EFFECTS OF AUTHENTIC LEARNING AND E-LEARNING IN AN INTRODUCTORY CHEMISTRY LABORATORY COURSE

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Abstract

Research into memory processes has progressed in recent years through the combined efforts of neuroscientists and cognitive scientists. This is especially aided by modern scientific research methods of the brain such as positron emission tomography and functional magnetic resonance imaging. The learner, through interaction with his environment, must actively create individual cognition; the brain is a dynamic adaptable organ. This research will limit the discussion of authentic learning and e-learning to an introductory chemistry laboratory course. The most popular, and yet the most heavily criticized style of laboratory instruction is the traditional (also termed verification or expository) style with a "cookbook" nature. On the basis of pilot action research, the goal of this study has been the use of e-learning for the purpose of placing more emphasis on the contemplation of chemistry's theoretical topics for effecting the quality of conceptual understanding. With systems thinking as a background, the qualitative research method was primarily used, but statistics of the external influences in the e-learning process were also improved. In an e-learning environment, the individually supported development of a learner's conceptual understanding was analyzed by SOLO-taxonomy by comparing the learner's own outcomes. The results show that e-learning with traditional laboratory activities has the effect of forming chemistry concepts, and results in meaningful learning. The SOLO-taxonomy would be a powerful tool for faculty for analyzing points of difficulty or confusion in students' understanding of chemistry concepts. To better understand the effectiveness of e-learning, studies have to be directed toward higher-order cognition by collaborative learning in addition to conceptual understanding of individuals.

Keywords: authentic learning, conceptual development, e-learning, learning in chemistry, SOLO-taxonomy
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1 Introduction

This study examines ideas of ways in which the learning process in an introductory chemistry laboratory course could be affected: authenticity and e-learning. The background behind the study is the common problems in Finland associated with the learning of chemistry: few students and the poor quality of knowledge and skills. The general theoretical starting point of the present study is to describe learning from the chemical and neuro-biological foundations of human cognition. A complete theory of chemistry education shall eventually include a synthesis of neurocognitive theory and a constructivist, in particular a socio-cultural, learning model. The learning function, a student’s studying, is defined in the study as a complex and a dynamic process between a learner and the universe, i.e., nature, designed physical systems, designed abstract systems and social systems. Science is an abstract system of meaning and symbols with which social interaction takes place. Here learning is seen as the result of an intentional activity and personal experience, as a result tuned to the whole of human existence. For instructors the issue in a learning situation is: To what extent is science’s system of meaning compatible with, or attractive to, the students’ socio-culturally-based systems of meanings?

Neuroscientists study the anatomy, physiology, chemistry, and molecular biology of the nervous system. The brain has to, however, be seen from a point of view of dynamism, the science of complex, adaptive systems: it is not the bits that count but the way they hang together (1). Recent neuroscience studies of the mind help in understanding modern learning comprehension. These also have important implications for education helping to explore the possibility of facilitating all individuals to achieve their fullest potential (2, 3). Speculations have changed into cognitive science in the last four decades and psychology (4) is willing to be a component of it.

In parallel with developing insights into the importance of the social and cultural contexts of learning (5–9) the qualitative research methodologies (10–13) have provided perspectives on learning that complement and enrich the traditions of experimental research. Qualitative research is typically a labour-intensive operation used for real problems. In the present pilot study of authentic learning it has taken three years to collect data and analyse these for reflection during the ongoing process and for the next process, e-learning. The aim of changing realities in order to investigate its effects on instructional lear-
ning highlights a social, reflective action as part of the present study. The action research (14–16) here is a combined qualitative and quantitative inquiry.

Little of the new research directions and the increased understanding of the learning process have found their way into the contemporary chemistry classroom or laboratory (17). Chemistry education has, however, much to gain from research. The qualitative researchers of learning distillation in a chemistry laboratory course point out that the traditional curriculum, with its combination of lecture courses and detailed successful laboratory prescriptions, is not succeeding in achieving the ultimate goal at the university level, the students’ own conscious thinking (18). The challenges for chemistry education research are a complex interplay between the global perspective of the process of learning and a logical perspective of the content. The researchers must be familiar with the field of cognitive science as well as chemistry. Communication of research results should include enough information to enable an understanding of chemists, whose training and education have been based on the behaviorist perspective. (19, 20)

From the perspective of socio-cultural learning comprehension, teaching chemistry has to be seen as the socialization of students into a community of practitioners, chemists, and as making chemistry meaningful within a student’s cultural milieu. (21) Because chemistry is an experimental science the laboratory should be a place for practising the ways of a chemist, and laboratory activities should be an essential part of the curriculum. Laboratory experiences have been purported to promote core scientific educational goals: comprehension of scientific concepts; the development of scientific practical skills and problem-solving abilities; and interest and motivation. According to recent studies, the ‘cookbook’ chemistry in laboratory classrooms doesn’t promote the development of higher-order thinking processes and doesn’t motivate students to choose the next courses. (22) How can students be engaged in both chemistry theory and practise, in conceptual development and in acquiring laboratory skills? Are authentic investigations a meaningful way enabling to compare and discuss gathered data within the socio-cultural contexts of chemistry? (23) What about new learning environments (24–26) using ICT? Are these environments engaging students in an active learning process of chemistry from their own starting points? Changing realities requires an organisational openness, including the teacher’s predisposition for trying new instructional innovations (27).

Recent studies have expressed many ways in which laboratory activities can be implicated to meaningful learning in chemistry, (28–35) putting more responsibility for learning on the learner, and giving fewer specific directions. The new perspective of the learning process can also be transferred to the teaching field of computer-aided chemistry (36), which is currently called e-learning. In the empirical part of the present study, the realization of the new ideas of laboratory learning are examined first as a learner’s personal experience in authentic laboratories with the tutelage of experts and second as the quality of conceptual learning tutored in a network environment during the introductory chemistry laboratory course. The nature of this research caters to individual needs and highlights individual differences in motivation and conceptual understanding, which are deemed significant in socio-cultural learning, and specifically in chemistry learning as well. (37)

The present study has used the five-level SOLO Taxonomy in the analysis of learning quality, and thus also in the analysis of the effectiveness of the changes in the learning process. The subject of chemistry seems complex to a novice learner because there are
many concepts that can be observed at the macroscopic level in the laboratory, but can only be explained at the particulate, microscopic level and described at symbolic levels (38). When practices are changed the essence of evaluation is the making of judgements: does this practice facilitate learning? Has this attempt at improving been effective? Many teaching models lack effectiveness in the transmission of concepts. E-learning has for example been successfully used in chemistry laboratory experiments to facilitate students’ conceptual understanding by simulation models, (39) and learning objectives have been evaluated by the four levels of learning (36). We still do not have a clear picture of how and how well e-learning promotes linkage of the three-level concepts of abstract chemistry in long-term memory. This hierarchical nature of understanding (40–42) is an object of wide interest, especially needed within qualitative research, but also in practical educational work. At the same time, modern cognitive interpretations of human information processing increasingly indicate that our interaction with the external environment and conceptual categories and strategies are intimately related to pre-existing conceptions, some of which are unique to our own experience. Hence, in constructing a modern theory of science education, it is the right time to include the neurobiological and chemical foundation of human cognition, especially with regard to the role of existing conceptions in guiding perception and encoding information derived from experiences with the cultural environment.
2 Learners as Systems

Human learning is the complex, continuous process of concrete reality, abstract science knowledge, and social interactions. Everybody has his own external and internal living situation that is affecting the learning process. The complexity of learning has led to this research’s use of systems thinking and asking what a learner is like as a system and learning as a function.

2.1 Systems Thinking

Systems thinking is suitable for studying the learning process because of the complexity of such an event; as a methodology it integrates different disciplines including different sciences in the form of models and analogues. The methodology is an intermediate in the status between a philosophy and a technique or method. (43) Changes in thinking at the beginning of 20th century led to the defining of a scientific paradigm. Today, forty years later, the new paradigm may be called holistic worldview; the world is seen as an integrated whole rather than a dissociated collection of parts.

2.1.1 Methodology

The principle behind the problem-solving methodologies used jointly in different disciplines and technologies is that phenomena occurring in the subject matter are reproduced in some other system, the analysis of which is easier. In an actual study the most effective systems thinker will be working simultaneously, at different levels of details, on several stages. (44) Removing the barriers between disciplines can also open up new frontiers, the study of which can facilitate the solving of practical problems. Such disciplines in the study of the teaching-learning process include the neurosciences, cognitive sciences and pedagogy. In essence they all study at different levels of complexity the physical-chemical processes of biological systems. The processes of the brain are the basis for thought,
and during learning changes appear in the brain; therefore insights into the operations of
the neural network and cognitive processes will help solve educational problems that
seem difficult to handle. (45) For triangulation, two theories of learning, neuroscientific
and educational, increase the reliability of the present study.

2.1.2 Dynamic interactions

A system is a functioning group of components linked together in a particular environ-
ment with which the system may collaborate to achieve its goals. An effective system is
always more than the sum of its parts. When scientifically studying the universe as a sys-
tem (See Fig.1) the same entirety is approached in different disciplines at varying levels
of complexity. Each level of study has properties, interactions in the environment, which
cannot, when examined in that sense, be reduced to another level. Even the properties of
a small water molecule remain unreduced precisely as oxygen and hydrogen even though
we know the distances and bond angles of atoms precisely. Interaction results in a new
level of complexity which has its own properties. In systems thinking attention can be
transferred between the different levels of a system, from one scale to another, from one
level of complexity to another, and from one network to another network. The result of
enormous complexity are so many disciplines that our knowledge of the world is divided
into specific parts. Because education proceeds discipline-specifically, the whole is disap-
ppearing from our thinking. Even when performing research and completing quantitative
tests, complexity requires us to make assumptions, which may cause an unknown factor
to have a dominating effect on our observations. (43)
Fig. 1. A systems map of the universe, paraphrasing Checkland.

Fig. 1 contains the systems which have effect as the background behind the chemistry learning problems processed in this research:

– Natural systems, of which the individual is a part, investigating, describing and learning from these systems.
– Designed physical systems, among other things laboratories, classrooms, and the peat power plant with its equipment. Experts and learners may use and create these systems.
– Designed abstract systems, for instance the symbolic information of chemistry. Experts may create and learners may use these systems.
– Human activity systems, e.g., the activities of an educational society and social interaction systems. The teacher and researcher seek to engineer and activate these systems.

In holistic research, problems are seen as systems and solutions are sought in a larger context, not merely from the classroom, the teacher or students and their behaviour. The holistic paradigm, with its background in systems thinking, is the opposite of analytical thinking: the individual learning process is examined while emphasising the interaction processes of an organisation. One structural part is not more valuable than another, and
no science which studies parts of wholes is the foundation of other sciences. The properties of the parts of a system can be understood only in its context, by studying the entire organisational network in action. Examining the teaching-learning system of a chemistry subject in a social and societal context is a holistic way of studying it. One part cannot represent the whole and the dynamic interaction in the network. (See Fig. 2)

Fig. 2. Shift a) from the parts of a system b) to the interactions between the parts of a system emphasizing studies.

How can the events which take place within the spatial boundary of a living organism be accounted for by sciences especially by chemistry? Due to the complexity of a living organism and because of human limitations, we must confine ourselves to the partial systems of a network while not forgetting the effect of the environment. There is no hierarchy between the parts of the network even though there are scale differences in the biological networks of humans – networks within networks forming clusters. The systems examination and understanding of brain activity and the learning process may lead to the right selected changes in the learning environment for achieving goals. Because the world in which we live is a coherent entity, we can try to describe it based on uniform principles while pursuing common concepts, the unification of science: we need the model of structure and organisation in different scales and the synthesis of approaches in the study of learning. In Schrödinger’s opinion (46) the obvious inability of his contemporaries in physics and chemistry to account for such events of living organisms as learning is no reason at all for doubting that they can be accounted for by those sciences.

2.2 Open and closed systems

While studying the world as a system, von Bertalanffy brought attention to the important difference between systems that were open to their surroundings and those that were closed. In classical chemistry, reversible reactions that result in equilibrium and are mathematically more easily described are studied in a closed system, while in biological systems material and energy flow in and out continuously: in a dissipative system new structures are born and earlier ones are dismantled into smaller parts. Irreversible processes play a fundamental constructive role in the physical world, appearing with a particular clarity on the biological level. The flow-through of energy and matter, input and output,
stabilises fluctuation. The continuous material exchange, in principle, includes all the chemical elements. Chemical processes in a living cell are thermodynamically and chemically in a so-called steady state, which is far from equilibrium. In this state entropy is low and thus this kind of non-equilibrium is the source of order. In its interaction with its surroundings the system goes through irreversible changes, self-organises and stabilises. Irreversibility is deeply rooted in dynamics, too. As opposed to a closed system, in an open system the same end state can be achieved from different points of departure and in different ways. A systems theoretical orientation in the examination of the whole brings out the creative side of a person. (47–49) In nature, a learner, as an open partial system, functions as an internally self-regulated (See Fig. 3), constructive and organizing system in which the parts of catalytic cycles either speed up (+) or slow down (-) processes.

![Fig. 3. A learner as a self-regulated, open science system.](image)

Natural processes taking place in an open system are often irreversible and are based on randomness. This results in a new view of matter: spontaneous activity converges in matter. New structures that lead to order can emerge spontaneously in catalytic chemical reactions that are far from equilibrium. The new dynamic state of the matter enables the system to interact with its environment: dissipative processes in an open system. Prigogine and Stengers (50) as well as Black (51) called this interaction inter-molecular communication, which can only exist far from equilibrium. In that case, matter can, in its activities, sense, perceive and take into account differences and changes in its environment.

From a scientific viewpoint, the definition of a living organism can be interpreted as an organized, interactive open system. According to Spinozan (52), nature is a continuous system and the desire for self-preservation is a characteristic of all who exist. In nature nothing is passive and responsive to influences as such. A fundamental characteristic is activeness. A person in this functioning entity of partial systems is one dynamic element. His activity, normal behaviour, is relative to the entire life situation. A person creates and forms his own environment. This means the continuous expansion of one’s operating environment through learning. Neurologist Goldstein (53) has suggested that the activity of an organism living in a normal situation does not aim at equilibrium, self-preservation, but at development, growth and “self-fulfilment”. Referring Nils Bohr (54) he said the reactions of an organism can be divided, from the physical point of view, into two sphe-
res. First, there is the sphere of macroscopic causality in which all reactions occur according to causal, mechanical, and chemical laws. Second, the sphere of the directing activity, down to processes of atomic order that, although not causally determined in their course, set in motion the macroscopic events. Bohr regards the more difficult to observe acausal processes, governed by probability laws, as the seat of that unity of reaction potentialities that constitute a living being.

2.2.1 Order in open systems

According to the second law of thermodynamics, entropy $S$ increases monotonically until it achieves its maximum value in a thermodynamic equilibrium. For an open system which exchanges energy and matter in interaction with its surroundings, entropy changes differ from isolated ones by the presence of a flow entropy that is transferred beyond the system’s boundaries. At the microscopic level, according to Boltzmann, entropy is the measure of the disorder of molecules, the measure of the degree of organisation. Entropy $S = k \log P$, where $k$ is Boltzmann’s constant and $P$ is the degree of complexity, the quantitative measure of atomistic disorder. The disorder it indicates is partly that of heat motion, partly that which consists of different kinds of atoms or molecules being mixed at random. If one of two states is favored by particles at the beginning, this lack of symmetry will go away in time. The Boltzmann order principle, which is the basis for understanding equilibrium structures, is in stark contrast to an order obtained through fluctuations of dissipative structures. (55)

The generation of entropy can be influenced by irreversible processes such as chemical reactions, conduction of heat and diffusion. In a closed system this leads to an increase in disorder. In an open system, in addition to these processes, there is the import of entropy into the system which can even be negative. As open systems, living organisms receive negative entropy from their surroundings. (46) Thus the increase of entropy in biological systems can be prevented, and order and organisation can even be increased. A biological system develops from disorder to order. Negative entropy, an increase in order, is the increase in information in a system. (56) As the information processing system of an individual, the brain develops like such a system. It organises, self-regulating, both as its own chemical structure and as organisation, as an independent construction.

2.2.2 Non-linear function

In systems where the dynamic interaction of components prevails, system self-control generated by feedback can take place. The last phase of the feedback cycle operation affects the cycle’s initial activity, repeating as an internal actual control in systems. This function is non-linear and can form loops. In biological chemistry, catalytic cycles are crucial, in which the enzymes or reactant of reactions control and guide the operation of systems, the birth of structures and the process of becoming organised. Many cycles form catalytic networks that contain loops. Nucleotides, among others, produce proteins that
conversely produce nucleotides. Hypercycles (55) are loops in which each link is a cata-
lytic cycle, as shown in Fig. 4.

Fig. 4. Closed loop: E\textsubscript{1} – E\textsubscript{15} enzymes catalyse each other’s formation in such a way that a cata-
lytic cycle is formed.

A system is a self-regulated, innovative organisation even when it is open to energy and
matter flows. In an individual human being, the biological system actively processes sti-
mulus while processing information by means of chemical catalytic feedback, among
others, as the signal proceeds to the synapses. In other words, feedback means a commu-
ication network which produces action in response to an input of information and inclu-
des the result of its own action in the new information by which it modifies its subse-
quently behaviour. In a nonlinear system the two responses may contain different informa-
tion. The robotlike stimulus-response, S-R-schema does not operate in a linear fashion in
the human brain (51, 57), rather a human is a self-organisation system.
3 Learning process

A human being and his surroundings form two partial systems of the universe connected to each other by matter and energy flow. They are organisations that are separate from each other but are still in constant interaction. Only through interaction with his surroundings is a being a living whole in which both biological and social factors unite and mental activity forms. As we live, continuous dynamic processes take place within us: the joint action of matter, energy and the information which they transmit. In other words we have an extremely sophisticated functional organisation. The interaction does constitute not linear, cause and effect reactions; rather it is the response to perception schemata derived from the goal of an activity. The response to a stimulus from its surroundings is structural changes in a non-linear, self-controlled network, which as an organisation is closed. This new biological order is both architectural and functional. Intelligence is the wealth and flexibility of an organism’s structural connections.

The basis for an individual’s processing of scientific facts, too, is the inner-cell genetic cognition system and brain system as well as the senses. (51, 58) A person’s brain system enables the ability to describe things through vocalised and written symbols. Language enables the social interaction peculiar to man and has also led to the foundation of culture: common knowledge, skills and experience (59). Thus it has been possible to accumulate knowledge and transfer it from one generation to the next. The contextual activity of our brains is based on our cultural surroundings. Through our actions and experiences, this environment is forming our own world view and is involved in the creation of our cognitive processes. Cognitive processing has its own task with factors that are in practice unchangeable and rooted in biology and on the other hand, relatively dynamic cultural factors.

3.1 Chemistry of learning

The chemistry of learning is the micro level of the learning process. The complexity of a single cell is illustrated by the fact that within its membrane hundreds of chemical reactions take place, many of which are not still understood. The nucleus of a cell contains
instructions that tell the cell chemically how to operate, how to rebuild itself after every cell division, and how to act and interact with other cells as they build and maintain the organism.

### 3.1.1 Genetic system

In the 1920s it was discovered in bacteria experiments that some chemical compounds produce the hereditary traits of cells. The molecules, as part of the cell’s metabolism, transfer genetic information, were confirmed to be nucleic acids in the 1940s, but it was not until 1953 that American James Watson and Englishman Francis Crick succeeded in determining the double helical structure of DNA. Nucleic acids have the structural qualities required for matter that transfers heredity: it contains information (in genes as the order of amino acids) and has the ability of coupling. (60) This genetic information guides the construction of an individual’s brain to make it ready for service as early as in the foetal period, but the development of readiness into operational skills is dependent on favourable learning conditions, on stimuli from the surroundings. Signals, information that enters the senses in the form of energy, make a child actively develop his or her skills. With the maturation of the nervous system and learning, operational skills, i.e., the processes of an individual’s information system, develop in spurts (61).

The gene control systems of the nucleus handles huge numbers of signals that arise from within the nucleus and from its outside cytoplasm. For example during development, growth and learning, information of the DNA sequence, genes from the manufacturing instructions of proteins, is transmitted while ribonucleic acid RNA (62) executes the synthesis of proteins in cells. RNA produces the enzymes which further produce DNA; the network is a loop. Since the components of a cell are produced by other components in the cell, the entire system is organisationally closed. The structure of the matter is information only in its context. (51) Depending on their structures and operating environments, synthesised proteins can function as building material, catalysts, material carriers and ion channels while degrading (disintegrating) and regenerating during a human’s entire life. These irreversible, non-linear and self-controlled reactions that maintain life require energy and matter from outside the system.

