecture a stand against this: "…the strong program (Edinburgh) has been widely understood as claiming that power and interest are all there are. Nature itself, whatever that may be, has seemed to have no part in the development of belief about it. Talk of evidence, or the rationality of claims drawn from it, and the truth or probability of those claims has been seen as simply the rhetoric behind which the victorious party cloaks its power. What passes for scientific knowledge becomes, then, simply the belief of the winners. I am among those who have found the claims of the strong program absurd: an example of deconstruction gone mad."

Collins (1981) expresses his view on the relation between nature and science with the "one liner": "*…the natural world has a small or non-existing role in the construction of scientific knowledge."*

Searle (1996, p. 199) constitutes the essence of the problem with the words: "I actually think that philosophical theories make a tremendous difference to every aspect of our lives. In my observation, the rejection of realism, the denial of ontological objective is an essential component of the attack on epistemic objectivity, rationality, truth and intelligence in contemporaty intellectual life. It is no accident that the various theories of language, literature and even education that try to undermine the traditional conceptions of truth, objectivity, and rationality rely heavily on arguments against external realism. The first step in combatting irrationalism…is a refutation of the arguments against external realism and a defense of external realism…"

To a great extend the development of theories of learning and the subsequent application of these theories on teaching rests on *constructivistic* theories. According to Matthews (1994), the nucleus of constructivism is expressed by Fensham (1992, p. 801) with the words: "The most conspicuous psychological influence on curriculum thinking in science since 1980 has been the constructivist view of learning."

Matthews, ibid.points out that the nucleus of constructivism is a psychological theory about how perceptions are created but *not* about what justifies these perceptions with reference to a foundation in a natural world, which is studied with scientific methods. Matthews (1995) expresses strong criticism against constructivism, on p. 92 he writes: "*My general claim is that what is good in constructivism is not novel, and what is novel in constructivism is bad.*"

Merton (1942, 1973) pointed out that science rests on four ethical assumptions: *Uniformity,* scientific laws are generalizable; *Communalism,* science should be accessible for everybody; *Disinterestedness,* a scientist tries to find the truth about nature; *Organized scepticism,* scientists should always be sceptical in their research.

A critical review of these assumptions is made by Kelly et. al. (1993). They conclude:

"...studies in the history, philosophy and sociology of science have helped redefine science from objective, impartial certification of knowledge to a socially constituted enterprise… Social studies of science in practice question these norms as real imperatives guiding the generation of scientific knowledge."

A critical stance against science is also taken by Latour, (citation i Gross et al. (1996): "*Flight from Science and Reason",* p.. 89). Latour points out that scientific concepts depend on ulterior motives; they have bad justification; they are unclear in their meaning and interpretation depending on changing historical and cultural contexts. Critic of science is also found in Cole (1996), Best et al. (1990). Rose (1997) talks even about science wars or wars between paradigms.

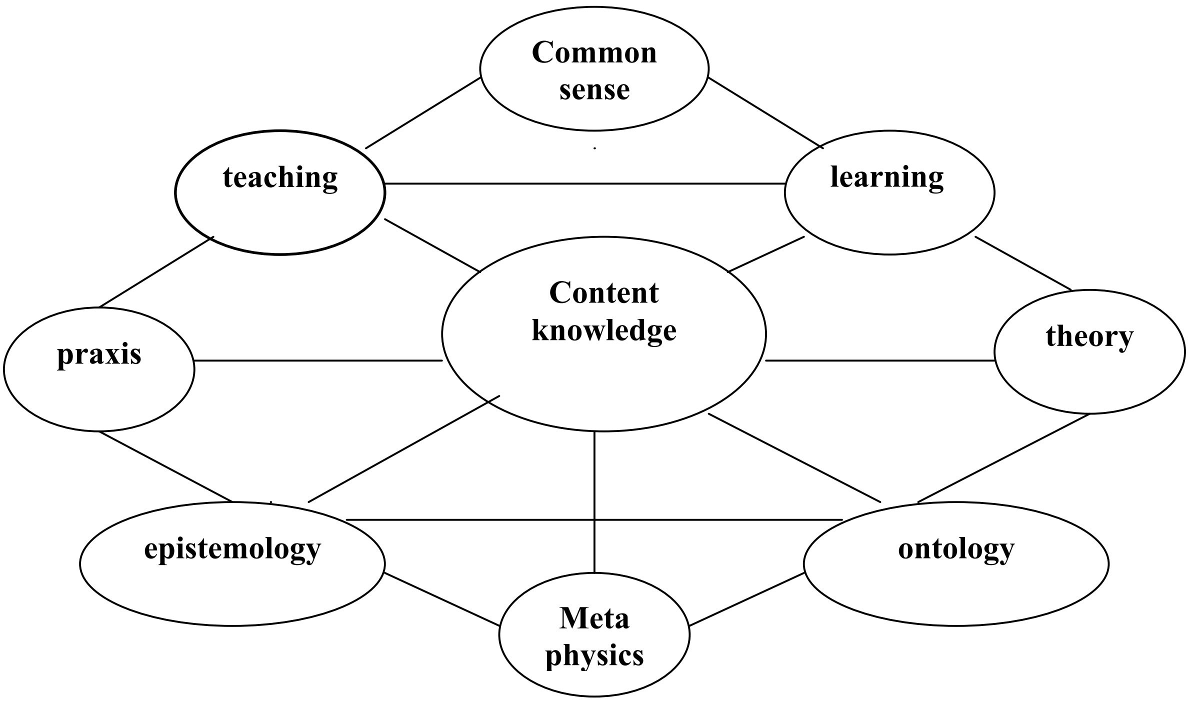
A strong stand is taken by Gross & Levitt (1994) against the theses about nature of science as they are expressed by social scientists. *Higher Superstition* is the telling title of their book. They named a conference report for which they were editors, Gross et al (1996), for *The Flight from Science and Reason.*