### 3.1.2 Brain system

The brain system of an adult person contains about 100 billion continuously changing and adapting cells which include the same genes, but which are specialised in different work tasks. The density of the neurons in the cortex is about 100,000 cells/mm3. The part which receives nearly 10,000 signals from outside the neurons consists of ramifications, dendrites, which branch out like a tree; each neuron is approximately connected to 104 others. A maximum of one insulating branch or axon surrounded by a myelin sheath leaves the cell centre. The axon transmits action potentials (63), the information, away from the cell body effectively towards other neurons; the head of the axon usually branches
out. With regard to the stochastic, doubtful (hazy) action of the chemical system, the mutual connections of cells are important. However, neurons do not touch one other, instead there is a small synaptic gap between them. This is the point of contact between the cell’s axon, which sends messages, and the dendrite of the next cell, which receives chemical signals. Synapses are small (0.5–1.0 μm) and very compactly packed, with about $10^9$ synapses/mm$^3$ and in 1 mm$^3$ there are many kilometres of axons and hundreds of meters of dendrites.

The information carried by a neuron is encoded in electrical signals that travel along the axon and into the nerve terminal. At synapses these signals are carried by one or more chemical messengers across the synaptic cleft and the input is non-linear. The activation and deactivation of the ion channels in synapses regulate the progress of the information within the cortex through transmitters. Ions, for example Ca$^{2+}$ and Na$^+$ permeate through ion channels along the ion channel proteins. These proteins can be ion selective or their kinetics are gate-controlled. When the energy threshold of the ion channel is received the conformation of ion channel protein takes place; one conformation lets ions go through and the other doesn’t. This is an assumption, in reality there are many vibrating conformations and that is why nowadays fractal modelling is used. (64, 65) Electrochemical changes in cell membranes release synaptic transmissions, chemical messages that use transmitters, including, for example, acetylcholine, serotonin, noradrenaline, dopamine and endorphins as well as the inorganic, gaseous nitrogen oxide. (Fig. 5) Amino acids are as transmitters usually in fast (glutamate) excitatory or inhibitory (glycine) synaptic traffic. Many substances, such as acetylcholine, have fast and transient as well as slow and long-lasting effects, depending on the postsynaptic receptor. The very last numbers of neuropeptides (substance P) act slowly, on the time scale of seconds to minutes. (66)

![Acetylcholine](image)

**Acetylcholine**

![Serotonin](image)

**Serotonin**

![Dopamine](image)

**Dopamine**

Fig. 5. Transmitter molecules of information.
When an fast (velocity 1–100 meters per second) electrical impulse (Fig. 6), a change in
the ionic balance of the cell membrane, arrives at the main branch of the axon, its presynap-
aptic vesicles release neurotransmitters. These cross the synaptic cleft and affect the
receptive membrane either in a stimulative manner in such a way that the impulse is
transferred to the next cell, or in an arresting manner so that the electrical discharge of the
next cell decreases. The impulse affects the growth or change in both cells of the synap-
ses. In practice, an individual synaptic connection is rarely able to start a nerve impulse.
What is required for triggering is several simultaneous stimulative inputs in order to
generate a sufficiently large voltage difference, i.e., membrane potential. (65, 67)

Fig. 6. Nerve impulse.

The generating of a difference in potential is the combined effect of impulses coming into
a cell, i.e., an information signal received by the cell, after the processing of hundreds or
even thousands of synapses. A neuron processes and transmits information as one basic
unit in the brain system. The sum of the signals is the interpretation of the information.
Signal processing is affected by the geometry of a cell, the summary and filter character-
istics of the cell membrane, synapses, local signal circuits as well as complex neuron cir-
cuits, “calculators” and “predictable elements”. (68)

Alterations in the brain that occur during learning seem to make the nerve cells more
efficient and powerful. In studies of animals they have found that in complex environ-
ments the brain has a greater volume of capillaries per nerve cell – and therefore a greater
supply of oxygen and nutrients to the brain. (69) In this way experience increases the ove-
ral quality of the functioning of the brain. The architecture of the nervous system, al-
though complex, follows a relatively simple set of functional, organisational and develop-
mental principles. The functional systems for perception, motor co-ordination, and moti-
vation interact even during simple behaviour. The progression of signals all the way to
memory while being linked to an information system that has already been formed is a multiphase process that is transmitted through different organisational units, nerve networks, neurones, synapses, molecules and ions both electrochemically and chemically. However, if each cell had a certain intelligence to make decisions on its own, many of the rather mechanical explanations of functions in body systems would have to be re-considered.

After having considered the organisation of life and the phenomena of observation, biologist and neuroscientist Humberto Maturana (70) described cognition, the process of knowing, as a biological phenomenon. Having defined the processes of a self-controlled, living system as cognitive, information processing processes, he, along with his colleague Francisco Varela, coined the term autopoiesis to describe organisations that are autonomous, self-referring, self-constructing and closed. When a system’s structure is the biological structure of the human brain, the activity of the brain’s organisation is the information processing of a neuron network. Varela (71) has expanded Maturana’s information processing, which excludes symbol functions, in his publication in 1995 with a hypothesis of the specific neural mechanisms of consciousness. His key idea is the resonance phenomenon, whereby different parts of the brain are internally connected so that their neurons release a flow that passes through at the same tempo, synchronised. According to the hypothesis, each cognitive experience is based on a specific cell assembly in which many different neural activities – sensory perceptions, emotions, memory etc. – are unified into a transient but coherent assembly of oscillating neurones. According to Varela, primary conscious experiences cannot be localised in any part of the brain, rather it is an indication of a partial activity of a particular cognitive process. The rhythmic electrical activity of neural circuits in neuroscience is studied by measuring the electrical activity of the brain. Does Varela’s hypothesis of the appearance of information, of representation in the brain, explain our self-controlled behaviour when a person is assumed to be an information processing creature and the basis of a person’s activity is information processing? What is the contribution of chemical information processing, of synapses in the representation of information in the brain? This occurrence of information in the mind of a human has been modelled with computer network models that are non-linear, dynamic and give feedback (72, 73).

### 3.1.3 Sensory systems

Senses are formed from cells specialised in receiving outside stimulus, i.e., receptors. Variations of the electrical activity of receptors are coded as electrical responses and are transmitted deeper into the brain along a nerve. There, too, signals are action potentials, local voltage increments and the release of synapses transmitters. Information is transmitted by means of the voltage increments of cell membranes. The cells at each level of the visual system are responsive to a special region of the visual field and the entire visual field is re-represented at each level in the visual system. By the use of microelectrodes it has also been discovered that cells in different levels of the visual system respond to different properties of visual stimulation. (74) Many areas of the cerebral cortex are concerned primarily with processing either sensory information or motor commands. These
areas are known as primary, secondary, or tertiary (sensory or motor) areas, depending on the level of information processing they carry out. The higher-order sensory areas integrate information coming from the primary sensory areas.

The sensory systems also filter and summarise. The schema, “a cognitive structure that represents organised knowledge about a given concern or type of stimulus”, (75, 76) is generated in the brain as the joint result of tens and even hundreds of thousands of nerve signals and requires beforehand an interpretation of reality, the learned manipulation of sensory outcomes. The percept may differ in a number of ways from the sensory information sent to the primary areas; the sensory information is transformed into a percept by such factors as earlier experience and context. With practice, we subconsciously become better at identifying familiar objects or distinguishing fine details in our environment. Perceptual learning incorporates the dynamic processes of cortical circuits with the processing of sensory information. (77)

### 3.1.4 Learning reactions

A general, fundamental purpose of science and philosophy is to create a universal theory that is as broad as possible. In the attempt to create a theory for describing the teaching and learning process it is, as usual, necessary to resort to models of narrow sectors. Many new neurophysiological and experimental psychological research methods based on science continually provide new information of the activities of the brain and memory. Instead of oversimplified deliberation of philosophical analysis there should be scientific research when approaching the problem of consciousness. We must also confess that even scientific theories are imperfect and can also result in oversimplifications. (78) A hypothesis, the idea of a scientific approach, too, often comes as a metaphor or narrative and is expanded on formally or empirically only in a later stage of the research. (79) Countless scientific domains are interested in the mind of man, intelligence, and thoughts: information processing, but the tools of more than one discipline are needed for a more comprehensive understanding. (80) The convergence of scientific fields has been demonstrated in this study.

Sir John Eccles, winner of the Nobel Prize in Medicine, has together with Karl Popper suggested that the world can be divided into three parts: States of consciousness (the activity of the brain and the neurophysiological regularities that govern it), physical objects and states, and third, knowledge in an objective sense, cultural heritage. Knowledge of a culture is transferred into subjective knowledge not only through spoken and written language but also through sensory perceptions in particular, and more extensively through experience (64, 78). Their definition about the parts of the world deviates from the definition in Section 2.1 but the active interaction between parts for cognition is common to both. The content of the mind and thought of people who have developed in different cultures is different although the activity of the brain is similar. The way of life in an information, or more knowledge consciousness, society and the reality we encounter conceptualises the contents of our thought in a different way from cultures that are more simple. (5)
Learning occurs as a wide-ranging process in the biological regulating system of cells, as a change in the brain structures and the activity of its synapses. The neuron network takes a new form as a result of learning: new connections are formed and some other defused. If no changes occur in the basic unit of signal processing, i.e., neurons, learning does not take place. (81, 82) In learning, the entropy of the system decreases when information is stored in the brain as new structure parts of the knowledge system. Neurophysiologically learning is

- the growth in the activity of postsynaptic cells as transmitters operate in the circuits of neurons
- permanent growth of the organism in synapses, which results in long-term potential (LTP).

The result is memory, the new functional processes of the organization of the brain and a relatively permanent change in behavior. (74) New large molecules that reduce entropy emerge into the system in a self-controlled manner from outside stimulus, energy and from the small molecules of cellular metabolism. The changes of functions caused by these structural changes also enter the system.

### 3.1.4.1 Reactions in synapses

An elementary type of memory, habituation, which releases less transmitters, had been localized in a weakening of synaptic connections in the late 1970s. After that the molecular events underlying memory storage were ripe for analysis. Models for human memory at the level of reactions were found first by the research of animals, later primarily by PET-studies. The studies suggest that short-term and long-term memory are two points of a graded process: First, both are associated with changes in synaptic strength. Second, in the both long-term and short-term processes the increase in synaptic strength is due to the enhanced release of transmitters. Third, modulatory transmitters, perhaps the most important serotonin to produce the short-term facilitation following a single exposure, produce long-term facilitation after quite a few exposures. Finally, an intracellular second messenger involved in the short-term process also turns on the long-term change. Sensitisation is a more complex form of nonassociative learning than habituation. Habituation and sensitisation have both a short-term form lasting minutes and a long term form lasting days and weeks. Learning, the long-term potentiation LTP, indicates that something in the chain involving presynaptic and postsynaptic cells has undergone modification. (65, 83)

One model of biochemical processes that needs earlier activation simultaneously with the information signal is the induction of LTP. Glutamate released by hippocampal afferents in a modulating role binds to three different types of receptor on the postsynaptic cell. Two of them are ligand-gated ion channels, meaning the transmitters bind by virtue of fitting into the slots and juts of the receptor molecules allowing Na⁺ and K⁺ ions to flow through. Glycine and may be others play the same role. The third receptor is a both ligand-gated and voltage sensitive NMDA receptor (so named because it is activated by the concocted glutamate analogue, N-methyl-D-aspartate). The NMDA receptor is a protein that has binding sites for both glutamate and glycine, but, in addition, it has a channel that opens to extracellular ions Ca²⁺, Na⁺ only when the cell is depolarized from its resting
level by roughly 30 mV or more. Once the NMDA channel opens, reflecting the dual factors, it stays open for about 100–200 msec, which is a long time compared to about 5 or 10 msec of ligand-binding glutamate channels. Perhaps this is a time constant that the system exploits in some manner related to the efficiency of learning. Once LTP is induced the postsynaptic cell releases a retrograde messenger NO, CO to the presynaptic cell. Producing the release of a transmitter, these messengers persist in continuing LTP. The LTP-NMDA-learning, the strengthening of the synaptic connection, needs electrochemical energy to spread from a different highly activated synapse located elsewhere. This is how LTP co-ordinates events in the learning context, and thus can play a special role in associative memory. (84)

The resulting rises in Ca\textsuperscript{2+} in the dendritic spine triggers calcium-dependent kinases that induce LTP, a growth of new synaptic release sites: the addition into the presynaptic terminals of new release sites and the insertion of new receptors in the postsynaptic terminals. In addition to repeated trains, the Ca\textsuperscript{2+} influx are thought to activate genes that are both regulators and effectors of growth and are thought to lead to structural changes, the growth of new synaptic sites. Newly synthesized proteins find the recently activated, marked synapses at which it should act. (85) Contextual memory requires this process and the hippocampus system in the brain. (74)

### 3.1.4.2 Analysing the brain

In the scientific approach of learning research there is the human brain and the signals it generates and receives. In the beginning of the 1900s, after the philosophical dualism ideas of Rene’ Descartes and the Russian school of thought, such as Pavlov’s reflex theory, the neurofunctional neural system was understood as a physiologically and psychologically integrated, active system. In addition, as electrical changes had been observed taking place in the nervous system in the 1800s, it was possible as early the 1930s to begin to measure the electrical activity of the brain. Now we already have information of how the brain processes and classifies sensory signals that come to it and are stored.

Electroencephalography, the EEG graph of cortex electrical signals, provides information of the activity of the brain usually using silver-silver chloride electrodes. (86) A surprising stimulus causes a sudden increase in the EEG. Neuroscience uses average responses ERP (Event-Related Potentials) of these so-called evoked responses to illustrate how different cognitive functions appear as electrical responses. The first observations of a connection between the reaction to stimuli and a voltage increment in the brain’s electricity of a test subject were made in the 1960s. (87–89) When the stimulus entering the senses is in conflict with the model formed into memory from repeating stimuli, the brain reacts to the changing situation. This is an MMN deviation wave (mismatch negativity) in the EEG graph registered as ERP, which indicates electrical activity in the brain. MMN is a sensory memory phenomenon which is associated with the prickling up of the senses and a rise in the measurable state of alertness. The study of neuropsychological alertness has become an area of application for the results. (90) With regard to learning research, a learner’s attentiveness, the internal control of the activeness of information processing, essentially limits the quantity of signals entering working memory and thus decisively affects
learning. Knowing the neural processes that affect the selection of information signals is an important objective in the study of education because attentiveness plays a role in determining how and what an individual learns. (91)

It is possible to measure electrical voltage increments from the brain that vary in frequency; these are called EEG Rhythms. With respect to learning research, the rhythm that has become the most interesting is the theta-rhythm (4–7 Hz). This is the frequency where most hippocampal rhythmic activity takes place. When studying the effect of reading and playing and watching video games on theta-activity, it was observed that this rhythm was increased only a little in connection with reading but abundantly while playing video games. Watching a game did not affect theta activity. In conclusion it was proposed that theta activity appeared during tasks that require concentration and attention. (92) The experimental evidence largely supports the hypothesis that theta activity plays a functional role in cell assembly formation, in a process which may constitute the neural basis of memory formation and retrieval. The frequency at which theta occurs is believed to be of critical significance (93, 94) Underlying the neurochemical systems researchers are, increasingly, suggesting that complex human memory is mediated by assemblies of interconnected neural networks.

Laukka et al. (95) have, by means of a video game in a simulated traffic situation, attempted to define the effect of performance development on theta activity. Test subjects received immediate feedback of their performance and more theta activity appeared in correct performances than in incorrect performances. When a test subject learns, he doesn’t need to complete each interval separately; instead the activity is directed straight toward the outcome. During learning, the activity of the nervous system is rearranged. This is visible in the measurable voltage increments of the brain in such a way that in the beginning of the activity changes increase, but the voltage increments of sub-operations decrease. In learning, the overall pursued result is essential. Tests show that during learning a test subject changes in such a way that the change can be noticed from the recording of brain electrical activity. Learning cannot be noticed immediately, instead the organisational change in the nervous system requires a certain number of drives in a simulated traffic situation. Speed in learning is often only the fact that the learner already has ready a majority of the systems which require learning to be supplemented. (96)

Today an important field for the application of cryogenics is neuromagnetism. In the laboratory of the Helsinki University of Technology (97, 98), an extremely efficient device applicable for studying information processing in the brain has been developed. As a result of this research, a neuromagnetometer is now in use in Finland; it can be used to monitor how the brain performs its primary tasks, the receiving and processing of information and the giving of commands. The transfer of information of the brain is based on the ability of nerve cells to send, relay and receive electronic messages. When cells become activated the small electric current passing through them causes a weak magnetic field in their environment. A neuromagnetometer measures the changes in the magnetic field generated by the cerebral cortex when, for example, we see or hear something, even when we imagine that we see or hear something, or when the brain gives the command to speak or move. This magnetoencephalography or MEG device has the ability to locate a spot within a few millimetres and measure brain activity that occurs in thousandths of a second with great accuracy with respect to location and timing and with no danger to the test subject in a magnetically shielded room. A combination of the electrical ERP measu-
rement and the magnetic MEG measurement can be used; if the ERP contains a combination of two unknown components and the MEG enables the determination of one of the components, it is possible to have the other one determined as well through subtraction from the ERP sum. (74) Evoked responses that appear at the same time can be separated out and the desired specific responses can be studied more accurately.

Fundamentally we can regard behaviour and activity as something that can be studied with neurophysiological methods, as long as it is possible to perform research at the molecular level, for example, in sufficient detail. (99) Medical applications are already in use and new radio drugs, among other things, essentially provide unlimited possibilities for tracing the activity and biochemical reactions of a living person’s system. With PET (Positron Emission Tomography) it is possible to monitor the activity, metabolism and blood circulation of organs. (100) Certain isotopes produce positrons that react with electrons to emit two photons at 511 keV in opposite directions. PET takes advantage of this property to determine the source of the radiation. In studying the receptor activity of the brain using PET and SPET imaging methods, \(^{11}\text{C}\)- and \(^{99}\text{mTc}\)-, \(^{123}\text{I}\)- as well as \(^{18}\text{F}\)- tracers are used for marking the small molecular substances that bind themselves to receptors. Radioactive matter radiates as it breaks down positrons, which causes the production of gamma rays as they encounter an electron in tissues: locating the active area is possible. Through this kind of research in neurotransmitters, it has been surmised that one of the many behaviour modification functions of dopamine is a reward system which generates a good feeling for a person when he or she has completed a task necessary for his or her existence. The feeling of success is also partially accomplished by dopamine. Although the activity of the serotonin transmitter of the central nervous system is known much less than that of dopamine, it is also known to participate in the regulation of moods. (101) The PET method is very suitable for studying memory functions and emotions, among other things, and the results are applied to many fields of medicine and even in psychiatry. Through research in brain structures, progress has been to the level of activity research, where emotions and information processing come together.

Cognitive neuroscience emerged in the 1970s as an integrated way to approach the mind and brain; it strives to understand the basic workings of the system made up of neurons. The processing of natural information has been compared to the way a computer processes data. However, the principle behind ADP (computer) systems, which are based on digital computation, is completely different from the non-linear operating system of the brain. The self-organising map based on neurocalculation and developed by Kohonen (73) does not try to illustrate or mimic the brain in its entirety, but with it researchers have come closer to natural learning and intelligent behaviour than with other computer models. The background of the modelling is the idea that the brain does not process bits but signals, groups of signals, perceptions which form certain kinds of map-like depictions of our living environments. By the same token, perceptions fed into a neuron chip place themselves in an arrangement in accordance with their natural connections, into maps. The network’s connections model axons and stresses, \(W_i\) model synapses, and define the function desired for memory, learning. A transfer function is used to get the peak limiting for starting values; this limiting is equivalent to biological thresholding. Only a part of the information gets through. Correspondingly, many networks use energy functions that are minimised during learning. (84)
3.2 Functions of learning

The functional organisation of the brain depends on experiences during the learning process. Instructional learning is, in general, a provoked process by learning environments as opposed to the spontaneous development of knowledge. The learning function is provoked by situations – forced by a teacher or other persons (social systems) and/or by the external situation of concrete or abstract systems. In a background, the biological development and adaptation of the nervous system explain learning. The cognitive and situative perspectives of learning differ in the level of an observation. The research field should have people working in both perspectives developing more comprehensive and coherent theories of the fundamental processes of learning. (102) In the brain system the laws of nature rule, but in instructional systems social laws rule. These, contrary to natural laws, can be broken. When a human is taught, he/she has to be seen as a socio-biological system. So only a learning environment can be changed by an instructional system.

Behaviorism was the mainstream in learning research from the 1910s all the way to the 1970s. It was oriented toward natural sciences and its research was concentrated in laboratories. On the basis of the stimulus-reaction (S-R) combination, researchers tried to understand the complex process of learning by making studies of behavioural changes that are too one-sided. Notwithstanding the criticism, there is no reason to forget all the elements of behaviorism and fail to benefit from it. (103) Cognitively oriented research came about in the 1970s, when learning was interpreted as information processing. As a result of learning, changes take place in a student’s information structures and course of thought. The subject of research was how students create their own representation of the world in which they live and function as well as how the construction of this knowledge system can be influenced.

Research in learning has revealed how learners form most of their concepts from personal experiences. New learning is decidedly influenced by their earlier experiences because self-acquired information is more permanent than that which is told by others. (104) For this reason a student often forms two world views: one based on experiences in his or her own cultural environment and a scientific world view learned at school. (105) Personal experience in acquiring scientific information supports the correct structuring of a learner’s knowledge. The background of the learning view based on experience comes from educational philosopher John Dewey’s ideas and the work of social psychologists Kurt Lewin and Jean Piaget. (106)

What is the significance of a learner’s whole learning environment, the physical, societal, cultural as well as external and internal situation on learning while the learner is a self-controlled individual in a society which acts non-linearly but dynamically and in a goal-oriented manner based on personal history? In the pilot research, by means of the information provided by a learning environment and society, the learning process is brought back to the living environment familiar to the studied upper secondary (senior high) school students. The amount of signals processed through one’s own authentic experience is large because of its visual nature, among other things, and adheres to the learner’s earlier information structures due to the cultural commitment relevant to him or her. Vygotsky (59, 107) ties thought to the dominant culture because according to him the selectivity of thought is the result of concepts generated through learning and development. His work places thought outside the borders of the laboratory of exclusiveness into
the context of living in a culture, and thus creates a new idea of the collective, communal origins of man’s presentation of knowledge.

3.2.1 External environment of process

In traditional classroom didactics, guided by behaviorism, the goal was to make teaching and learning effective while the agrarian society was being transformed into an industrial society at the beginning of the last century. The structures of reality and the environment were divided into small lesson constructs, whereupon the connection to the learner’s own living environment was lost. In addition, when the monitoring of activities and requirements for efficiency led to large student groups, classroom teaching had developed into its present form. (108)

Work in the information society demands more and more thought and work performance that differs in quality from the skills required for work during the time of mechanised industrial production. As the goal is active operation in work tasks, a paradigm shift is needed in learning research. Learning is interpreted as a process in which the learner actively creates his or her world view and creates cognitive systems by processing perceptions by him or herself. (109) The learner’s own questions related to the issue being learned, and the learner’s own experimenting, problem solving and comprehension should awaken within the learner. Feeling that the issue is for him or herself is the significance given to a stimulus signal as the schema that originates from the situation and from personal history and which directs activity. According to these assumptions of learning, learning is thereby situation-dependent and is a new knowledge structure or comprehension created by making observations during interaction with the environment. With the cognitive view of learning one must add active and concrete interaction with high technology and the socio-cultural operating environment. Activeness, self-control, growth of the self and self-reflective abilities are peculiar to biological systems, to man, but they must be knowingly developed. The focus, then, must be shifted from teaching to learning or, even better, to active knowledge creation. The learner ought to feel what it’s like to do something, not only to be a student: passing exams, getting grades, turning in homework, and so on playing a kind of academic role.

As learning was earlier in this study defined as something more than the storage of information material transferred by teaching, it can be considered to cover all human activity. We learn during our entire lives through experience and thought by using cognitive structures created into our minds for awakening perception and combining new information to earlier learned knowledge. The educational scientist who emphasised functionality and experimentalism in the learning process in the beginning of the 1900s was John Dewey, whose model of learning is in Fig. 7. In Dewey’s opinion, stimuli and reactions should not be seen as back-to-back processes independent of each other, rather as a whole that defines the other. In the model, impulse, perception, the information received from it and its evaluation are repeated. This evaluation directs attention at a new impulse and the spiral continues until there is an output after having become mature for its purpose in the symbiotic interactive processes from blind impulses.
In Dewey’s view, experience is comprehensive, dynamic and developing. Thus body and soul, thought and action, sensory perceptions and reasoning, information and emotion, individual and social must be matched together in theory as well as practice. If the information is truthful the information is useful. When a person discovers the significance of a piece of information, the desire to solve problems awakes within him or her. The key is activity and influencing through it. In fact the pragmatism represented by Dewey precisely emphasises the connection between practical activities, skills and knowledge. The truthfulness of knowledge is tested in practice. When our knowledge proves to be useful, relevant and viable and helps us function in our environment, it can be considered truthful. On the basis of the theory Kolb defines the experimental learning process: Learning is a process wherein knowledge is created through changes in experience. As a process, adaptation and learning are emphasised as the opposite of content and output. In the continuous creative process, learning changes experience in its objective as well as subjective form. In order for us to understand learning we must understand the nature of knowledge and vice versa. Learning theory based on experience is a holistic, integrative view of learning which combines concrete experience, reflective perception, the conceptualisation of abstract and active experientiation. (106)

Piaget’s key concepts in the attainment of information that enables a person to perform are schema, assimilation and accommodation. Cognitive change, learning, occurs when a schema does not lead to a result but leads to “an awakening of restlessness” (perturbation) and this vice versa leads to accommodation, which is the foundation for a new dynamic equilibrium in biological systems. Learning and knowledge, which are created by an event, are precisely instrumental. There are two instrumental levels in Piaget’s cognitive theory. On the sensory-motor level action schemes instrumentally help an organism achieve goals in its interaction with its world of experiences. On a reflective abstraction level operative schemas are instrumental, helping organisms achieve a coherent network of concepts which equally reflect their operating paths as well as their thought paths, which have proven to be viable in the organism’s current experience. In this multi-phase process, which contains feedback cycles, associations occur when a connection between two or more thoughts, feelings or actions occurs. (110) Goal-oriented behaviour is emphasised in Piaget’s theory and according to him, schemas form and change
with experience. In connection with the concept of viability, social interaction plays an important role strengthening the experiential reality.

Vygotsky’s sociocultural perspective of learning emphasises social and cultural bases as significant influential factors in learning. The contents to be learned are always first outside the learner, in a social environment, but in an active, participative, apprentice school-style social environment they become internalised through meanings. (59) In his systemic psychological study Vygotsky emphasised the mediated and indirect nature of the relationships between a person and his surroundings. The key characteristic of the higher functions of the brain is an integrated intermediate link between a stimulus and reaction: a tool, a symbol or system of symbols, most often language. A direct impulse reaction is inhibited and a helping stimulus X facilitates the completion of the operation with indirect, enclosed meanings. A person’s consciousness is a derivative of social contacts and enables one’s own behavioural control from outside from a cultural basis, not only from biological bases. (111) According to this theory, thought and learning must, in fact, be studied while linked to the cultural environment and the available systems of symbols and other instruments. Culture offers instruments for thinking, and as these instruments change, the thinking of an individual also changes. Through learning and experience a person’s external activities are gradually internalised, or transformed into internal activity. One of Vygotsky’s views that expand thinking is the concept of action as an intermediate link between a person and the community. Learning is understood as a constructivist activity where something new is created at least for the learner, as is created in science and art. (112) In other words, learning is an issue of internalising cultural instruments.

The zone of proximal development in Vygotsky’s thinking lies between two levels of development, between the actual and potential level of development. By developing learning so that the person acting as a guide is an expert with a mastery of the subject, it is as if the learner is given “construction scaffolding”, by which he or she achieves more than by independent performance in his or her knowledge construction. The applications of this idea of a zone of immediate development have proven to be good for the advancement of learning. (81) With the aid of a more experienced person it is possible to arrive at the skills and abstract concepts which are just beginning to develop. When the learner is participating in the activity, guidance is not necessary given verbally, but comprehending communication more broadly provides an opportunity to disseminate understanding through action as well. (113)

This sociocultural interpretation of learning by Vygotsky forms the basis for teaching models developed on the basis of situational cognition. Situationalism enables a learning environment rich in signals and high in quality, where a person’s cognition system creation process accordant with a constructivist view is realised through the participation of the community in the activity. Schools and universities make up their own cultures, which are separate from the authentic cultures in which the learner participates in later in work life and daily life. In practical activities, teaching is instead done by producing knowledge, thought and understanding in real activities. Learning is not differentiated from application, form from content or cognitions from the social world, instead abstract information is immersed into the authentic world subject and is used as a tool. (114) This broader conception of learning would mean seeing the creation of knowledge as a worthy activity of society (115) that young students have some part in and see as continuing and
advancing to higher levels. (116) Both perspectives – the individual cognitive vs. the social and the situated – offer powerful insights into students’ learning.

3.2.2 Inner filtering process

As a biological system a person’s activity, and so also learning, is goal-oriented. The factors that direct and energise this activity are called motivations. According to activity theory, a person’s activeness cannot be analysed without situationalism (117). Motives, the sources of activity, are cognitive functions that are emerging and have emerged from the whole life situation; a modification of the previous state in the brain system is a historical phenomena. The goal-orientation of a person occurs as a psychologically subjective state: as an experienced need or mood. Physiological motivation means, for example, the state of the brain’s electrical activity observed from an EEG. States of alertness vary equally when directed by thought as well as exterior stimuli. The bases of intrinsic motivation are images, beliefs and attitudes: the knowledge structures of our brain created through experience from a cultural environment.

Network models (118) suit the modelling of the schema concept. The relatively general structures, schemata, are module-packed in such a way that the activation of any part results in the activation of the cognitive structure of the whole schema. The regulation of information-encoding in lower order cortical areas by higher-order areas is called the role of top-down influences in learning. First, (bottom-up) the cognitive system in the brain seeks the schema that best corresponds to the elements of the particular input. After this, in the second (top-down) process the schema functions actively as the director and controller of attention in such a way that the even the details of the signals essential for the schema get processed in the cognitive system and new features become structures of the schema. The final representation of information can therefore contain elements from the specific stimulus at the time of the experience as well as elements from the general prototype. (119, 120) In the process of understanding, it is not true that facts that gradually become included in the whole as parts can be evaluated simply quantitatively, so that our knowledge becomes more firm the more parts we are able to determine. On the contrary, each single fact always has a qualitative significance. This single new fact perhaps revolutionises the entire conception on the basis of former findings and demands an entirely new idea, in the light of which the old facts may have to be evaluated in a radically different way. Learning is so knowledge-dependent.

The attention signal may have a role both in the ongoing processing of sensory information and in the encoding of learned knowledge. A recent study has shown that the top-down influence can be extremely specific to different discrimination tasks at the same visual location. (77) Normally attention is directed first to those elements of the stimulus which differ from the schematic representation. However, when the schema ends up opposite a deviant information signal, it is activated attentively to search for elements that are congruent with the schema, to focus on indeterminable pieces of information and to fill them with existing details. For cognition processing, familiar stimulus signals are fundamentally important in a learning situation as they facilitate the processing of information. It is easier to travel along a road or path which has been used previously: the reduc-
tion of action potential causes facilitation. The part of the neuron network has already been partially activated due to earlier use. A real-world object, bottom-up, and abstract information, top-down, come adaptively together in the cognitive process of authentic environments. In the teaching of chemistry, the starting of laboratory work, for example, with a new theory has not been known to facilitate learning. (121) This can be understood by the schema theory: no coherent schemas of a new theory have been found by the students. Learning a theoretical concept can be made easier if an internal model has already been formed for the student based on data as a point of reference for the new abstract concept. (122) Finding a connection from a learning environment at the most general (bottom-up) level to an individual’s cognition structure opens a channel and orientates attention (top-down) toward the acquisition of more detailed, abstract chemistry information, too.

Due to insufficient capacity of the brain, stimulus data entering our senses simultaneously are filtered: The S-R, stimulus-response connection is not fixed or linear, instead it is in accordance with an individual’s personal history and state as well as the situation. The orientation and selection of attention is influenced by anticipations and expectations tuned by earlier situations just like the motives and objects of interest, the entire life situation. Attention, which serves as the internal controller of the activeness of cognition processes, can contain, on a simplified level, screening performed either by the senses or knowledge memory (LTM). In reality, each cell of the nervous system at all levels reacts only to some information signal selection. (123) Precise task conditions depend on which stimulus signal is experienced as relevant and irrelevant, something that facilitates the production of an information structure or something to be discarded. Many deviations of social event routines have been noted as irrelevant unless they are particularly colourful and lively. Strong stimuli and changes in a stimulus awaken attention (MMN, among others). The stimulus is processed and remains in cognitive structures. Small deviations from a schema cause only a weak commitment and the observation is quickly forgotten. When an information signal to be processed is being selected, a signal that is the most coherent with the schema always has a head start; this helps the signal travel and helps change an observation into cognitive structure, in other words, helps put it to memory. (119)

In Bartlett’s (124) opinion memory is based on the placing of significance. Personal experiences and valuations determine what we remember and how we use new information in screening. The personal relevance of an object of learning in complex and changing tasks produces the appropriate activity in new situations. (125) In an authentic learning situation, new implications and shared understanding is generated through observation and activity in the laboratories of partners in collaboration with the laboratory staff. A meaning becomes one that is common to the community and the individual. When the whole operating system of teaching is being changed, the learner’s learning improves through the understanding of the meaning. Through collaboration with the staff of a laboratory, even a novice’s knowledge approaches the level of an expert. (126) The cognition structure of chemistry is then the cooperative output of the learner and the socio-cultural, historical situation, a new kind of learning experience. The learning environment might influence the creation of the learner’s chemistry cognitive structure. Learning has become easier and better in quality because abstract information, a method of analysis, has been embedded into an active practical activity in connection with the solving of a real world
problem. Internalising the significance of the chemistry might be supported in cognition also by e-learning: awakening the intrinsic, inner motives of individuals by the modern, digital environment. Knowledge management and strategies that learners have to employ in e-learning are more necessary as skills for learning and future working in chemistry than being able to store large amounts of data into one’s memory.

Of the three sub-areas of school contentment in upper secondary school – the emotional, action and cognitive components – emotion is the strongest, and often the cognitive and affective area do not support each other but are components in different directions. Curiosity, which is typical in human beings, is based on an individual’s biological heredity, and tunes cognitions where emotion, which is a strong force in people of upper secondary school age, should be made into a parallel element that energises the learning situation. (127) One element of school contentment is the meaningfulness of school studies. Kosonen (128) studied the meaningfulness and motivation of studies of upper secondary school students with questionnaires and interviews. In a study of school attendance and the study motivation of candidates for the matriculation examination (high school graduates), the pursuit of advantage and success turned out to be the most common impetus, but intrinsic and contextual motivation were also common as cognitive factors. The link between theory and practice appears problematic in the minds of students. Upper secondary schools teach theory which students are never able to experience applied in practice. The significance of theory and practical application make the activity of students in upper secondary school goal-oriented, motivated. The study indicated that nearly half of all students are not able to use their thoughts and personality in a balanced manner in upper secondary school.

The meaningfulness view emphasises the central significance of orientating toward the future in learning motivations. (129) Students themselves set goals for themselves and along with that, assume responsibility for control, which leads to deep processing and metacognition.

- Meaningfulness
  - has significance,
  - serves purposes and is relevant,
  - is experience with controlling the learning processes,
  - the achievability of aims
  - controllability

The cognitive and affective part of meaningfulness comes together in intrinsic motivation, i.e., achieving the goal itself rewards the learner. The lack of affectively-experienced meaning results in lower motivation. The cognitive conflict which furthers the accommodation of the schema, which, according to Piaget, advances the development of intelligence, may even become a barrier to learning. The suitable combination of relevance and controllability is the key issue behind meaningfulness. The changes of brain functions may occur effectively in meaningful learning environments.
3.2.3 Appearance of learning

According to Maturana and Varela communication is not the transmission of information, but rather principally a co-ordination of behaviour. Language is a cognitive instrument, a tool in a circularity between action and experience. Their key saying is “All doing is knowing and all knowing is doing”. (130) In an environment of significances, the realising of a desired behaviour expresses learning. A student does not merely create his or her own world view, but also creates his or her own operating environment through significances, for example when making choices about studies and individual learning situations. A change in behaviour and the operating system demonstrates learning and thereby a change in brain activity. If a new organisation of the brain enables the functions that have been set as educational goals, it can be said that the content to be learned has been understood. The organisation of a brain system represents the “memory” of the system; it is the result of the selection of structures that takes place in a person’s development as well as in a person’s learning. Thus from a systemic view “putting to memory” means a change in the way of organising the entire learner-environment system. The organisation of the nervous system does not change immediately: chemical reactions in the brain have their own reaction speed and a change in structure takes time.

If we accept only linguistic, symbolic output as the expression of something learned, our concept of learning is too narrow. When human learning and intelligence is perceived as a context-dependent process, it is then possible, when evaluating results, to ask how this learner functions in the knowledge construction process (131) Studying cognitive processes as action research in authentic and e-learning instructional contexts is different from testing conditions disconnected from context, but it provides more information of situational functioning ability, planning and problem solving actions for fulfilling the intentions. Learning manifests itself as operational functions (132), which are routinised performances.

3.2.4 Affecting learning

All of our perceptions must be based on information supplied through nerve impulses, and we form a representation of the outside world from this information. The perceived world is not an image but our brains’ own creation because our senses react only to part of the physical and chemical energy, and a generated nerve impulse activates individual memory knowledge stored in our brains, which then provides the included interpretation for our perception. (133) Anticipations tuned by a situation play an important role in interpretations that appear in perceptions. Learning is based on the interpretation formed by one’s own nerve impulses. The self-controlled organisation of an active learner creates its own knowledge structure where processing does not progress in a linear fashion, but is the combined creation of changes of an organism’s steady-state conditions. We can attempt to influence learning from the outside only through the amount and quality of sensory stimuli, and even these are interpreted on the basis of the content of the learner’s brain and the situation as he or she actively gravitates toward his or her goal. An organism functions actively as an open, self-controlled system going toward a significant goal.
as the dynamic chemical state of matter interprets the observations of changes in the environment and accommodation of the system.

The aforementioned is a presentation of the spiral process of change in the learning theory of this activity analysis from behaviorism to a new theory of learning created through the research results of many different disciplines: partially dismantling the old theory of learning, in part flexibly accommodating the old and the new. The process, which has advanced through the information processing of chemistry, biology and the neurosciences in the direction of pedagogy, is a structure that has been experienced to be important in comparing different kinds of learning environments. (134) The cognitive science of today: neurosciences and cognitive psychology based on chemistry and biology, artificial intelligence, cultural anthropology and pedagogy, provide a stronger theoretical and methodological framework for studying cognitive processing and learning than have been previously available. Teaching created from this basis is also quite different from that which emerges from behaviorism and association psychology. The background behind the creation of the learning environment of this research is Resnick’s (135) briefly presented theory of situation-dependent cognition:

1. Learning is a process of knowledge construction, not recording or absorption
2. Learning is knowledge-dependent: a person uses current knowledge to construct new knowledge
3. Learning is highly tuned to the situation in which it takes place.

Studies of the aforementioned cognitive sciences support this theory of situated learning; this theory emphasises that all cognition of a person is situation-dependent: Learning as information processing is bound to the culture, time, place and situation where it occurs (136) (previous Resnick 3. and Section Inner filtering process). Information which the learner already has of the learning environment and information which gives meaning to the content of his or her experience of the learning environment facilitates learning (previous Resnick 2. and Section Inner filtering process). An individual’s knowledge and the information of a society adapt and weave a larger network of concepts into the learner’s cognition. An organism has the ability to accommodate its structures in the flow of experience (previous Resnick 1. and Section Chemistry of learning). Many stimuli such as words are meaningless by themselves and need to be processed for combining with other input. The characteristics of objects to be compared also need to be processed. The resolution of information (Resnick 1.) in a student’s brain, the emergence of large information networks (Resnick 2.), in modern learning environments as compared to a school context (Resnick 3.), can enable the later recollection of information and its transferability to another context. (137)

The goal of teaching is to allow learners to gain skills and knowledge as well as activities pursuant to these goals. The theory of the learning process and the factors that regulate it fundamentally influence the planning of education and teaching at the practical level. The constructivist view of learning, its radical version in particular, emphasises the subjective and personal nature of learning to the extent that a student’s experiences or learning history cannot be objectified. (110) Then the question is how the objects of an environment, then, can become the subjects of a person’s thinking and how can we affect this learning situation if learning is the reorganising of each learner’s own system of concepts. When biological factors and the very dynamic cultural factors of our information
society are taken equally into consideration in the processing of information, it is possible to begin developing a learning situation into one that is optimal, beginning with the goals, and one which facilitates a learner’s learning.