An attempt to analyze and to overbridge these conceptions about the nature of science and the nature of learning is made by Ott (1998, 2000).

This discussion about the nature of science and the nature of learning affects science education. It is therefore fruitful to try to analyze the factors involved in this dicotomy of opinions. This war of paradigms is often fought with subtle means. As always it is the winner who dictates the conditions which in this case might affect syllabus, curriculum and resources for science education. It is therefor of value to try to develop a simplified mental matrix.

The Matrix

The matrix for analyzing this *paradigmatic conflict* is constructed in the form of a romboidic figure which is vertically standing on one of its corners.



The philosophical aspect

The foundation element of the matrix is the factor *metaphysics.* This is a point of view from which values and views originate. These values are often so frequently used in our everyday life that we regard them as self evident. There is for example a difference between being a metaphysical realist who assumes that nature exists and being a metaphysical relativist who assumes that everything is relative to something else. There is also a difference between a phenomenological and a newtonian approach to science as exemplified by for example the conflicting theories of colours according to Goethe and Newton. This leads to a *dualistic*, a *non-dualistic* or a *relational* connection between the science and the natural world.

One of the elements in this philosophical trojka is *epistemology,* theory of knowledge: How do we know what is truth? How do we recognize truth? These question go back to the writings of Plato.

The other element is *ontology,* the theory about the content of the world: What is the world made of? The historic background reaches far back to the ancient philosopher Thales who questioned what the world was made of. One modern example of the search for the ultimate consistence of our world includes the famous principle of uncertainty : Does this describe an epistemological or an ontological uncertainty?

The epistemological question about how we reach true knowledge will affects how teaching and learning is organized and performed. The ontological question about what the world consists of affects similarly the content of science teaching.

The operational aspect

This aspect takes, in the discussion of science education, its origin in the factor *content.* This factor, in the center of the matrix, is on one side flanked by the factor *praxis.* Praxis denotes, in this context, the physical performance in the classroom. The factor content is on its other side flanked by the factor *theory.* The teacher utilizes different theoretical approaches in his teaching, for example: constructivism, socioculturalism, phenomenology or liberal education..

The interactive aspect

This aspect has as its uppermost point the *preconceptions* or *common sense* which a student has. The other factors which are included in this aspect are *teaching* and *learning.* These three factors interact in the learning of the student and the teaching of the teacher .

Discussion

When studying the rombohedric representation of these factors, the first observation and reflection is that the elements which are opposing each other in the figure, are in a way related. The preconceptions of the students may have a close relation to her metaphysical conceptions. In the same way, the teachers theories about teaching, affects her praxis within the classroom.

The center of the matrix is the *content of science* .One link which unites pedagogy to the content of science is expressed by Schulman (1987). He created the concept *Pedagogical Content Knowledge*. In this concept pedagogy and content are united and Shulman points out that this is what the teachers profession is all about:

"But the key to distinguishing the knowledge base of teaching lies at the intersection of content and pedagogy, in the capacity of a teacher to transform the content knowledge he or she posesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students."