Memory is concerned with time, so in effecting learning with spatial dimensions, the time dimension, too, has to be controlled. There are many after-effects of the reactions that take place at synapses when transmitter substances are released. Some of the effects disappear almost instantly, but others last for varying lengths of time from a few seconds to a lifetime. Long-term changes are important for attaching meaning to perceived stimuli. Such meaning is acquired when neurons fired by the stimulus become associated with concurrent activity in the motivation systems, with the existing cognition. In the learning situations of large groups there is not always the possibility to take care of one learner’s processing time. Likewise it isn’t always possible to think about one learner’s existing knowledge. The new information technology gives tools for self-guiding the learning process (24, 138): environments, contents, activities, interacting feedbacks and time for processing.

Emotions are described as the relationship of cognitive and physiological states with the hypothalamus as the regulating structure. The interplay between the amygdale, the hypothalamus, the brain stem, and the autonomic system, on the one hand, and the amygdale and frontal and limbic cortex on the other hand, results in emotional experiences. Emotions are very embedded in all learning process components and can’t be cast off the process. The usefulness of positive feelings have to be considered in creating learning functions. Emotion has also been the object of WHO-research. (139)

3.3 Learning environment of chemistry

Because chemistry is at root an empirical activity an individual’s learning of chemistry is the learning of concrete natural systems and the abstract domain. They might not be two separated systems for the reason that the abstract chemistry system is one theory domain of nature created by human. That is why “Scientific theory is a reading of ‘the book of nature’, requiring circular reinterpretations between theory and observation and also theory and theory, and also requiring ‘dialogue’ about the meaning of theoretical language within the scientific community.” The basic principles are obtained by the creative interaction between theory and the facts that emerge from observation and controlled experiment. (140) Observed nature as a macro level and molecules as a micro level are scales for chemistry to be learned. Also, it is important in science education to appreciate that human’s scientific knowledge is both symbolic in nature and also socially negotiated. Because the concept formation and knowledge acquisition of chemistry are based on the empirical study of phenomenon, empiricism is the most important approach in learning. (141) In that case at first there is a physical system, nature. Second the social system of humans actively interacts with this. Third the interactions of these two systems create the abstract system of the chemistry domain.

The classroom and auditory teaching of chemistry which applies a behaviorism concept of learning pacifies the learner; the teacher transfers information and learning is processed as some kind of information copying. (142) The brain activity of a person who sits
by and watches is not as activated as that of one who functions actively. (143) The teacher and teaching material supplies information as clearly as possible and the hope is that the student absorbs it just as it is presented. However, according to the organism’s organisation and the new theory of learning (Section Chemistry of learning and Section Function of learning), a learner him- or herself creates his or her own implications for the subject being learned, that is, if he or she even pays attention to the subject being learned in a pacifying classroom context due to the difficulty of perceiving consequence. Specific data separated from its context finds a point of reference poorly from earlier knowledge structures, and crossing the potential threshold of information processing is unlikely. Behaviorism emphasises the exterior regulation of learning, the amount of stimulus signals and ready-cut teaching content. Behaviorism does not address the actual learning process even in its research. A learner who has maintained his or her attention and already has an extensive knowledge structure creates his or her own interpretation of consequence even in classroom teaching. However, there are not enough of these learners studying chemistry in upper secondary school and studying after that to achieve the goals of education in Finland. The study found that 46 % of students, who were usually the most successful – medical students – were orientated toward repeating, were superficially orientated, wanted precise instructions for tasks and were only outwardly motivated. (144) Even a student in upper secondary school wishes for meaningful, relevant information and application opportunities for him or herself. (145) Before a learner can enter into thinking about and explaining the natural world he or she must engage in a process of personal construction and meaning making. (146) From the very beginning of the learning process filtering and LTP affect the learner’s inner cognitive functions through his earlier structures.

Based on the schema theory, the slow expression of knowledge and skill in school teaching is understandable because relevant information is taught in school contexts without exception in such a manner that concepts and principles are learned consecutively and separately from strategies, methods and practical problem solving. The traditional lecturing in chemistry may be compatible for some low-order thinking skills, but incompatible with most high-order cognitive skills. (147) In school, the chemistry information and skills normally learned are separate knowledge structures and do not spontaneously transfer into a new situation where the knowledge is applied. The skills required by the information society, problem solving and decision making, are often separated from the relevant content as well as objects of thought and action. Schemas are created separately and are not activated in a new situation in the desired manner, instead that which is learned remains a prisoner of the learning situation and application becomes difficult. Application is only possible if the information is dynamically organised sufficiently well: as relevant content is combined with real world applications through methods and problem solving, the information network is formed as a whole that is seamless with respect to time and place. Cognitive content-specific information structures are essential, but they are not enough to produce skilful, expert behaviour capable of application. Learning that is more flexible is achieved through contextual learning. A context anchors knowledge into a broader knowledge structure that is activated in a new application situation. Without a context, knowledge is so specific that coherent information with its schema cannot be found in a new situation. (148) According to research, after content-specific learning the cognitive functions don’t support application.
3.3.1 Laboratory class environment

The abstract theory contents of chemistry have been discussed in education problems: teaching contents that have been reduced and eliminated. Changing the level of difficulty has been criticised by the higher level of education and by students who seek challenges. (149, 150) The emphasising of content in the teaching and planning of science education doesn’t consider the process of learning and the development of the natural research skills of the learner. Higher order thinking skills, process and research skills are more functional for learners than individual knowledge proceeding from the explosion in the growth of information. (151–154) Developing process and research skills are needed: First, more well-built learning environments than traditional classrooms; second, the ideas of essential theory contents; third, active practical and cognitive working individually and socially.

Chemistry has been studied and learnt by experiments in nature and in laboratories. Mechanical and imitative activities have not, however, necessarily resulted in learning. (155) Experiments are significant when the type of activity has been selected carefully and the meaningfulness of the task has been well internalized. (156, 157) Then the empiricism is the part of the analysed wholeness of the chemistry domain and a learner will be motivated by the task on the basis of his /her earlier cognitive structures of chemistry. But is laboratory work in school education effective? Have the work content and the laboratory skills of goals been selected usefully? According to research results, motivation and the ability to get through courses have been increased even at the university level by connecting theory with practice, for example, in the teaching of analytical chemistry to agro-nomists: samples to be analysed related to agronomy from the substrate of plants. (158) Those who are applying the contents of chemistry do not perceive abstract information as necessary unless it has been embedded into applications of their own domain. Even when the work of a school laboratory tries to mirror the work of a natural scientist, for a learner its most important content is to help him or her understand the concepts of natural science. Do we still teach the techniques that have long since been automated in the world outside of school or have become meaningless in some other way? Sufficiently strong connections to scientific research motivate students, provide an illustration of the nature of science and collaborative learning, develop communication skills, dissolve the boundaries between disciplines and dismantle the barriers between the real world and school. Actual scientific research, from planning to success or failure, with all its phases of imagination, creativity, techniques, persistence, collaboration, disappointment and difficulty must become familiar as early as comprehensive school. (159) By gradually increasing the openness of a laboratory task, the learner gets a more realistic picture of the nature of science and also ends up needing to use common, shared information in the solving of a problem.

When fictitious task contexts were used in school learning, students did not value them even though learning was pleasant because they could figure out an issue by themselves instead of having the content to be learned told to them. In the opinion of students, an imaginary task separated from an authentic work context provided only an ostensible practical activity. According to researchers, the application task of science carried out independently in a fictitious industrial context did not work and they even asked whether
an external work context can ever be significant when included in the institutional framework of education. (23)

The results of students as young as 13 in English school teaching in an international comparison study of practical work (TIMSS, Third International Mathematics and Science Study, 15,000 students from 21 countries) are remarkably good. In their tasks, students used scientific methods and also managed through more open research tasks. The results can be explained by the role of practical work in science education in English schools: by the type of practical work and the quantity. English students had strongly learned coping rules for the types of tasks being tested. Do they understand the connection between compiling subject matter and conclusions? Teaching based on standard rituals should be avoided and greater consideration should be given to what would be a suitable method for the compiling of reliable data and how the material should be interpreted. (160) In English colleges, an A-level chemistry course includes practical work and the newest cultural context of the chemistry theory. The role of the theory enter into narratives, into the themes of practical works and into the visit of an industry. (161) However, the learning takes place chiefly in a school environment and the central difficulty in the curriculum is the lack of engagement with pupils' autonomy at the level of intellectual judgement. (162)

The learning environment is the ensemble where learning takes place. It can be operationally defined as those external influences that interact with the learner during the learning process: (163) working spaces, tools, technology, specimens, chemicals and abstract chemistry as well as social interactions. These are the potential external stimulus for a learner. A learning environment created in accordance with the situation theory also considers in these elements the learner’s earlier knowledge history, which is the internal input of a cognition. This kind of whole is assumed to produce high quality learning of chemistry: learning that creates significance structures applicable and transferable. (164)

### 3.3.2 Authentic environment

Systems thinking in the contemplation of a learning situation considers holistically the cognitive structures of culture in the learner’s memory and the culture situation outside the learner. Learning is like the other functions of a human tuned into the time, place and situation where it occurs. One goal of a cognitive model in education development is to create a dynamic system which breaks the solitude of classrooms and gives a basis for the adaptation of a changing situation. One promising aspect is authentic learning in which the goals of learning are equal, both thinking and communication and contents and skills. (165) Authentic tasks with the most possible comprehensive contexts of a learning subject simulate the real world and facilitate learning. (166, 167) The study findings indicate that students develop higher-order process skills through non-traditional laboratory experiences that provided the students with freedom to perform experiments of personal relevance in authentic contexts. (168)

In classrooms, knowledge is chiefly characteristic symbolic knowledge. However, the majority of a skilled employee’s knowledge is tacit, implicit and mute. Alongside this, strategic knowledge, learning – and problem solving strategies, ought to be the goals of
learning. The active accomplishment of an analysis problem drawn from an authentic environment, with the aid of an expert, provides an opportunity to experience the existence of such knowledge and to apply the domain subjects. The complex knowledge learnt in a real world situation shall be anchored comprehensively into cognitive structures and doesn’t leave inert: it shall be applied in practice. Adapting the source material, the characteristics of ideal learning environments are described in four dimensions. (169)

Content
- Domain knowledge
- Heuristic strategies
- Control strategies
- Learning strategies

Methods
- Modelling
- Coaching
- Scaffolding and fading
- Articulation
- Reflection
- Exploration

Sequence
- Complexity
- Diversity
- General ideal before its parts

Sociology
- Situated learning
- Culture of expert practice
- Intrinsic motivation
- Exploiting cooperation
- Exploiting competition

In the introductory laboratory course it is in particular possible to learn not only domain strategies or domain contents but also both of these together. Expressly in an authentic environment as a learning strategy there is meaningfulness and thus a learner’s intrinsic motivation may be energising. Meaningfulness will be found in the controlled complexity of cultural contexts with the scaffolding of experts. The general ideals of chemistry were introduced first and then afterwards theories and facts were learnt by reflecting in particular.

What significant differences emerge between previously used learning environments and an authentic, context-dependent learning environment from the perspective of the information processing of a chemistry learner when as the basis are an organism's functioning system and holistic system theory? Information executed in an authentic work environment during laboratory work and experienced visually and through all the other senses and applied chemistry information itself also increase the quantity of stimuli. Is there also a difference in the quality of stimuli in these circumstances? How is new information of chemistry supplied by a familiar real environment processed in the brain? Does its processing, remembering and related activity differ from what is accomplished by a che-
mystery learning situation experienced without a cultural connection in a school classroom? The pilot research hypothesis has been the emergence of a difference: the facilitation of the processing of information and higher quality learning, which would result in a change in one’s attitude toward chemistry as a school subject. There are very few educational researches in societal context which have been directed at studying the appreciation and applicableness of learning subjects. (170)

3.3.3 E-learning environment

As we move from an Information Society to a Knowledge Society, the education system is well placed to take advantage of the revolution in learning environments. The powerful research in human cognition makes possible support by Information and Communication Technologies, ICT, a limited short term (working) memory capacity and even “to con” learning. The text-based instructions in conventional laboratory manuals may overload a working memory by presenting more new information than students can process and very little or even no useful learning takes place. (171) The manual, which incorporates visual material that boosts information processing, helps students gain significantly higher scores on cognitive, affective, and psychomotor domains (172). Besides developing visualisation, the face to face communication over the last ten years has partly changed into the electronic communication that has many names: computer-assisted learning/teaching, distance learning, network learning, virtual learning, e-learning and, lastly, mobile learning. E-learning means the use of new multimedia technologies and the Internet to improve understanding by facilitating access to resources and services as well as remote exchanges and collaboration. The basis is summarised: (173)

- E-learning is based on reliable technology, but is pedagogically oriented
- E-learning is a social process and should facilitate interaction and collaboration between people
- E-learning implies organisational change and teacher/tutor training.

Technologies give indirect ways for an instructor to awaken a learner’s active cognitive working: asking, explaining, comparing, outlining, analysing etc. At the same time, by using interesting internet links, videos and repetition materials a learner can take into account his/her own pre-existing knowledge, skills, beliefs, and concepts that significantly influence what he/she notices about the environment and how he/she organises and interprets it. This, in turn, affects his/her learning with understanding: the abilities to remember, reason, solve problems, and acquire new knowledge (59, 61). Besides authentic working tasks for learners by e-learning technology, it is possible to create connections to experts and to the authentic tasks of society. First in the cognitive perspective the aim is to create processes and structures that are assumed to function at the level of individuals. Second in the situative perspective the aim is to focus at the level of interactive systems that include individuals as participants, interacting with each other and with materials and representational systems. (9, 102) Via synergy it may be possible to effect the learner’s will and the desire to commit one’s self to an active learning process.
An e-learning environment empowers the learner in every situation: at school, at university, at work, at home. The new technology diversifies and gives new possibilities to modify learning environments similar to authentic environments, too. The education organisations of Finland have, at every level, made their own Knowledge Society Strategy and renew it every few years. The vision by 2005 made extensive use of the first-rate action practices of networked teaching and research in universities (174, 175) The e-Learning Initiative taken by the European Commission in Brussels has led to The e-Learning Action Plan (176) and the allocation of funding for several projects, an action to boost the change from traditional education to systematic application of ICT for the provision of flexible learning and competence building- designing tomorrow’s education in Finland also. The background behind the change in higher education was the signing of the Declaration in Bologna in 1999 on establishing the European Area of Higher Education by 2010. The new learning environments of chemistry may be characterized by the aims of the virtual university: (177)

- Up-to-date (reflectivity, velocity)
- Good achievability (openness, flexibility)
- Good productivity (effectiveness, competency)
- High quality (research, teaching)

The current learning materials placed into Internet don’t resourcefully facilitate a self-regulating learner into the possession of chemistry knowledge and skills. To increase effectiveness, active experiments and studies of environments with new kinds of contents are needed, taking into consideration the characteristic, macro and micro levels and also the symbolic language of the chemistry domain.

According to the learning theory, e-learning depends primarily on how well ICT systems support the sharing of concepts and experiences, the interactions of humans and collaborative working. Some studies have indicated that e-learning is more effective than face to face interactions in the higher level social interactions and thus would improve learning through the deepening of understanding. (178, 179) In particular, the study results of the effects of graphical overviews, which are followed by the domain structure in hypertext, indicate the conveyance of knowledge in its own rights. Learners may unconsciously be encouraged in knowledge acquisition. (180) The visual sense is influential in active individual knowledge building. Web-based multimedia homework through WebCT was designed to help students gaining a better understanding of general chemistry. (181) This study didn’t show any significant quantitative difference in students’ performance, but positive outcomes in terms of reported student attitudes were observed. We can still ask what about quality change? However this approach allowed the instructor first to give graded homework assignments with feedback without having to invest the considerable time, thus increasing productivity, and second, it allowed students to attempt their homework in problem areas while receiving feedback. Another study (182) found a positive correlation between voluntary extra use of the quizzes in the Web-based interactive package and the final course grade. The researchers suggest that undergraduate students were motivated to pursue additional practice as they perceived some benefit in this student-centred study tool and could access it at any time. The above researchers are proceeding to refine the questions and the tutorial assistance by including conceptual questions as a way to guide students toward deeper levels of understanding as we did in this
study as well. When the goal is not merely to share facts by technology but both to achieve understanding and to mediate the models of experts’ cognition and operation, multimodal instruction shall be better as a tool than unimodal, text-only instruction. (183) In complex contexts it gives packed information signals through multimedia and hyper-texts to students, which may be better not only as an activating tool but also owing to limited working memory and shorter training time.

In the jobs of the knowledge society we use, to a great extent, data outside our own memory. It is fundamental to find the right signals for the situation and to be able, with their help, to create functioning solutions based on previous knowledge. The processing of outer and inner knowledge to a successful acquirement procedure is the essential skill of our society. A person’s own contribution in knowledge activity may only be creative functions, combining the information structures of society, institution or company. He doesn’t need the ready bits, only the ability to process information. These skills may be practised in authentic situations or e-learning environments where an individual hasn’t got a ready information packet limited only to chemistry but a holistic basis for solving the problem. We may ask whether it necessary to store into memory any details of contents after a goal has been achieved. Would it be enough to be able to acquire and process data productively in the situation, perhaps for a new product, too? The knowledge building at the level of cognition processes is, in addition to remembering, the important level of learning, of which quite a few have been tested in institutions. Do these cognition forms have different functions and/or structures in the brain system? How can these skills be practised? Together or separately? Is the e-learning environment good as a tool?
4 Research objectives

The central aim is to emphasise practical work in order to improve the learning of chemistry at the introduction level. With systems thinking as the background, the efficiency of actions for changing the learning process is investigated at the levels of individual cognition and learning environments.

1.1 Research problems

The pilot study researched ways to excite the upper secondary school learner’s cognition system for learning: authentic learning environments enthusing the learning of chemistry. In this study the chemistry instructor concerned with helping students develop conceptual understanding supports students learning at an introductory laboratory course in an e-learning environment. At the end of the course this new learning process replaced the test used previously. This study focuses on the virtual interaction cycle of theoretical and experimental chemistry in the learner’s cognition during the laboratory course.

The research problems are:
1. How were the supporting functions for understanding chemical analysis realized in an e-learning environment?
2. How was the individual learning of theoretical topics of this course facilitated by net interactions?

This study has many features of action research. The researcher of this study and the course instructor/tutor worked together to put into practice that which Lewin has incorporated into his developed education research method, i.e., action research (184): democracy, participation, and affecting in action as well as scientific development as social change. The research is done for teaching faculty that support and promote the research and development related to e-learning environments.

The research data are the activities in the designed virtual interaction environment for the introductory laboratory course, a questionnaire for the course students and the learner’s net tasks processed during this course. The e-learning environment, Optima, collected the data of two laboratory groups (18 students in Group I and 17 in Group II) all through the introductory chemistry course in autumn 2002.
The learning situation is described in Fig. 8: the parts of the learning environments and interactions between them (Compare to Fig. 1 and Fig. 2 in Section 2.1.2).

Fig. 8. Learning situation of an active learner.
5 Research spiral

The spiral of action research is a reflective, probably continuous development process set in a social situation. This study spiral (Fig. 9 below) has moved and acted (Chapter 2) both on the individual and social levels, which form the basis of human learning (Chapter 3). The objects of this inquiring activity are the modes of actions and the whole action situation in teaching and learning chemistry. In the spiral of action research a cycle of planning, implementation, observation and reflection are repeated. So in the research there are the characteristics of flexibility, self-repetition and cumulating. (14, 15)

The action research process has its roots in Dewey’s model of learning, which emphasises the role of action, experiment and repeated experience as the basis of learning and developing knowledge (Fig. 7). Existing and experimental knowledge are used by the researcher and the teacher to implement changes and to improve practices in an interactive process. The reality is changed, so that it could be studied. On the other hand the reality is studied so that it could be changed. (16) This action research is an approach for the professional development of the researcher and the teacher of this study: to shift their emphasis and focus from teaching to learning.

Fig. 9. Implementation spiral of the research.
This action research had the goal of positive outcomes in learning chemistry. For triangulation, the basis of the educational development was an increasing understanding of the molecular and system level of human learning, but the research was realisable on the macro level. Qualitative methods can help uncover the students’ perception of learning environments because the methods of data collection and analysis are geared toward building an understanding of what people do, know, think, and feel through what they say, write, or do. (12) The voices of the students need to be heard for creating an understanding of how and why new learning environments possibly facilitate learning.

Using e-learning for theoretical course topics in the latest part of research spiral, it was possible to follow the learning process of the contents. The statistical history of the documents and interactions used has been saved in the improved environment. Thus the dynamic function could be quantitatively analyzed. On the other hand the quality of outcomes could be concluded by the social effect of the tutor interactions.

5.1 Course description

The goals of the Introductory Laboratory Course in Chemistry were to get acquainted with working in a real laboratory doing the essential exercises in general chemistry. (185)

The laboratory exercises were (in English Experiment 3, Appendix 1) (186):

Experiment 1. BUNSEN BURNER. BALANCES. MEASURING VESSELS.
Experiment 2. GRAVIMETRY. DETERMINATION OF IRON CONTENT.
Experiment 3. GRAVIMETRY. DETERMINATION OF NICKEL CONTENT.
Experiment 4. ACID-BASE TITRATION. DETERMINATION OF SULFURIC ACID.
Experiment 5. TITRATION CURVES. ACID-BASE INDICATORS, BUFFER SOLUTIONS
Experiment 6. INORGANIC SYNTHESIS. REDOX TITRATION. PREPARATION AND ANALYSIS OF IRON(II)OXALATE.
Experiment 7. ION EXCHANGE. DETERMINATION OF NATRIUMSULFATE.
Experiment 8. SPECTROPHOTOMETRIC ANALYSIS. DETERMINATION OF IRON.
Experiment 9. ORGANIC SYNTHESIS. PREPARATION OF ACETYSALICYLIC ACID.
Experiment 10. SEPARATION OF CAFFEINE FROM TEA.
Experiment 11. LAYER CHROMATOGRAPHY. ANALYSIS OF ACETYSALICYLIC ACID AND CAFFEINE.

In the authentic situations of the pilot research, there were some substitute methods that were used in the university. For example in Experiment 8 for the analysis of a real process water sample of the peat power plant, there was both another reagent in place of o-phenanthroline for iron (Appendix 2), and also a modern spectrometry (for example Hitachi U-2000 UV/VIS in Environmental Laboratory).

In the university laboratory course, annually about two hundred students, in group sizes of 15–20 students, work for a period of four hours a week for eleven weeks according to the schedule. There were some supplementary lessons available for students to make up for the missing laboratory exercises due to absence or failing in the performance of the quantitative analysis. During the first lesson a student was provided with a personal
lockable toolbox, a form for signing the tools in the box, and the rules for working in the laboratories of a chemistry department.

5.2 Authentic learning

The pilot research (137) has been carried out in an upper secondary school during a chemistry laboratory course of three years, 1998–2000. The idea of collaboration with the laboratories of the surrounding community was used in order to solve problems in the school’s chemistry education: the number of students ought to be increased. The subject of the research was comparing the laboratory work contexts of the authentic learning environments and the instructional learning environments. The research problem of this action research spiral was:

Does the co-operation net support the learning process of chemistry in an upper secondary school?

The effectiveness of the authentic learning environments has been approached by means of the next questions:

1. What subsystem and/or function of the learning process that impressed the learner was emphasised in the increasingly networked learning environment of chemistry?
2. How do the environments of the learning process and the different task contexts affect the quality of an individual’s cognition?

Behind the research was the way of developing the curriculum which had become essential in Finnish education: developing functions improves quality in schools. (187) This means developing schools into versatile learning centres interacting with the surrounding society, to create netting learning environments. The goal of the research circle was the elevation of experimental activities increasing the level of action and inquiry in collaboration with authentic workplaces and a university. By means of the co-operation the available instruments and spaces of the learners were more modern than at school. The acquisition of knowledge and skills was an active, personal experience aiming at professional understanding and application. Science, technology and social interactions were concretely the holistic perspective of the empirical learning environment.

The three-year action research was the reflecting and interacting process of students, teachers in the upper secondary school and the researcher. (14, 15, 188) The repeated planning, implementation, observing and reflecting produced qualitative data: the earlier tested feedback questionnaires (189) D2 (Appendix 3), notes and videos D3, tracts D5 (the subject of an essay: Studying chemistry through laboratory work in collaboration with the community), interviews D6, as well as quantitative data: the number of course participants. The goal of comprehensive data in several contexts of learning can be seen as triangulation. Non-manuscripts, videos, supported in developing both the course and the categories. (12) All data were put to use but the most justified opinions about the learning experiences were given in the half-structured interviews created with the help of the categories, in the interview notes 98 and after the data reflections in the interview.
The crux of the data analysis exposed the core categories of situation theory.

5.2.1 Emphasising systems and functions

An answer to the first pilot question (p. 54) was sought from the learning environment experiences of course participants from different years. The learning theory elements presented by Resnick (Section 3.2.4) were found by combining the category matrices.

(D2,5,6 (1998, 1999, 2000), see Table 1)

Categories:
Category 1: Experiences with the physical system of a learning environment.
  Description: Learner’s experiences with working spaces and tools, technology, specimens, chemicals.
Category 2: Knowledge system of abstract chemistry
  Description: Learner’s experience with chemistry laboratory application
Category 3: Activity systems between individuals
  Description: Interaction experiences of learner/teacher/expert
Category 4: Individual’s activity in dynamics between systems
  Description: Learner’s own activity experience in action.

Table 1. Categorised data of the pilot project: Questionnaires D2, Tracts D5, Interviews D6 in years 1998–2000. The number of mentioned learning experiences is marked lastly.

<table>
<thead>
<tr>
<th>Learning environments</th>
<th>Category 1</th>
<th>Category 2</th>
<th>Category 3</th>
<th>Category 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. School laboratory</td>
<td>D5(99)1</td>
<td>D6(98)1</td>
<td>D5(99)2</td>
<td>D6(98)1</td>
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<td>D6(99)1</td>
<td>D6(99)1</td>
<td>D5(99)3</td>
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<tr>
<td></td>
<td>D6(98)1</td>
<td>D6(99)3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. University laboratory</td>
<td>D2(99)8</td>
<td>D2(99)2</td>
<td>D2(99)2</td>
<td>D2(00)3</td>
</tr>
<tr>
<td></td>
<td>D5(99)2</td>
<td>D6(99)2</td>
<td>D6(99)4</td>
<td>D5(00)1</td>
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<td>D2(98)10</td>
<td>D2(98)1</td>
<td>D2(98)6</td>
</tr>
<tr>
<td>3. Authentic environment</td>
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<td>D6(98)5</td>
<td>D6(98)3</td>
<td>D6(98)4</td>
</tr>
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<td>D2(99)3</td>
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</table>

Table 1 contains data (D), gathered using different methods (2,5,6), from different research years (1998, 1999, 2000) and in addition, the numbers of students, each of which relate experiences of different learning environments in the data of a particular category.
Negative experiences are printed in italics: experience with the school’s limited spaces, in a larger group it was not possible for the student to do things by him or herself, and a non-regular employee in an authentic environment as a tutor who only allowed a limited amount of independent activity. The number of these experiences was small. All other student comments included positive feedback, often expressed strongly. Comments about application experiences in school came only from those tasks which were newly introduced in 1999 as a significant analysis for students: determining the salt content of sausage and acidity and the buffering capacity of a soil sample. Students brought their own specimens for these analyses.

The framework curriculum of the Finnish upper secondary schools in 1994 states that in teaching chemistry it is important to continuously guide methods for acquiring information where an experimental approach would be essential in upper secondary school. However, the applied course designed to be carried out traditionally in a school laboratory in the research school was not realized. By adding variety to the learning environment, it was possible to repeatedly attract the necessary number of students to the course. On the basis of data gathered in the action research and based on theory, an explanation is sought for the increase in choices when experimentation is the approach and basis of the whole course.

The most important external energising factors of the learning process were in Table 1 such physical systems, (Category 1) in which the information of an abstract system, chemistry, (Category 2) was embedded, i.e., authentic environments. From this learning environment, the first internal dynamic factor energising the learning process was found for the student:

1. Embedding abstract knowledge into the learner’s living environs gave significance to chemistry knowledge. (Fig. 10)

   “...yes, it’s always a question of hands-on experience – it's good if what we learn is practical and if we talk about what my attitude used to be toward chemistry, compared to how I like it now, I was sure inspired... I realise that there's more there than just calculations and work – we were able to study practical uses and it was just more multi-faceted... it seemed that in school, things were more theory-based and the environmental laboratory was more interesting in that we were able to look at natural systems. I hadn't chosen any advanced chemistry courses, but then registered for them at the last second.”

   “…exactly, if it could be completely concrete like this. Yes, of course theory is very important, but it's a lot easier to remember it and retain things and it's a better learning method in my opinion... more interesting at least, in my opinion, and I got a lot more motivated when I could see that chemistry is all around us and it's not just in textbooks.”

In this case learning was felt to be meaningful: the learner is already, thanks to existing knowledge structures, ready to receive and understand information he or she takes in. A meaningful significance experience is thus achieved by the internal relevant information association of the individual, not a context objectively defined outside the situation. From the socio-cultural information structure basis of the learner, the
laboratory activity creates a context for the abstract knowledge of chemistry. A task is easier to learn when placed in a familiar environment. (7)

The student’s inner structures create the basis for his or her thinking and to the language used as a tool for interaction and for the interpretation of meaning. (Resnick 2. in Section 3.2.4) Furthermore, some learners’ experiences showed that the laboratory work that was performed in school and connected to their living environs – ground buffering, salt content of sausage – were meaningful chemistry analysis contexts. With their analysis specimens brought from home, these contexts were also part of the physical system of the learning situation. Although these situations were not, in fact, equally authentic as a power plant and environmental laboratories, their familiar cultural context gave meaning to chemistry information.

“...were able to study interesting subjects such as the ground... things we come across thing all the time in everyday life, but don’t immediately think about chemically. But when a person starts to think about the subject from a chemistry point of view, like the ground for example, I mean, it’s a totally familiar subject – but we don’t actually know anything about it.”

“Yes, that buffering solution was interesting for me, anyway; we had to get a soil sample ourselves.. it was fun.”

Fig. 10. Meaningful learning environment of chemistry.

In an experience derived from an authentic context new to the learner, it was essential with regard to chemistry information processing that the learner felt it was familiar and close to him by way of meanings provided by the physical environment: a structure equivalent to the partial information received from a learning situation was found from the learner’s cognitive structure; this further activates attentiveness from the previous structu-
re into deviant elements of the information signal. During the thought process, the learner converts his or her perceptions through interaction with earlier cognitive structures into new information in order to understand the meaning of their contents. Information is categorised by meaning. Combined with time and life experiences, categorisation produces meaningful control of activity.

As another significant internal energising factor, working in sites in the learner’s living environs (Categories 3, 4) allowed the basic default of this research (compare also Resnick 1. in Section 3.2.4):

2. The learner’s self-regulation in the learning process

“…you can do as much as possible by yourself, such as all solutions and so on, you can do as much of the work as possible. At least I myself, like, learn a lot better if I do something myself and don’t just read.”

“…at the university, just like at school in my opinion, but you had to be a lot more independent…Yes, I like (independent working), I have to study carefully so that my work doesn’t depend on others so much, although it is, you know, a nice support and security when a friend watches to make sure it doesn’t go wrong, but it was like…at school you think that you’re always part of a group. (Elsewhere) it wasn’t so guided, it was more independent than at school.”

“…in the environmental laboratory it was free and you could use the devices by yourself…It was good that the person talked about using the devices and what they are for and showed them to us quite comprehensively, showed us their work stages and then showed how a spectrophotometer, for example, worked … and then the pressure cooker and showed us the other systems…it was so comprehensive…Then he/she monitored us the whole time when there were fewer people and in that way advised us… opposed to that the teacher rotated in the school because there was a lot more people…At the university the work was quite independent…(essential in the course) we could do things so it wasn’t just reading from a book, instead you could really do things.”

This self-regulation was clearer than in the time-based, group progression executed in school and university. The significance of the interaction systems (Category 3) was mostly support in independent working. An expert in his job also provided a model of his own data collection and information processing both verbally as well as through his skillful behaviour and even actions, which the students observed especially in the environmental laboratory.

According to research, meaningfulness, as partial information in the learner’s cognitive processing, and self-regulation, as a function, both seem to contain a strong emotional component in the brain. These will be examined as cognitive phenomenon in the answer to the second question. This emotional component could, for its part, correspond to Resnick’s expression of tuning to the learning situation (Resnick 3. in Section 3.2.4). This is created by the physical environment with its significance interpretation.

In chemistry data collection the basic experimental work was for the students the most important reason to gravitate toward this applied course (D1 (98) 47%, (99) 60%) However, the course is not usually carried out with this number of students (fewer than 8 beginners) and nobody would have achieved the objectives of the course. Yet the level of
chemistry objectives should comply with the level of the learner’s thought: at the start of
upper secondary school fewer than half of students are at the level of formal reasoning.
Experimental skills in handling laboratory equipment and materials are important and are
goals that are best achieved in learning environments that are perceived as more indepen-
dent. The accuracy and usability of analysis results for the decision-making of an expert
added to the value of experimentalism in the learning experience. A student working
safely and with self-confidence was the goal of the course, which was also visible in the
verbal evaluation by the teacher. In fact it has been discovered that the teacher’s observa-
tions of work can result in information of a student’s work that is considerably more
diverse than information derived merely on the basis of the student’s written answers.
(153) Laboratory work based on the learner’s active information construction is thought
to teach process skills as well as scientific understanding. However, this requires changes
by teachers in the traditional timing and implementation method of tasks (National Sci-
ence Education Standards, USA (192)). In fact while this study was being carried out,
small changes have been made, but they have been directed at the context, not at the
method of implementation in a laboratory, which, as it turns out, would also have been
reasonable. Now, however, the goal was to find additional value to cognitive processing
from the context, which seems to be at least as meaningful for students. Context would
appear to especially affect the learner’s attitudes toward chemistry and would also point
to the retention (permanence, constancy) of content information through understanding.

5.2.2 Processes in an individual’s cognition

When the analysis of the phenomenon being studied, the teaching-learning system experi-
ence of chemistry students, had been carried out in different learning environments, it
was possible to try to answer the second research problem through systems thinking (Sec-
tion 2.1.1). Interpreting the answer found to the previous question was done for theory tri-
angulation by separating the core of the learning phenomenon of chemistry completely
away from its original context and describing it on the basis of foreknowledge of neuro-
science. (193) In describing the chemistry learning phenomenon, the internal energising
factors found before – self-regulation and significance interpretation with their emotional
components – were completely separated from the context of learning chemistry, from the
learning environments. Interpretation for self-regulation as a function of dynamic cogni-
tive activity and significance as part of information with its emotional components was
sought from the neural network, the human brain and its information processing.

A key finding concerning the communication between brain cells during the past two
decades is that it is not fixed but that activeness and experience can modulate it. At the
first level a brain cell functions as the basic tool for memory storage when experience lea-
vies an engram (memory trace) on the brain. Thus in the biology of memory, as a synthesis
of sciences, a change is taking place in the understanding of the mind as molecules. The
second level is the cognitive activity of the brain as systems and, as some of the most
important discoveries, the different forms of memory as well as clearly retrieved logics
and different kinds of brain circuits that stand out in PET Scans, for example. Self-organi-
sation is the ability of the neural network to change its synaptic connections in accordance with the required task:

1. The complex nature of learning tasks positions memory into extensive areas, into different places of the brain system (Section 3.1.2, Section 3.1.4.1 and Section 3.2.2) (2).

“…practical issues and more variety” (the student is speaking of authentic environments)

“In the iron assay we assayed iron so that in …the environmental laboratory. (The sample)…was from a well …the (iron) had some effect on the quality of the water… Basically the materials that were placed there (during the analysis) and those kinds of mixtures were familiar but the equipment was completely new, they were completely different almost, or essentially the same but then because they were electronic and so on, they were different. The spectrophotometer was, of course, completely different. There isn’t one at school at all and that calibration, fixation, we hadn’t had them before, it was completely unfamiliar…all of these zero specimens and such comparison systems were also new, but they were not any more laborious that others either…”

Complex experience increases the overall quality of the functioning of the brain. Changes in the dynamics of the neural system, in memory, seem to make the nerve cells more efficient. These alterations take place either as a result of environmental effects or as a result of the dynamics within the brain system. The environment, however, always functions only as a trigger into action potential through its effect, but doesn’t specifically or directly change structures. Each individual reacts to observations based on the internal, non-linear organisation models characteristic of his or her brain. Inside the learner’s brain, self-controlled significance interpretation sought from long-lasting engrams formed from previous experiences takes place between the external stimulus and reaction.

Conscious directing and selection of perceptions must continuously complement the perception circuit, the attention process, which has been studied with ERP and MMN measurements. The more diverse and visual the stimulus experience, the greater the possibility of finding a significance interpretation. Furthermore, after feedback there is a greater possibility of processing the perceptions of the situation, the new information being learned: functioning through short-term potential to long-term memory.

2. According to test results, memory is especially accurate for meaningful, visual material: (194)

“During the laboratory course I noticed many things I hadn’t earlier understood,… I started to understand calculations, even the old calculations better now when I look back after the fact…and I do look purposefully, how they were supposedly so difficult, so no, there’s just something there, so some small practical issues have stuck so that – I didn’t understand them before until in that course, when it was possible to prove them by doing them.”

The meaningfulness of chemistry altered the cognition of students, helping them to understand points of difficulty. What we pick up from our perceptions depends on previous structures since previously performed information processing has facilitated the activity of the synapse: has depolarized the presynaptic cell by increasing the amount of
transmitter and has also depolarized the postsynaptic cell by activating and/or increasing the ion channel. We perform self-controlled selection that is not the cognition of our spoken and written language, but significance interpretation performed in an electrical and chemical form in the context of the situation (Section 3.1.3). Although synaptic changes, which are the basis of learning, prefer to appear in certain types of neurons, the complex nature of a learning task likely makes these neurons activate at least through a reflective pathway if not directly. In inner cognition, self-control and significance interpretation steer information processing as it strives toward increasing organisation in the brain network. What brain systems are required in the coding, storage and retrieval of information as significance interpretation is being exploited? In the following study the neuroscientific basic principles of Kandel, Schwartz and Jessell are used. (83)

Long-lasting memory has two basic forms. Nondeclarative memory is subconscious and guides and stores perceptions, motor functions and information processing skills and habits. As different forms of learning, habituation, sensitisation and classical conditioning all use synaptic plasticity, for example the depolarisation of ion channels as storage mechanisms into nondeclarative memory. The pre- and postsynaptic facilitation accounts for the changed activity after learning. Chemical communication, the diffusion of transmitters over a 20 nm-wide synaptic gap, is fast and selective and becomes easier after the signal depolarises the ion channels. Learning is also critically dependent on what type of receptor the transmitter binds itself to and how it functions in the postsynaptic cell: the conformational change of the protein and opening – which takes a few milliseconds – of the ion channel, or the longer-lasting (minutes) inner biochemical activation of the postsynaptic cell caused by the receptor. Short-term memory, STM, which we utilise during work as we transfer information into more complex memory stores, also utilises synaptic plasticity.

The significance of simple synaptic connections in the storing of events and facts into declarative memory is based on ongoing guidance of behaviour and information processing in the momentary working memory. The emergence of the permanent form of memory, however, takes time and requires several phases. One of these phases is the modulation of information representations – that are original and independent of each other – which takes place within the hippocampal neuron network. The role of the hippocampus is a connecting function in the systems of the brain. During this function, electrical activity that lasts hours, days and even weeks has been observed through microelectrodes; the facilitation caused by this activity is called long-term potential LTP. Contextual memory, a learned function connected to the environment, needs the hippocampus during the memory recording phase. At that time the signal is created into information significant to the individual by combining information with existing electrical and chemical information networks (Section 3.1.3). Until memory has stabilised into declarative structural memory, the process is prone to disruption. The stabilisation of memory to the cerebral cortex results from anatomical changes, from new protein synthesis taking place in neurons. At the cellular level the change from short-term to long-term facilitation means changing from process-based memory to structural-based memory. A long-term structural change, proteins produced by genes into new connections between neurons, emerges only in the branches of axons where short-term facilitation occurred first. The later phase of LTP additionally requires the building of new receptors, proteins into the surface of the dendrite of the postsynaptic cell. Later-stage LTP correlates with
the growth of new synapses. The chemical factors of an individual cell, e.g., the increase in ion channels, do not, however, by themselves explain the emergence of an engram, which is distributed in the self-organizing and self-activating neural network. Simultaneous changes also take place in the billions of synapses of the neural network; as a result, the transmission ability of certain synapses improves, the ability of others is weakened, and thus the entire network reacts in a changed manner. In addition, as a result of internecine competition, some neurons and synapses are eliminated. The remaining synapses become stronger in such a way that it becomes easier for signals to travel when passing through them. The action between the structures of the memory system is facilitated, which accounts for the selectivity and significance interpretation of memory search, among other things. Declarative, structure-based memory has been found to be especially reliable as storage for general information and a recorder of integral parts and main features:

3. A new significance structure created autonomously will, in future, generate a new kind of neuronal network reaction, a new kind of behaviour.