According to Schulmans conception of teaching, this operational level will fan out into the four subfactors: *comprehension* and *reasoning, transformation* and *reflection.*

That selection of content for science education might be a problematic issue has been discussed by Roberts (1982) who pointed out that selecting a science content might be done in seven different ways: *Solid Foundation, Correct Explanation, Science Skill Development, Self as Explainer, Structure of Science, Everyday Coping, Science, Technology and Decision.*

These emphases link teaching and the selection of content. We have often to ask ourselves as teachers why we do a certain selection of content for teaching. In what way does this selection relate to the preconceptions of the student? There is a need for "*situated justification in action"* and "*on action"* of the selection which is made. This justification could be performed just as Schön (1983) discusses by the term "*reflection in action".*

A researcher in neurocognition, Anderson (1996) writes about the selection of content and the dynamical process of learning: *"The neurocognitive synthesis appears to be especially instructive in helping us understand the dynamics of human active participation in learning currently labeled as constructivist."*

Here is an interesting connection to the constructivistic theory of learning. Anderson goes on: "…understanding the dynamics of human information processing suggests that teaching more conceptual organizing categories rather than large bodies of specific scientific knowledge may enhance the accessability and generative use of the knowledge. This is captured in the aphorism "less is more". This implies, that from the perspective of the learner it is favorable to describe few concepts. These concepts should instead be described with many variations and in differing contexts".

This way of presenting subject matter is also discussed by the phenomenographists Marton and Booth (1997). These authors stress the need for variation in the presentation of content.

Schaverien (1999) applies another perspective on learning and discusses the biological functioning of the brain. This might lead to many consequences for the selection of relevant content and subsequent pedagogical applications: *"…what is being proposed is the reinstatement of brain functioning as a biological process, with all that this entails for a modern biology of learning: essentially that is a view of brains as Darwin machines which generate and test ideas on their value. For technology and science education researchers familiar with the modern history of ideas about generative learning and their precursors in the writings of Dewey, this seems a small step to take, and it is one which is now well supported by neuroscientific evidence… However, its educational implications are powerful: no longer can learning be considered to occur by means of instruction, but rather by means of selection."*

These results affect how content should be organized in order to interact with pedagogy. It is pointed out that it is important to select a few key facts or general ideas which could serve as explicatory models or as mental tools for the students in their everyday life.

In this analyze the theories by Piaget are encountered as these mentalistic theories stress the importance of linking facts into the mental schemes of the learner. An extension of this model is that the learner, according to Vygotsky´s sociocultural theories, is influenced by an external context of learning. It is important to establish links between this external context and the learners internal mental schemes. Vygotsky points out: learning takes part in two stages: first in an interpersonal and social stage and secondly in an intrapersonal or psychological phase.

This way of regarding learning leads towards *eclecticism* which implies unification of theories of learning, for example the mentalistic and the sociocultural theory. These theories have opposing as well as uniting aspects.

Kvale (1992) describes the change from a Piagetian and mentalistic approach to learning into a Vygotskian sociocultural approach*: "From the archeology of mind to the architecture of a sociocultural landscape"* .

In interactive teaching, the teacher communicates and interacts with a group of students. In negotiations within the group and with the teacher the content should be discussed from a variety of perspectives. The knowledge of the teacher is thus important in this context as a discussion without subject knowledge is moot.

Often a metaphore for learning is used, in which the brain is regarded as a computer with a software program and a hardeware memory . The cells of which are possible to be filled with information. A new conception of the brain has however emerged. The brain is thus regarded as ruled by the principle of *neural plasticity.*

The links and interconnections in a brain are, according to this theory, *not,* as in a computer, firmly wired. The brain changes as we learn and it changes also as we forget. The content of the brain could in this case be regarded as being constructed by its own experiences and thus to a certain degree selfmade and in continuous development on its own terms.

Kelso (1995) describes what he means when using the concept neural plasticity:

"Like a river, whose eddies, vorticies and turbulent structures do not exist independent of the flow itself, so it is with the brain. Mental things, symbols and the like, do not sit outside the brain as programmable entities, but are created by the never ceasing dynamical activity of the brain. The mistakes made by many cognitive scientists is to view symbolic contents as static, timeless entities that are independent of their origins. Symbols, like the vortices of the river, may be stable structures or patterns that persist for a long time, but they are not timeless and unchanging."

These theoretical approaches point to the fact that content and pedagogy are linked. This implies that selection of content should be made with the aim, not to teach a lot of unconnected facts, but instead to try to create a conceptual web in the minds of the students. In this web the content, pedagogy and brain functions should interact in a positive way.

Matthews (1994) refers to the physicist Ernst Mach, who already 150 years ago pointed out that he was sorry for those creatures who get mixed in a web consisting of a multitude of facts as in a spiders net: a net to weak to hold them but strong enough to entangle them.

It is however important, in a world with trends of anti-science and pseudo science, to analyze the content of science carefully from the philosophical perspectives of epistemology and ontology. In these perspectives the philosophical questions about the nature of science emerge and are brought to the forefront of science teaching. This implies that a study of the roots to science and to science teaching has to be done in order to be able to answer questions about the legitimization of the subject. Thus epistemology and ontology of science is useful.