“I hadn’t selected (further courses) in chemistry, then I chose them at the last minute.”

“In my opinion, laboratory work done at a place not in school is a truly good thing in chemistry education. With regard to my own future, working at Fortum and in the environmental laboratory and the University of Oulu gave some direction with regard to my further studies. I could have done even more work in other laboratories, especially at the university. Studying chemistry is fun!”

Although declarative and nondeclarative memory differ from each other logically and anatomically, the memory recording of both is based on LTP potential. Declarative memory, which requires the hippocampus, is associative and conscious. Searching from memory is based on a series of associations, certain thoughts, imaginations and emotions: one part of the network of information receives the familiar signal; it activates the other parts of the network through learned connections. LTP stores skills, such as work routines and learning strategies, directly without the hippocampus by means of electrochemical signals that affect the information processing efficiency of neurons in certain parts of the cerebral cortex. Nondeclarative memory is not conscious. Both long-term memories, however, need the genetic system, protein synthesis for anatomical changes.

4. The structural change of declarative memory at the start of the learning process of new conceptual information is made easier when a previously traveled information path is used: In that situation, some familiar signals bring facilitation into the information processing of the neural network.

“…precisely this, that it would entirely concrete like these. So of course the theory is like, extremely important, but it like, enters your memory much easier, stays there and is a better learning method in my opinion… In my opinion at least more interesting and it motivates much more, you notice from it that this chemistry is around us, that it is not only in school books and it is motivating.”

“I like, like to study things…in my opinion it was really educational that it, like, truly dealt with those things.”
“.the buffer solutions, that we didn’t get it until the later course and then there was a question about it in the matriculation examinations, too...there was this graph problem and it was really easy in my opinion...”

A learning situation that is authentic and creates connections into old structures expands the memory network that emerges from conceptual information and improves memory search, which can be interpreted as improvement in understanding. In the central and frontal parts of large brains there are several structures, which have traditionally been called limbic systems. With limbic structures, one of which is the hippocampus, there are plenty of connections to the interbrain and large cerebral cortex. Thanks to these connections this area of the brain is considered in psychology to be one of the important centres of emotions and motives, but which are, however, the result of the joint action of several areas of the brain. The learning of information, facts and events – storing into declarative memory – always uses so-called limbic structures in the formation of connections. The emergence of skill engrams does not utilize the hippocampus nor, then, authentic learning through it. However, skills and operational strategies can be actively stored into the cerebral cortex for model learning, subconsciously and cumulatively working by itself, repeating activities in a meaningful environment. When searching for information from our memory, is it possible, however, to distinguish these engrams that differ in logic during the storing phase?

In the formation of association at the operational level of the cognition there is a connection to emotions. Emotion is part of information processing in the brain of a healthy person. A signal that is travelling through the amygdala into nondeclarative memory and which has been observed to be transmitting emotional information, has a connection to the learning of positive associations. (195) A signal travelling through parts of the limbic system, the amygdala and hippocampus, is processed in the hypothalamus. Experiencing pleasure consciously and even physiologically is possible because the hypothalamus communicates back with higher centres of the brain: cognition and emotion affect each other on a reciprocal basis. According to the hypothesis, experiencing emotion is the compilation of autonomous reactions and cognitions that emerges in the hypothalamus. The hypothalamus affects the autonomous nervous system by modulating information and at the same time controls the production of hormones directly or indirectly. When an individual interacts with his or her exterior surroundings, the information structure of the brain comes along and modulates behaviour, which, as an inner state from the stimulus of the amygdala, has already been processed by the autonomous nervous system and the endocrine system integrated by the hypothalamus:

5. As one partial system of the brain, a learner’s dynamic self-regulation in action and the significance interpretation of content being learned contain the emotional component, according to the results of this study. How can this component be construed as affecting a learning event?

"It was truly interesting to familiarize myself with different laboratories. Each laboratory was a little different. I felt the environmental laboratory was more pleasant because the tools were automatic (precise results).”

"It was nice to study medicinal substances in the pharmacy; I might use them myself someday. The tasks of the university were fun because there were appro-
appropriate tools there. Writing the specifications required a lot of work, but was rewarding.”

“Studying chemistry by means of laboratory work probably gives a better picture of working with chemistry than would studies based on pure theory lessons. It also brings with it a good, maybe even stimulative effect on studies.”

“The course was moderately laborious and time-consuming, so it takes away the last bit of motivation to study, especially if the course is already nearly full otherwise, for at least 4 weeks after the course has come to an end.”

Pleasure is an important but poorly understood element of behaviour. In the processing of information, the hypothalamus, which is in contact with the parts of the cerebrum involved with all information processing, is a critical structure in the production of the compilation of outer and inner stimuli, the emotional experience. In addition, researchers have discovered that paths that use the dopamine of information processing as a neuron transmitter reward and confirm behaviour. Many other transmitters as well participate in the production of pleasure by, for example, indirectly activating dopamine-energetic neurons, which are required in motivation. How is this kind of self-stimulation confirmed? In the area of association, the amygdala in particular maximises environmental contacts that produce a positive confirmation signal and minimises those that result in unpleasant emotions or danger (Section 3.1.4.1). The research provides hints that this also functions in the learner’s processing of information as the significance provided by the context, along with the emotional experience, boosts the understanding experience.

The hippocampus is essential in conscious learning during the intermediate phase of memory recording, and as part of the limbic system ties emotion with cognition.

"As necessary and concrete work, the chemistry lab work in the environmental laboratory and IVO were sensible, as it was at school too. It was nice that I was able to familiarize myself with the chemist’s trade and job tasks at workplaces where they were beneficial. The university trip was poorly timed, as were the lessons after four o’clock, otherwise a well-organized fun course. Work somewhere else is more enjoyable than at school, maybe because of the environment.”

“Altogether a totally interesting diversion, even though my fun-seeking mind tends to procrastinate specifications to the last minute.”

“In no way is chemistry my whole life, maybe one-thousandth of it at this point, so this course did not engrave any super deep memory tracks into my cerebral cortex.”

“This “splashing around” has indeed been even enjoyable at times, and I don’t consider it at all impossible that a thousandth would become a hundredth or even more at some point in life, the teachers and instruction have been good…”

Learning seems to depend on the atmosphere of the situation, which has a long-lasting effect. As the most important scientific discovery in 1992, scientists projected that nitric monoxide, which is considered poisonous, is a transmitter that affects emotions. Compared to other transmitters it has unusual characteristics: it isn’t stored in synaptic follicles, instead nerve cells produce it as needed, it also penetrates the cell membrane without a receptor. While information has been observed by means of other chemical synaptic ope-
rations as being directed only from a presynaptic to a postsynaptic cell, nitric monoxide has been observed signalling back to the presynaptic cell, activating transmitter synthesis. This communication that travels backward is activeness-dependent facilitation: the effect is only for that moment in the activated cells. In long-lasting potential, LTP is a self-confirming communication activity also when performed by other transmitters. Nitric monoxide has been found to be one of the strongest of these transmitters that affect LTP, and thus affects learning as a self-stimulator as well. (196)

Researchers have concluded that motivation is an inner state of organisation which is supposed to explain the variety of behaviour reactions. States of motivation have three functions: a directional, activating and organizing function. (197) In the study, the strong orientation of attentiveness and concentration toward a task was observed in the collaboration laboratories; the basic condition for this was the learner’s active personal cognitive process: the discovery of significance. Thus the learner builds inner representations of external reality, seeking explanations and significance for phenomena – facilitated paths for information processing from neural networks. From this interpretation of the situation the next energising effect in observations was evident as the learner’s activeness of the activity compared to group work situations and appeared as strong expressions of emotion in interviews and writings: emotion was activated. As guidance from outside was reduced, attention was directed toward the activity internally controlled as its own activeness. The effect of this kind of motivation-organizing inner state was best seen in the fairly independent work permitted by the learning environment: as the individual’s behaviour components, the reading of work instructions, working with materials and tools and the writing of a casebook combined into successive, coherent, goal-oriented behaviour (Fig. 11.).

Fig. 11. Three most important action systems of a learner.
In an authentic environment the learner processes the diverse information signals of the learning process while seeking the most suitable signal or voltage increment possible from the distributed signals of the censor system in information modules formed by significances of the motivation system. At that time it is possible for an adaptive resonance to emerge from +signals that strengthen each other; this enables a new structure and function, learning, through the feedback cycle. (Fig. 12.)

![Diagram](image.png)

**Fig. 12. Loop of learning process in a learner’s cognition.**

When creating new chemistry knowledge into brain structures, recollecting and bringing information from memory into use is made easier when a time and location component is attached to the information module in a manner that is as significant and pleasant as possible. The support of an expert adjusts the difficulty level of the work with the learner’s abilities as well as possible and, together with familiar signals, creates an enjoyable, safe and balanced emotional state. The formation of signals and improvement in recollection are part of learning quality and lead to a new kind of behaviour: toward learning orientation in chemistry. The emergence of significance categories for chemistry as part of culture and also science may create a learning orientation that is aimed at understanding instead of the learner’s performance-oriented behaviour. The recollection of information structures generated this way is facilitated by culture, everyday knowledge and emotion, in addition to the content of chemistry.

### 5.2.3 Pilot findings

The system-based research method used in this study into learning is holistic: learning is part of a large operation system in which the learning and activity of an individual are determined in the interaction between the learning situation and environment and the learner’s active interpretation of the situation. When interpreting exercises, the meaningfulness of content and the overall situation, a learner uses earlier experiences, his or her
knowledge structures, as motives and director of attention. Existing information with its value, attitude and emotional elements is a schema that intrinsically motivates learning and which is tuned by the situation as nerve impulses (Fig. 11 and 12). Because chemistry, as a historically new science in everyday life and education, has few formed specific information structures for students in upper secondary school, even fairly common schemas from the real world can facilitate learning in the beginning of education. The awakening of attention through significance and application experiences directs the acquisition of information to contents of chemistry and methods of information collection. Through qualitative learning research, it has been observed that contextual learning also results in greater self-esteem in the learner and thereby creates the foundation for attitude changes. (198) In addition to attentiveness, information also affects mood and attitudes and vice versa. When we function on the conscious level, information is intertwined into the emotional reaction. (119)

5.2.3.1 Finding 1: Meaningfulness for understanding

In an authentic learning environment the quality of the learner’s learning process, the cognitive activity, improves: by finding meaningfulness, the understanding of abstract information increases, activeness in the acquisition of information grows and attention is directed at the new content being learned, and the organisation of the learner’s own learning process is made possible. These were the central and essential learning experiences found in the study toward which the quality evaluation of learning should be directed. As to how the products of an authentic learning process in chemistry can be evaluated, it is an important separate topic worthy of research and one that also affects the building of knowledge. A new conception of learning, a renewed teaching-learning system requires a renewed evaluation. (199) With regard to the individual, significant learning experiences may remain even as hidden knowledge, but may also develop, through an interactive experience with an expert in practical activities, into a new level of awareness. The indicator of reality of significances comes from practical activities and ways of using language. (200) In this study, the requested specifications, which were for the evaluation of laboratory work, steered the choices and learning as partly negative experiences in an undesired manner.

Students felt the authentic analysis problem used as the starting point for laboratory assignment increased the relevance of chemistry, the meaningfulness of learning and promoted understanding also in an institutional context. In the interviews, the interviewees still remembered one year later the assignments done at the school laboratories, too, where they analyzed the salt content of foodstuffs and the buffering capacity of a soil sample. The analysis situation was realistic and it was associated with the learner’s living environment, it was not an imaginary problem. From these learning contexts a permanent engram remained, an extensive memory schema that assisted in recollection. Analysis problems that consisted of only chemistry theory were not remembered. (D6(66)3) Emotion has an effect on the meaningful experience provided by significance, through inner stimulation and context even in the school environment.
In the network of the chemistry learning environments developed during the study the elements that take into consideration the interests of the individual student were found: (201)

- simulates real-life environments
- enables the student to learn at his/her own pace
- reduces the “fear” factor
- removes problems of classroom behaviour
- increases individualised learning
- produces more information for evaluation
- realises situated learning in connection with doing

These elements are portrayed as relevant to modern society. In this pilot study, however, this kind of chemistry teaching model is not implemented with the benefit of information technology, but rather as authentic. Thus information for the evaluation of the course came only as traditional writing on paper and through the teacher’s observations. The diverse networking of the learning environment, which was visible in the school’s course information, was able to get enough students to select the applied course in order to be able to carry out the course. Students felt that the information that came from outside was a relevant and meaningful choice with regard to the learner’s information and/or motivation structures. Already when it was time to select a course, the context was thought to bring added value to experimentalism, which was one aim of the study: to increase the number of chemistry students.

In the laboratories of big groups, a chemistry student working traditionally according to ready work instructions is active in a limited manner. Activities are carefully controlled from the outside. Internal biological regulation in information processing cannot function as it mechanically repeats working instructions as one member of a large group. The current method of operation in laboratory work has been criticised for its ineffectualness and inability to motivate the learner. (202) Consciousness of one’s thoughts, learning and knowledge and the use of this information in the regulation of one’s own learning is hindered by an overly controlled learning environment. A concept of learning based on the cognitive sciences allows for the desired time and one’s own controllability in a learning situation for a growing young person, a future worker. Activeness can be increased at not only the operational level but also the information processing level by gradually increasing the openness of the task in an experimental approach. Then it is precisely the individual’s active, own learning process that is emphasised in the brain. The process skills of the natural sciences develop step-by-step and achieve a high level when open research assignments are performed in a meaningful (relevant) context. (203) The significance becomes apparent in a situation wherein the learner him/herself is dynamically present. Embedding learning methods into their context is not only beneficial but also necessary because something learned through such activities is not easily forgotten. (204) we received hints of this in this study: something learned in interpretation context was still recalled by the interviewee even after a year as opposed to chemistry analysis problems that were not context-dependent.

Work group situations based on behaviorism and executed in a school or university environment do not advance the development of group work skills as it requires each student to get through a given task independently. Students are not given time or space to
develop mutual trust, efficiency of communication and conflict resolution skills for future situations. The group is a group only for the teacher to manage the mass teaching situation, not for making learning more effective as a process of the learner. According to chemistry learning research, even chemistry is learned better in social interaction as active learners. (205)

5.2.3.2 Finding 2: Improved activeness

Cognitive and laboratory work skills emerge from the learner’s effective activity in work and social interaction when the execution of an analysis assignment succeeds with the support of an expert’s information processing in a cultural context. The activeness of a person of upper secondary school age in an authentic environment is used at both the inner cognition and functional level. The understanding and application possibility that emerges in the activity, the development of cognition skills and practical work, make the information alive and meaningful. The significance of abstract knowledge is created in the active systems of people. Activity contexts are systems which integrate the subject, object and tools into one entity. (206) Becoming aware of a meaningful purpose activates the biological system to observe and process information.

In order to gain personal skills and lasting action abilities, the information systems of the domain are needed and vice versa. The efficient formation and use of information systems, especially those presented at the macro level of experimental science and the micro level of chemistry language, require dynamic skills: thinking skills, study skills and higher level cognitive abilities. According to Resnick, there are three fundamental characteristics in the active development programmes of these skills (6):

- socially distributed problems that have significance in the context of the whole
- includes training that encourages the learner to observe and comment
- is organized around the learner’s subjective information structure and interpretation

If the only acceptable manifestation of something learned is a linguistic, symbolic output, learning has been perceived too narrowly. When a person’s learning and intelligence is perceived as a context-dependent process, in the evaluation of results it is possible to ask how this learner functions in the information construction process. (131) The promotion of cognition processes in normal contexts is different than in testing conditions separated from context, but gives more information of operational ability according to the situation. In this study, learning becomes evident as an operational function of completing a chemical analysis for which, as a result of a sub-activity, there is also written specifications. Learning is also interpreted as the inner dynamic function of the learner. This way the study has aimed to emphasise the activity between parts of the system and their significance with regard to the whole (Fig. 2b).

Learning the language and conceptual system of chemistry and the flawless production in writing and/or orally as the resultant for classroom teaching has been difficult in upper secondary school. In this study this became evident when the university required specifications for all assignments, which proved to be extremely hard. Valuable skills, which should be taken into consideration when evaluating learning, are learned in the context of
practical assignments and analysis. Being able to get through an assignment is already an indication of learning, which, when given as feedback to achieve the objectives, serves as an external energising factor for the learner. Information is not internalised directly but rather through the use of tools in activities. These tools change as information and skill become more and more abstract. Students gradually progress from the operational experiences of general chemistry applications to chemistry concepts, and readiness for demonstrating symbolic learning increases. Learning the symbolic language of chemistry is facilitated in a real world situation. More and more students of upper secondary school can find meaningful and thus relevant information schemas as the learning environment expands into an authentic one, and are able to continue on toward a more specific chemistry information structure: from general to specific. Context-dependent learning produces more flexible learning results: the connection between something previously learned and new information in a new situation is generated more easily. When the connection is to other structures of the learner’s knowledge, the information structure is different from mere connections of learned content.

5.2.3.3 Finding 3: Emphasised emotional component in cognition

According to the study, the emotional component, which is closely linked with cognition, is also activated in a dynamic and authentic learning environment. At the same time, the feeling that one knows something affects learning: a catalytic cycle exists and feedback in the form of emotion is self-regulation for learning at the level of molecules, neural circuits as well as the senses and even motor activity. As relevant visuals and activity increase, awareness, not just information, increases within the learner because the number of associative information signals received into thought increases activity and thought and thereby operations in the brain. The use of declarative, conscious memory is activated, in contrast to the storage of specific and disjointed pieces of information and partial skills of the behaviorist learning theory.

The feeling that I know, the feeling that I can is meaningful because it creates, among other things, a preconceived idea for the learner of his/her own condition. Triggered by intrinsic beliefs and expectations, this functions as a factor that energises learning, as a motive. A cognitive emotional reaction also emerges from the effect of the activity-elevating outer brain, novelty value and finding the coherence of different subsystems. At that time the learner feels he/she has a command of the situation. The contents of activities vary in different cultures, but the element common to pleasant experiences is their dynamism, which itself rewards itself. The result of this study is the strong effect of a cognition subfunction, the emotional function, in a meaningful learning situation, which is supported by pedagogic research as well as the neurosciences.

All these findings are conclusions reached by listening to learners’ voices. The data have been analyzed using an open coding schema. The truthfulness of these findings has also been evidenced by the quantitative data of research. The comparable applied chemistry course in Finnish upper secondary schools was completed by about 7% students without authentic laboratories. Of the finishing upper secondary students, 25% were in the research school in 1999, 13% in 2000 and 19% in 2001. The students also
selected more courses in chemistry: In the whole country 4–5 courses were selected annually by 5% of students, but in the research school 33% selected 4–5 courses in 1999, 19% in 2000 and 28% in 2001. The increased experimental knowledge of the learner effected an action desirable both at the individual level and society level. The lack of experiments in chemistry teaching is conceded to be an extensive problem. (210)

5.2.4 Credibility and transferability of pilot study

The understanding achieved in this study demonstrates the significance discovered by the learner, the application skill demonstrated by the learner in activities and the transferability of what was learned into a new environment, as was discovered by the teacher. Finding significance helps the learner remember, and application and transferability are basic skills required by the work communities of our society today. However, for more detailed research on application ability and transferability it would be necessary to use assignments that are more open in authentic learning environments. Problem-centred learning has proven to be relevant with regard to understanding and the application of chemistry principles as well as providing skills for teamwork. (211) As this action research progressed, we changed only one component of the group work tasks in university inorganic chemistry, the meaningfulness experienced by the learner on the basis of situational theory and the neurosciences. The openness of analysis assignments did not increase because the learner continued to follow ready work instructions.

The information produced in this study by the researcher brings only one local and personal perspective into the teaching-learning systems of chemistry. The information in this pilot action research, however, was created as a social construction with the chemistry teachers of the upper secondary school who participated in the study, and categories were brought to the field for them to examine. The chemistry laboratory course in this upper secondary school is being further carried out even after the study, which demonstrates ecological validity. The use of two theories, pedagogical situational theory and neuroscience, as well as the collection of diverse material during three different courses increases the reliability of the study. Comparison with studies made of the university’s godparent class activity (121) and a field trip by students of upper secondary school to Kemira (comparing feedback Appendix 3) (212), supported the results of this study, which was conducted in the same cultural context. (20)

A change in the scientific concept of learning from behaviorism to socio-constructivism (213) and further on to socio-cultural contextualism (204, 214) of the learner’s learning requires changes in laboratory work and their implementation customs: taking into account the whole learning situation. The situation is never neutral in the learning process. The results of this study are transferable from the authentic learning environment to even an institutional learning environment through a change in operational culture. A change in the role of the teacher into a guiding expert in an open learning environment where the learner performs in different contexts independently or as a small group, utilising information technology that varies in the amount of openness given and creates significance, is a change of learning culture in the function of the physical as well as social system. The potential of this outward cultural change in changing the learner’s cognition
into a dynamic, intrinsically activated, directed and steering process is one of the key challenges of chemistry education in the new century. (215) In the study of chemistry learning we also need a multidisciplinary approach in order to understand the cognition of a learner.

5.3 E-learning process

The latest part in the research spiral was the implementation of the pilot project findings from the designed physical, authentic system into the abstract, chemistry system with e-learning. The important separate topic of the research was how the outcomes of the learning process in chemistry could be evaluated. The contents of the real laboratory experiments were the same in both research projects. After the plan was considered, it was revised according to the hallmarks of the new science of learning: learning with understanding. The findings led to a greater emphasis on individual activity for cognition and action in an e-learning environment. This learning process was going on throughout the course, and it replaced the written test usually organised in the end of the course. Emotion, which is always involved in cognition, was taken into account as was, among other things, students’ voluntary participation in the research, independence in choosing working time and facilitation of information acquisition.

5.3.1 Experimental design and procedure

The researcher designed the framework used in e-learning in the closed Optima environment. (216) The goals were to adapt the high quality contact learning of a laboratory into recognising the individuality of learners and to search for pedagogical compatibility between old traditions and new learning comprehension using e-learning as a tool. The supporting effect was allocated to the individual process thinking of learning. The contents of 11 tasks with 41 questions for each learner, links to web pages and four supplementary theory documents were created by the tutor/instructor emphasising the role of a tutor in e-learning. The whole design process proved to be efficiently interactive between the course teacher of two laboratory groups and the researcher. The researcher created the www-version (186) of the course carried out in the closed environment.

At the research groups’ first session, the students had been informed about the possibility to participate in the research. Voluntary students, 18 in Group I and 17 in Group II, received a password to enter the environment and written instructions on how to log in. One person in Group II chose the test before the virtual working. In the laboratory the students made the same traditional cookbook experiments as those who were not participating in the research. Additionally they could be provided virtually with modern safety instructions instead of an old out-of-date booklet, and with interactive tutoring to support the understanding of the laboratory experiments. The aims were to boost working in the laboratory with a virtual environment so that students could

- Feel safe during active working
– Find selected information of individual significance
– Find the significance of domain knowledge
– Feel they understand what they are doing

Before each experiment the learners were offered an opportunity to recall previously learned knowledge concerning the actual exercise to utilise it in their cognition. The learner also tentatively processed the new knowledge. The basis for cognition in the laboratory working situation was created, and the mechanical progress by following the recipes might be inhibited. The reflection of an individual piece of knowledge after the labs might take place in the deliberation of applied tasks. In accordance with the tutor's instruction, the learners worked in the e-learning environment Optima before and after each laboratory experiment. The learner could choose the suitable working hours for herself/himself during the week of the experiment in question. The tutor commented on his/her personal tasks. This way the activity of every learner was increased in terms of cognition exceeding working in large groups and thus information signals could be efficiently received for the significant schema of individual domain knowledge.

The theoretical topics found in the experiments were:
1. Chemical interactions, especially
   – solubility Exp. 2, 10, 11
   – complexes Exp. 3, 8
   – ion exchange Exp. 7
2. Chemical reactions, especially
   – proton transfer Exp. 4, 5
   – electron transfer Exp. 3, 6
   – esterification Exp. 9

The qualitative development of the learner’s answering to the tasks of experiments 3, 5, and 8 were investigated in the tutoring interaction. Thus both chemical interactions and reactions were selected for the research along the course. Two of them, 5 and 8, were reflective post-tasks assessed by the students (Section 6.1.2). The task of Experiment 8 is also an application of the chemical analyzing method. The activeness, the amount of the students’ dealing with the information and links of course contents and their interactions with the tasks and the tutor could be followed in the e-learning environment. Results can indicate how activeness in the e-environment and the social e-interaction with an expert/tutor can help the individual learner in the cognition of concepts.

5.3.2 Evaluation of learning

The facilitation of the meaningfulness and activities in the e-environment supported the students in developing their conceptual understanding of chemistry. There are a variety of methods available for learning evaluation. (217) A standardised instrument, the Structure of Observed Learning Outcomes, SOLO Taxonomy (218) was selected for the evaluation of the hierarchies of understanding, of the outcomes of virtually-tutored students, because this evaluation instrument has been increasingly adapted across institutional and disciplinary contexts, for example in the learning of the basic concepts of informatics (219),
to analyze laboratory data in clinical pathology (220) and online learning of commercial aviation pilots. (221) In addition to evaluating chemistry learning, Hodges and Harvey (222) found this method to be a powerful tool in an organic course. This preceding study seems to be the only application in chemistry learning and innovated the present actuation. SOLO Taxonomy is able to probe the depth of students’ understanding of complex ideas by describing students’ learning in five hierarchical levels related to a student’s ability to apply appropriate concepts in answering questions, connect concepts together coherently, and relate a concept to new ideas.

The levels of SOLO Taxonomy:
– Prestructural level I (p): No recognition of appropriate concepts or relevant processing of information
– Unistructural level II (u): Preliminary processing but question not approached appropriately
– Multistructural level III (m): Some aspects of question addressed but no relationship of facts or concepts found
– Relational level IV (r): Several concepts are integrated coherently so that the whole has a meaning
– Extended abstract level V (e): the coherent whole is generalised to a higher level of abstraction

For an investigated task, the researcher and the instructor defined a criterion that corresponded to each level of learning in the SOLO Taxonomy. Each student’s outcomes were evaluated individually by both the researcher and the instructor, using these criteria to validate the researcher’s subjective judgement. The example of evaluating by SOLO is the post-task for Experiment 3.

Question: From the link you will find the structure of Chlorophyll A. Describe the structure by using the following terms: central atom, type of ligand, acceptor, and donor. Is it a chelate? Justify your answer.
– Prestructural level I (p): No recognition of the appropriate concepts, ligand, acceptor and donor, or relevant processing of information.
– Unistructural level II (u): The molecular structure is related by the naming of Mg$^{2+}$ as a central ion and N-atoms as donors. The chelate structure is not defined or is misunderstood.
– Multistructural level III (m): The ligand in chlorophyll is a tetradentate ligand. The chelate structure is given consisting of Mg$^{2+}$ as a central ion and a ligand where N-atoms are named as donors. No relationship between concepts is mentioned.
– Relational level IV (r): The concepts of acceptor, donor and ligand are integrated into a coherent whole that has meaning in the structure of a chelate: the quality and quantity of the processes of electron donations and acceptances are given
– Extended abstract level V (e): A coherent whole is generalised to a higher level of abstraction exploiting the individual’s earlier knowledge of photosynthesis and hemi.

According to Vygotsky (59) the intelligent action of a human develops when one internalises the artificial tools created by culture for thinking. In the researched chemistry course the learner’s higher intelligent action can develop from a lower level, perhaps starting from the prestructural level through social interactions and e-learning actions. In addition to speaking and writing in his/her mother tongue, the tool for thinking is the symbolic lan-
guage of the chemistry domain, which the learners learn to use in their own cognitive processes. The external laboratory action is as if recreated at an internal, symbolic cognitive level. The validity of SOLO levels for assessing learning quality is what an experienced teacher would regard as “quality”. Based on the studies, SOLO definitely seems to relate to school accomplishment, in the way teachers currently and typically assess students; at the same time, it addresses other aspects of cognitively relevant processes: cognitive abilities, achievements, learning motives and strategies.

5.3.3 Tool for the e-learning process

On the basis of the pilot results, earlier studies and this research theory, the main goals of developing this virtual, enriching chemistry learning environment, contents and organisation, were:

- To take into account different learners’ needs in learning (Chapter 3)
- To provide the interaction cycle between theoretical and experimental chemistry (154)
- To support learners’ empowerment in learning through self regulation in learning (137, 223)
- To use a flexible tool for social interaction and for individual data collection from groups of students

The University of Oulu as an institution has selected three web-based learning environments from which in 2002 you could choose: LCProfiler, WebCT (224) and Optima. The first one has been in use and studied at the Department Of Process and Environment Engineering, in the Faculty of Technology, University of Oulu (26). It is a commercial, closed learning environment developed at the University of Oulu, but not generally used thereafter the year 2002. The second one, WebCT, on the other hand, is perhaps the leading e-learning system for higher education worldwide. It is a partner to thousands of institutions in almost 100 countries, including the General Chemistry course (181). The third option, also developed at the University of Oulu, Optima (216), was already familiar to both the researcher and the instructor because they had personally used it in their studies as learners. They thought Optima could be a practical tool in the elementary laboratory course: it consists of several different services that can facilitate the interaction between students and teachers and also between students. There is also support available for the users of Optima in the university and the possibility to work in Finnish. Using the Optima would give valuable information about how well it works in tutoring the group during a chemistry laboratory course built around several themes.

The philosophy behind the development of Optima has not been to construct fixed, ready-made structures for users. Instead the aim has been to generate a modular learning platform with which one can construct a learning environment that responds to his/her particular needs and views. Due to the structure of Optima the user can choose the desired type of e-learning and decide how to apply it. Thus it became possible for the instructor and the researcher to assume responsibility for the learning process and to plan the e-learning needed in the course.
5.3.3.1 Tool for creating an environment

The environment is the upper-lever structure in the architecture of Optima, which is administered by the Admin user of the whole university. The admin user is responsible for co-ordinating the e-learning activity creating new users and workspaces. The workspace is a mode in the environment in which the researcher and the instructor had carried out their training. Both were given full administrative rights as supervisors. This role made it possible to create an operational environment in which the project was carried out. The supervisor can designate environment users as workspace members.

The admin defined the general access rights for environment users via environment – level profiles. As a supervisor the instructor defined the access rights of the students. Each workplace has four profile types: supervisor, tutor, user, and visitor. The members of the chemistry course had the profile of users. The profile is a list of all functions and tools that are available in Optima. The admin and supervisors can set the permissions for different user groups separately for each case, making use of the environment flexible. In this study the separated, individual interaction environments were created for both laboratory groups but all students had access to the common materials brought under the contents section of the Chemistry workspace.

The Chemistry workspace, like the entire Optima, consists of elements that are called objects. An object can be any internal or external document type, but it can also be a discussion list, folder, subfolder, or function. Each object has the same standard characteristics:
- The owner of the object defines its access rights by setting read and write permissions
- The metadata fields of the object can be used to describe the contents of the object or give instructions for using the object
- The object can be linked, copied, or moved from one place to another
- The object can be complemented with other objects or sub-objects

5.3.3.2 Tool for a learner

After logging on, each student can see the common objects of the course in his/her own workspace, where his/her folder for own materials is also located. Optima’s top frame displays functions that enhance the user’s work at the environment level. Through the desktop, the user can administer the messages, documents, annotations, bookmarks, and settings in the environment. With the search engine, the user can locate messages and documents. The Help link displays instructions for using the environment. The chat option, which enabled real-time discussion, was not used in this investigation.

At the beginning, to enhance grouping, students sent messages to all course participants introducing themselves and discussing their previous studies in chemistry. This discussion forum was available for each group throughout the course. The preparation for the laboratory works was possible by means of the Optima objects: the timetable (Fig. 13), the safety information (Fig. 14 Optima information of physical systems, laboratory: the safety guide), theory documents (Fig. 15 Optima information of abstract systems, chemistry: the theory materials) and tasks (Fig. 16. Optima tool for learning and collecting
data.). The task-types objects could be copied by the students under their own name in
their workspace. After that they could perform the tasks, leave them waiting to be wor-
ked on later or send them straight away to the instructor/tutor for comments. The interac-
tion loop between the student and the tutor could be repeated several times depending on
individual needs. It was possible to work everywhere logging on with a password on a
computer that is connected the Internet. The enabled process-working may improve a
learner’s self-regulation based, for example, here on the effective, partly self-selected
interactions of external information and internal knowledge and on the other hand con-
rolling internal and external conditions; for example, time management, study environ-
ment, different distractions, concentration on the task, emotions and motivation (225,
226).

Fig. 13. Optima information of social systems, university: the timetable.
Fig. 14. Optima information of physical systems, laboratory: the safety guide.

Fig. 15. Optima information of abstract systems, chemistry: the theory materials.
5.3.3.3 Tool for collecting data

The Optima environment collects the user statistics of the workspace and its objects (Fig. 16.) They are both personal and those consisting of all the members’ activity. Links to www-pages in text objects couldn’t be statistically controlled in Optima. It would be useful to know if students looked at and examined these links. That is why links could be built into the environment in another way acting as independent objects, but it might be impractical in a learning situation. It would be inconvenient for users and might affect their working. In this e-learning research the most utilised data in Optima was the history data of the interactions between the learners and the instructor: the saved repeated loop of the learner’s task processing and the tutor-instructor’s supporting comments. This kind of data made it possible to follow the individual learning process.

Fig. 16. Optima tool for learning and collecting data.

Optima can also collect information about collaborative working in knowledge building. The collaborative learning group solves problems in the workspace which is closed to other members but the tutor. In the interaction of learners within one small group knowledge may be actively built. That is the next very interesting research aim in the learning of chemistry.
6 Results and interpretation

6.1 How were the supporting functions for the understanding of a chemical analysis realised in the e-environment

Research theory and pilot findings concerning experienced meaningfulness and activity in the human learning process were put into practice as the interaction of chemical knowledge and laboratory work. In other words, the e-learning environment was a tool for the interaction of conceptual understanding and procedural understanding. Thus, it integrated an abstract system; chemical contents and a physical system; laboratories and a social system; tutor/students together (Chapter 2). Both the voluntary net activities concerning facts for analytical and synthetical skills in the course and the obligatory course tasks were revealed (could be followed) quantitatively and qualitatively as students’ individual functioning in the environment.

6.1.1 The quantity of functions

The quantity of the learning functions indicates that pursued, self-regulated activities were realised in the e-learning of the laboratory course. The quantity of the functions of students has been analysed by collecting the statistics of the Optima environment. The voluntary actions of learners, in addition to the task interactions studied later, are in Fig. 17. The opened objects 1781 is the sum of the contents used in e-learning for two groups. These 35 students have opened an average of 51 objects during the course. The created objects are the individual tasks objects for each experiment. Messages were not sent at all by 20% of the students, who, however, actively read other’s messages.
In this study the students’ functions with common objects have been examined using classifications from system theory (Section 2.1.2). The meaningfulness (significance) of an *abstract chemistry system* in empirical working was the focus of this research and the most improved one: the virtual environment as the source of the domain information, an abstract chemistry system, was used by 70% of the research students. But they opened the objects as follows: Gravimetry was opened a total of 105 times, Titrimetry 84, Absorptiometry 64 and Organic methods 61 times. Previously studied facts, the abstract chemistry object for revision, were used by 37.1% of the learners. For Internet ones, like www.oph.fi/etalukio/opiskelumodulit/kemia, the opening number couldn’t be tracked. The material in English, partially offered for revision chemistry, was read by 40.0% of the learners. Repeat learners made up a total of 57.1% of the students. Green Chemistry, which is deemed as belonging to a physical system, was studied by 28.6%, and Analysis of Process Waters at Peat Power Plant was studied by 37.1% of students. Each student has looked at the course information concerning the *social system* of the university, in some cases several times during the course. Only some were interested in safety working. Nine students examined the safety of chemicals. Fig. 18 Statistics of the common objects opened in the e-learning environment shows the large differences between students working with common voluntary objects. Students’ needs and study habits are different but there is also room for boosting their studies. For instance the e-environment offers versatile opportunities for learning better occupational safety.
Fig. 18. Statistics of the common objects opened in the e-learning environment.

The prerequisite for the completion of the course was the tutored interaction working with given tasks, producing about 900 interactions. Over 90% of the entirety of eleven exercises was done in the net environment. Two students had some problems in sending their tasks forward; one student sent tasks by e-mail and the other one used paper copies. Additionally one student completed his Internet working orally. There were an average of 81 tutored interactions for every 11 experiments performed by two groups on the Internet. There were clear characteristic features of a student’s individual process working habit behind every interaction:
1. copying individually labelled tasks in the environment
2. saving
3. partial cognition episode written Version X immediately or later
4. saving
5. continue writing later
6. repeating the cycle if preferred (typically 2-3 times)
7. sending the finished document to the tutor

The tutor instructed the students to do pre-tasks before the experiments in a laboratory but to send also pre- and post-tasks after laboratory working. That is for the self-regulation of students and due to the limited time of the tutor. Then the tutor commented and directed the student’s learning process forward when needed in the learning cycle (Fig.
During this process a learner had time for cognition (Section 3.1.2, Section 3.1.4 and Fig. 12) and also for the utilisation of his/her versatile information acquisition: social networks, physical and internet libraries. Group I needed more tutoring interactions, an average of 43.2/task, than Group II, an average of 38.2/task. Some students produced independently acceptable outcomes, but typically they needed one directing tutoring per task, sometimes even six ones.

6.1.2 The quality of supporting as experienced by the learners

Feedback for the e-learning part of the course was given by 80% of the students. There were both multiple-choice and essay questions in the questionnaire (Appendix 4: Feedback). Working in an e-learning environment was perceived as significant both from the perspective of course completion 60.7% and the motivation of studying chemistry 89.3%. 39.3% of the respondents found the new course completion to be extremely significant. 78.6% of the respondents felt that working with the Internet tasks had a considerable affect on the understanding performance of the analysis during the laboratory session. This was the most noticeable feedback given for the multiple-choice questions of which 96.4% experienced at least some affect on understanding learning. Help for working on the Internet had been received by 46.2% every time and 42.9% mostly as needed.

The answers of 28 students to the four open-ended questions 1B-4B of the course feedback were analysed using an open coding scheme (209). The students responded with similar experiences in several questions especially in the first and the second ones. Themes were sought from transcribed responses and coded by the researcher. This six themes are: understanding, learning environment, no test, independence, e-tasks and e-material.

![Fig. 19. Effects of the researched e-learning function as experienced by the learners.](image)
Understanding (Fig. 19): According to the eighteen comments, the most spurring effect was the experience of understanding, meaning goal-orientation in learning:

“…helped and was compelled to understand what really happened in each laboratory assignment.”

“…had to reflect, I comprehended.”

Changes in the interactions of learning systems as an explanation for understanding:
The organisation of work was appraised to better enhance theoretical understanding than merely glancing through the booklet and mere empirical working, cookbook-working. The three themes elaborated the reasons for the goal-orientation, deep approaches to learning, as opposed to the surface approaches to learning; the (new, easy, interesting) tool, a learning environment for active cognitive working with feedback interaction and discussion (15 comments), independence of time and place (11 comments), no test (6 comments). (Fig. 19)

Even though an open coding scheme was used in the inspection of the above results, comparable components were found in theoretical understanding for the positive effects of learning in the virtual university: self-regulation in learning strategies, goal-orientation, positive emotion. According to the students’ experiences an interesting tool, the e-environment activated the learners and gave opportunities for self-regulation in a learning situation. Learning strategies had been by resource management: time and study controlling (11 comments). In the background some had test anxiety (6 comments) as an emotional component of self-regulation. In the student’s goal-orientation the task value was high because a learner felt him/herself capable of mastering demanding course experiments (18 comments). This self-efficacy was a strong component in the motivation to develop self-regulatory skills. For the supporting effects of the environment (15 comments), students mentioned novelty value, sufficient materials, working ease, and social interactions, messages and discussion, which gave students the feeling that she/he is not alone with tasks and problems with the network. Studies (226) show that different motivational components, such as self-efficacy, internal goal orientation and test anxiety clearly correlate with the use of cognitive and metacognitive strategies. Based on the increased self-regulation and activity, the inputs for knowledge building increased. The experienced meaningfulness of chemistry, the understanding, could be used as an energising motivation (Fig. 19, also pilot results in Fig. 10 and Fig. 11.)