The question about how a teacher should act in a classroom and what theories of teaching and learning she should rely on are factors which have close links to content. In this case it is important for a teacher to be able to justify the method she is choosing by reference to a theory of learning. From the key factors in the model links could be formed to different theories of learning.

A tendency to noticed,iis a trend towards applications of theories which are based on the sociocultural perspective of learning. In these theories the content of science is discussed and mediated to the learners in their interaction with artifacts as well as with other learners.

Language and communication are constitutive in the process of learning. Learning is, according to the sociocultural theory, regarded as appropriation of intellectual and physical tools which are used to solve problems in everyday life. It is in this context however important that learners in their communication with their peers not only do discuss scientific concepts in situated scientific context but that they observe the epistemological and ontological questions which are appropriate to the subject studied.

In this context a natural connection is thus made between the operational level and the underlying philosophical level. To act in the operational level without justification from the philosophical level may lead to a misunderstanding of the nature of science. The context and content of teaching should be founded in a philosophical and historical context of the creation of knowledge.

As an example one could observe that students preconceptions often are founded in an aristotelian worldview. At school they are however supposed to treat science according to a newtonian worldview. The aristotelian worldview might however be more natural for the students as it is founded on observations in the everyday world. Wolpert (1992) in his book *The Unnatural Nature of Science,* discusses this discrepancy. He poins out that in the everyday world the unknown is explained by reference to what is known. In science the known is, on the contrary, expressed by reference to what is unknown. A discussion of the strange nature of science is given by Cromer (1993) in his book with the provocating title: *Uncommon Sense. The Heretic Nature of Science.*

The factors above the operational level connect the nature of learning and the art of teaching. This level has links to the operational level as theories for learning will affect the interaction between the teacher and the student. Nielsen & Kvale (2000), question if teaching really is a prerequisite for learning. Students are observed to learn a lot in informal contexts were social communication is predominant. This way of learning is even more important nowadays when the monopoly of access to knowledge, which the school system has had since antiquity, is being challenged. It is challenged by the wide access to computers and to the enormous amount of information which is contained within Internet and by informal learning in science centers. There is a need to reorient teaching from giving information to selection, structuring and justification of information. There is also a need to study the process in which information is converted to knowledge. It is thus important to distinguish between information and knowledge. One definition of knowledge which distinguishes it from information is, according to the sociocultural paradigm, that knowledge is personally owned and situated within mental schemas of learners. This is opposed to information which is to be found in exosomatic environments as, for example, libraries and Internet. In order to get access to the information on Internet student have to have appropriate knowledge to be able to formulate relevant questions. This legitimizes also the central possition of content in the matrix.

In a sociocultural perspective on learning, a discussion about learning is evolving around the concept *Legitimate Peripheral Participation.* This concept was developed by Lave and Wenger (1991) and implies that students start as legitimate participants in a profession from a peripheral position and slowly move towards a center position in which they take on more and more of responsibility in the profession. This is a model for learning which to a certain degree will affect the new teacher education program in Sweden. This way of learning a profession might however not pay due attention to the fundaments of the profession in a historic and philosophical tradition but might prepare students for a more instrumental and situated behavior in which just institutionalized and contemporary pedagogical methods are exposed.

The uppermost factor which symbolizes the preconceptions of the students has a strong link to the teacher - student interaction level. The preconceptions which the student has should act as a startingpoint for teaching. It is obviously the starting point for the students learning. The words by Ausübel (1963) in which he urges the teachers to make sure were the students are and to start teaching from there are always an important remainder about the connection between content and preconceptions.

Summary

In this didactical matrix, the content of science is at the center of the matrix and all the other factors interact with the content. The level of teaching and learning links together the factors praxis, theory and content. *How* we know links together content with epistemology; *What* we know, links together content with ontology and metaphysics. The matrix sheds light on interactions between these factors. A powerful didactical web is created

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Резюме

КОНЦЕПТУАЛЬНАЯ МАТРИЦА ЕСТЕСТВОЗНАНИЯ

Ааду Отт

В дидактической матрице содержание естествознания находится в центре матрицы, а остальные факторы находятся во взаимодействии с содержанием. Уровни преподавания и учебы взаимосвязывают таких факторов как практика, теория и содержание. *Как* мы знаем связывает содержание и эпистемологию; *Что* мы знаем связывает вместе содержание с онтологией и метафизикой. Матрица проливает свет на взаимодействие этих факторов. Таким образом возникает мощная дидактическая сеть.
Ключевые слова: естествознание, дидактическая матрица.

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