Changes especially in the interactions of a social system as an explanation for understanding: The tasks were the most important contents for the directing component of motivation (Fig. 19) into chemistry learning. The students emphasised the significance of the extra questions and feedback comments of the tutor in understanding the theoretical, abstract chemistry in the experiments. The meaning of pre-exercise working was seen as the facilitation of laboratory working. The especially mentioned (9) tasks were the applied ones, which were completed after laboratory working because reflection as an active mental process was seen to promote understanding. (227) That is why two of those kinds of post exercises were selected for a quality evaluation of tutored tasks using Solo Taxonomy.

According to the feedback answers of 3B the students perceived all the Internet tasks to be generally good ones (14 comments).

“All tasks were at the same level: you got to think about lab working and why.”
The reflecting elaboration is mentioned in students’ answers as a good learning strategy: “The ‘why’ questions were excellent.” The particularly good ones were closely associated with laboratory instructions. Doing tasks like this was said to be better for learning than studying for tests. “Define concept…” tasks were not liked (2 comments). As regards applied ones, two kinds of comments were given of the more open tasks: challenging tasks were good, useful for understanding (9 comments), but five (5) comments criticised these ones as being difficult, even devious. Specific opinions (3 comments) expressed the understanding of the pH- and buffer solution via the tasks. Only two comments were given about calculating being a good task.

Answers in question 4B concerned problems in e-learning and they nearly entirely consisted of various technical ones (13 comments) or, in the beginning of the course, the insufficient IT-skills of a learner (7 comments). The support in Internet working was said to be sufficient during the entirety of the course (15 comments). Several students (14 comments) wished for more help in their own situation in the beginning of the course though on the other hand they thanked the tutor, who had the energy to answer their questions, too. After they got started some students mentioned they had observed a change in their skills in and attitudes toward ICT.

The results indicate that the spiral of learning was realised as the learner’s understanding, experienced not only on the level of action but also on the level of conscious thinking during the course. Appealing to the biological properties of humans, the same end state of learning could be achieved from different points of departure and in different ways by different learners: self-regulation of time and of one’s own cognition in the learning process were put into practice using e-learning. The symbiosis of the theory and experimental work in chemistry was qualified as high by the learners.

6.2 How was the learning of theoretical topics (theme, subjects) of this course facilitated by e-interactions

The students used the e-environment of the abstract chemistry system, the theory contents, for the task working. Their outcomes were qualitatively analysed before and after the e-interactions of the social system, tutoring. The personalised instruction or feedback here was as an e-tool for helping the learner identify errors in learning outcomes and to substitute them with the correct cognition.

6.2.1 Effects of tutoring interactions

A systems theoretical orientation in the pilot examination has earlier brought out the significance of the self-regulative side of a learner. In the tutored, self-regulation situation each learner of the course had worked a total of 41 task answers, some of which were essays, and the other short ones. 99 essays of the 1435 answers of both self-worked and tutored tasks were evaluated using SOLO taxonomy (Section 5.3.2). These outcomes of
both laboratory groups, Group I and Group II, were related to the experiments 3, 5, and 8 of the course. The content of the tasks were: the structure of chlorophyll A for Experiment 3, pH in the solution that has reached the equivalent point in the acid-base titration for Experiment 5, and the planning of the spectrophotometric analysis of a brass wire for Experiment 8.

### Table 2. Changes of 99 tutored task outcomes in SOLO-levels.

<table>
<thead>
<tr>
<th>Group</th>
<th>Prestructural (p)</th>
<th>Unistructural (u)</th>
<th>Multistructural (m)</th>
<th>Relational (r)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group I</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-worked outcomes</td>
<td>18</td>
<td>19</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>Tutored outcomes</td>
<td>5</td>
<td>14</td>
<td>26</td>
<td>5</td>
</tr>
<tr>
<td>Group II</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-worked outcomes</td>
<td>4</td>
<td>18</td>
<td>22</td>
<td>5</td>
</tr>
<tr>
<td>Tutored outcomes</td>
<td>0</td>
<td>6</td>
<td>29</td>
<td>14</td>
</tr>
</tbody>
</table>

Fig. 20. Results of the students’ improved understanding after networking with tutor.

In Table 2 and Fig 20, about 75% of students achieved levels of recognising several aspects of the task subject (multistructural 55.6%) or even most or all aspects by attempting to reconcile them (relational 19.2%). The research theory (Section 3) explains difficulties in simultaneous cognition, which leads to filtering meanings in individual cognition. Tutoring interactions enabled the students to create meanings of chemistry topics and helped the most difficult level change, from pre- and unistructural to the multistructural level, i.e., to process several facts simultaneously. Without the students’ interactions with the chemistry contents and repetition links in the e-environment, the knowledge levels would have remained a level below 60% for pre- and unistructural levels and 40% for multistructural and relational levels (before tutoring). The understanding of laboratory experiments could be really difficult. Fig. 20 shows SOLO levels of tree task outcomes of every individual student’s 41 tasks. The whole e-learning of the laboratory course can be estimated significant for higher conscious thinking of chemistry. The results could also explain the tutor’s observation of students coming to the laboratory more confidently and ready for individual work.
6.2.2 Examples of changing the SOLO-levels

The tutoring was the action for changing the quality of the learners’ learning outcomes after the e-learning environment should have promoted and facilitated learners to maximise use of their intelligence and knowledge.

Examples of the interactions for the post-task in Experiment 3

Task: From the link you will find the structure of Chlorophyll A. Describe the structure by using the following terms: central atom, type of ligand, acceptor, donor. Is it a chelate? Justify your answer.

Example 1: The transition from a unistructural to multistructural level by student 3 of Group I:

Unistructural (Optima Version 2 in Fig. 21)

“Chlorophyll is a chelate because the central atom (Mg) is bonded by two dimethylglyoxime-molecules, i.e., ligands in which nitrogen atoms act as donors so donating an electron pair to the bond and magnesium acts as an acceptor receiving electron pairs and thus forming the bonds. The ligand in question is a doubledentate one.”

Tutoring:

“The ligand is not doubledentate. The porphyrin ring in Chlorophyll is similar to the one in Heme (see the picture in the link) so how many dentate is the ligand in question?“

Multistructural (The same outcome after tutoring: Optima Version 4 in Fig. 21. Example 1: Tutoring the tasks of Student 3 G I for Experiment 3)

“Chlorophyll is a chelate because the central atom (Mg) is bonded by two dimethylglyoxime-molecules, i.e., ligands in which nitrogen atoms act as donors so donating an electron pair to the bond and magnesium acts as an acceptor receiving electron pairs and thus forming the bonds. The one in question is a tetradentate ligand.”
The comment:
Here we can see the difficulty in the evaluation of learning. In the first version the student has used the aspects of central atom, acceptor and donor, even finding some relationships of these concepts. Yet the processing is preliminary concerning the concepts of chelate and ligand. The version is almost entirely on the multistructural level. In the tutored outcome the concepts of central atom and ligand are not more integrated coherently so that the whole chelate would have a meaning (relational level) though the bonding of the ligand to the chelate is now named correctly. This outcome also shows how students often transferred special facts, here a reagent dimethylglyoxime into a more common concept.

Example 2: The transition from a multistructural to relational level by student 15 of Group II:
Multistructural
“In chlorophyll A Mg atom acts as a central atom into which four nitrogen atoms are attached. Mg forms with porphyrin, a chelate in which porphyrin acts as a heksadentate ligand. Nitrogen atoms act as donors and magnesium acts as an acceptor. Chlorophyll helps the transformation of water into carbon dioxide to obtain carbon hydrates. This takes place in chlorophyll, transferring a high energetic electron to another molecule and receiving a low energetic electron from another. In question is a chelate because one porphyrin molecule forms more than one bond with magnesium.”
Tutoring:
“Why is the porphyrin circle a heksadentate ligand?”

*Relational* The zero outcomes (two) before tutoring and zero (five) after tutoring in Group I (Group II)

“In chlorophyll A a Mg atom acts as a central atom into which four nitrogen atoms are attached. Mg forms with porphyrin a chelate in which porphyrin acts as a tetradentate ligand. It is tetradentate because it has four donor atoms (nitrogens). Nitrogen atoms act as donors and magnesium acts as an acceptor. Chlorophyll helps the transformation of water into carbon dioxide to obtain carbon hydrates. This takes place in chlorophyll, transferring a high energetic electron to another molecule and receiving a low energetic electron from another. In question is a chelate because one porphyrin molecule forms more than one bond with magnesium.”

(The same outcome after tutoring)

The comment:
This task in the beginning of the course concerned only the structure of one molecule, the complex chlorophyll the name of which is well known to the students. It has the essential support for the students’ meaningful cognition, for the adaptive resonance and LTM.

A summary of the past task in Experiment 3:

*Prestructural* The 2 (1) outcomes before tutoring and after tutoring 1 (0) in Group I (Group II).

*Unistructural* The 11 (8) outcomes before tutoring and after tutoring 5 (1) in Group I (Group II)

*Multistructural* The 3 (6) outcomes before tutoring and after tutoring 10 (11) Group I (Group II).

*Relational*: The 0 (2) outcomes before tutoring and after tutoring 0 (5) in Group I (Group II)

Here we see one reason why the tutor has drawn the conclusion that most of the students in Group I didn’t use (improve) the e-environment in the best way for working though they have good IT skills. The students of Group I needed more social scaffolding for the lowest levels of quality than Group II did during the whole course.

**Examples of the interactions for the post-task in Experiment 5**

**Task:** When is the solution of acid-base titration in an equivalent point neutral or when is it not? Justify your answer. Look for example at the link and find more information about titration curves you can find here under chemistry.

*Example 1:* The transition from a prestructural to multistructural level by student 15 of Group I.

*Prestructural:*
“When we mix acid and alkaline solutions, neutralisation will take place if there is an equivalent quantity of acid and base in the mixture. Equivalent quantity means the amount which is in accordance with the balanced reaction equation. As a result of the reaction the pH of the solution changes, too. If there are not equivalent amounts of the
solutions, the solution is either acidic or basic depending on, of course, which solution in question there is more of.”

Tutoring:

"In the equivalent point acid and base have been neutralised but what is formed in the titration of a weak acid/base with a strong base/acid that affects the final pH-value of the solution so that it isn’t always 7?"

**Multistructural:** (The same outcome after tutoring)

“When we mix acid and alkaline solutions neutralisation takes place if there is an equivalent quantity of acid and base in the mixture. The equivalent quantity means the amount which is in accordance with the balanced reaction equation. As a result of the reaction the pH of the solution changes, too. When we titrate a weak acid with a strong base, the pH of the equivalent point is clearly more than 7: The result is that an anion formed from the weak acid binds protons. When we titrate a strong base with a strong acid the pH in an equivalent point is 7. The strong acid is always fully fragmented to ions and the anion can’t bind protons.”

**Example 2: The transition from a unistructural to multistructural level by student 7 of Group II:**

**Unistructural:** (Optima Version 3 in Fig. 22)

“When we titrate a strong acid with a strong base the solution should be neutral (pH=7) in the equivalent point of the titration. As we titrate weak acid again, the equivalent point is on the alkaline side.

So, if another component or both are weak, the solution is acid, neutral or alkaline based on the relative strengths of acid and base.”

Tutoring:

“So what is formed in the neutralisation reaction of a weak acid and a strong base or correspondingly, a weak base and a strong acid, which affects the pH-value of the solution at the end point of the titration?”

**Multistructural:** (The same outcome after tutoring Optima Version 4 in Fig. 22)

“When we titrate a weak acid with a strong base the pH of the equivalent point is clearly over 7, as a result, an anion formed from the weak acid binds protons. An anion formed from the strong acid can’t bind protons because the strong acid is always in its solution perfectly broken down into ions (protolysed). Protolyses is the equilibrium reaction in which the position of the equilibrium represents the strength of the acid and base.”
Fig. 22. Example 2: Tutoring the tasks of Student 7 G II for Experiment 5.

Example 3: The transition from a prestructural to relational level by student 16 of Group II

Prestructural
“...The solution is in the equivalent point when there is an equivalent amount of acid and base in the mixture, in other words the amount which is in accordance with the balanced reaction equation.”

The first tutoring:
“What can the pH-value be at an equivalent point?”

The same student after first tutoring:
“The pH-value can be whatever depending on whether we use strong or weak acids and bases in the titration."

The second tutoring:
"Give a justifiable example of a) the titration curve of a strong acid with a strong base and b) the titration curve of a weak acid with a strong base."

Relational:
“a) example of the titration of a strong acid with a strong base:

\[ \text{HCl(aq)} + \text{NaOH(aq)} \rightarrow \text{NaCl(aq)} + \text{H}_2\text{O} \]
The titration curve rises at first gently sloping and when we are near the end point of titration the curve changes to nearly vertical. After the end point the curve changes again gently sloping as it approaches the pH-value of the base solution. At the end point pH = 7.
b) the titration of a weak acid with a strong base:

\[
\text{HCOOH(aq) + NaOH(aq) } \rightarrow \text{ HCOONa(aq) + H}_2\text{O}
\]

The titration curve resembles the titration curve of a strong acid and base titration curve, but in this case at the end point pH > 7, because the anions (HCOO⁻) formed from the weak acid bind protons.

(The same outcome after second tutoring)

The comment:
The e-learning environment gave an opportunity for the repetition of upper secondary school chemistry. The theory of titration was also new for some university students but it was necessary for the analysis in the course. Trying to ease students’ cognitive burden by the links seem to have succeeded in many cases but some outcomes have obviously done without using the links. The researcher couldn’t track it in the environment.

A summary of the post-task in Experiment 5:

**Prestructural**: Most of the outcomes (7) in Group I but only 3 in Group II before tutoring and 2 (0) after tutoring in Group I (Group II).

**Unistructural**: The 4 (7) outcomes before tutoring and 3 (4) after tutoring in Group I (Group II).

**Multistructural**: The 6 (7) outcomes before tutoring and 9 (9) after tutoring in Group I (Group II).

**Relational**: No (no) outcomes before tutoring and 3 (4) after tutoring in Group I (Group II).

**Examples of the interactions for the post-task in Experiment 8**

**Task**: Brass is metal alloy, which contains copper and zinc. The exact amount of copper can be determined with absorptiometric methods using a spectrophotometer. What kinds of work phases would there be in the quantitative determination in question when starting from a bit of brass wire?

**Hint**: You can use the handout you received in the analysis of iron but start by planning the initial sample treatment which is needed before the measuring can be done.

**Example 1**: The transition from a prestructural to relational level by student 1 of Group I.

**Prestructural**:

“At first you must probably dissolve a known quantity of brass (the small bit of a brass wire, the mass of which is known) in a solvent, for example an acid. Then you separate the copper- and zinc-ions from each other….

I don’t know what kind of work stages there are in an initial treatment. I can’t find out anything since we haven’t got facts.”

The comment message for the tutor:
Hello, I haven’t finished the post-task, because I don’t know what to answer. I tried to find information from the net but it was in vain. I need more hints!
Tutoring:

“You don’t need to know details! You have now dissolved the brass wire and will continue with information like how copper can be made to absorb at the wavelength of visible light if its own colour is not intensive enough. Then apply the determination of iron we have done.”

Relational: (The same outcome after tutoring.)

“At first one you must dissolve a known quantity of brass (the small bit of a brass wire, the mass of which is known) in a solvent, for example an acid. Then you separate the copper- and zinc-ions from each other. The achieved solution that contains copper ions is an analysis solution. So that the absorptiometric analysis of copper would be successful we allow copper ions to react with in such a matter that after the reaction has taken place, a matter that strongly absorbs radiation will be formed, for example some chelate of copper.

We also prepare standard solutions and a blank solution. Standard solutions can be prepared from a salt of copper, which easily dissolves in water. Standard solutions would be such as the copper concentration is in the ppm- scale and varies. The concentration of every standard solution is known. We add the same amounts of the same matter as we added to the analysis solution. The blank (zero) solution can be merely water or consist of the matters that we have added to the other solutions except not including copper ions.

We do the absorptiometric analysis with a spectrophotometer. We put the zero solution into the cuvette that has been rinsed beforehand with that solution and adjust with this solution the base line of a spectrophotometer so that the absorbance value is zero. Then we put into the spectrophotometer the standard solution with the highest concentration (the standard solution in which the copper amount is the highest) and the spectrophotometer draws for us an absorption spectrum (a graph where the strength of absorption is the function of the wavelength of radiation) from which we choose the max value of the absorbance and look which wavelength this maximum value corresponds to. We choose this wavelength for the quantitative determination. After that we measure at this chosen wavelength radiation the absorbance of each standard solution and from the received results we draw a calibrating curve with absorbance as the function of concentration. Then we measure the absorbance value of the analysis solution and read from the calibrating curve the concentration that corresponds with this absorbance, i.e., the concentration of the sample.

This is how the exact amount of copper in the brass wire can be determined.”

Example 2: The transition from a unistructural to multistructural level by the student 12 of Group II.

Unistructural (Optima Version 4 in Fig. 23)

“I don’t know. A lot of thinking has gone into this task… a little help for this, please. So brass should be got as ions in the solution …zinc and copper are not noble metals so could these possibly be dissolved in a strong acid? What about hydrolysis? Then we would make the solutions of different concentrations and obtain fine graphs with the apparatus.”
Tutoring:
“At first you dissolve brass wire into a suitable solvent (what solvent it is has no importance here) and dilute the concentration to the ppm –scale.”

Multistructural: (The same outcome after tutoring Optima Version 7 in Fig. 24)
“Thus, we make standard solutions in different ppm’s. We add a zero-solution into a spectrophotometer (one cuvette in two places) and we adjust its absorbance readout value to 0, i.e., we calibrate. We leave the other cuvette into the apparatus as a “reference object”. Then we start from the highest ppm value and run an absorption spectrum at a certain wavelength interval. → we obtain the curve and we see which wavelength has the biggest absorption. We use this wavelength for the investigation of other standard solutions.”

Fig. 23. Example 2: Tutoring the tasks of Student 12 G II for Experiment 8, Page 1.
As a summary:

**Prestructural** The 9 (0) outcomes before tutoring and after tutoring 2 (0) in Group I (Group II).

**Unistructural** The 4 (3) outcomes before tutoring and after tutoring 6 (1) in Group I (Group II).

**Multistructural** The 3 (9) outcomes before tutoring and after tutoring 7 (9) Group I (Group II).

**Relational:** The 1 (3) outcomes before tutoring and after tutoring 2 (5) in Group I (Group II)

The comment:

The tutor observed that the applied post-task for Experiment 8 required a lot of social discussion with peers and with a peer and the expert. This sort of task may be a good type of problem in chemistry for collaborative working in e-learning environments. Peers might with collaboration achieve the extended abstract level of SOLO: make hypotheses and generalisations of situations not previously experienced based on the relevant data and the interrelations.

### 6.2.3 Comparison of changes

Tutoring changed the level of the three analysed task outcomes from the prestructural to the unistructural level seven times, to the multistructural level five times and to the rela-
tional level four times. From the unistructural level to the multistructural level the number of changes was twenty-one and to relational three. Transitions from the multistructural level to the relational level were five times and none to extended abstract. The total number of SOLO level changes were forty five, from which thirty two were one-level, eight two-level, and five three-level moves.

In the two lowest transitions, there seems to be a low intrinsic motivation, for instance familiar schemata (Section 5.2.2) for chemistry. More broadly, according to other researches and perhaps also here, these students may have a low extrinsic motivation in instructional learning. (228) At these levels at issue was not a limiting cognition capacity of the brain: in the unistructural level only one datum relevant to the task is required. In addition to intrinsic motivation, transitions to the multistructural level require the understanding of several points and thus successive processing of data in the working memory. This seems to suggest a distinct shift in the complexity of the outcome. For example the task for Experiment 3 (Fig. 25) has the elementary content of chemical bonds in molecules and the context of our nature environment. The first step in the cognition of the learner is the inner motives for the interpretation of the chemical symbols in the chlorophyll a-molecule: familiarity with this subject and its chemical symbols. The second stage of cognition is in this context understanding the meanings of several concepts: acceptor, donor, ligand, complex, chelate. This successive processing occurs in the self-worked second example (Section 6.2.2). Also found were relations up to the concept of chemical complex. The learner's processing didn't completely reach the relational level: the chelate was not defined correctly. The transition to a relational level seems to be more demanding than the others: in addition to relevant data, making interrelations by induction is commonly difficult in cognition. It demands simultaneous working, the ability to hold two or more data in mind while seeing or providing relationships between them. One of the functions of long-term memory is to help here, with practice and time to store automatised schemata as resonating neurone structures. These schemata permit the learners to categorise information in simple, easily retrievable units: here to see the ligand as a whole and so to understand the chelate. To most of the learners, who were novices in the chemistry domain, this had not yet become automatic though the schema of ligand was acquired during the experiment in the laboratory. In the above-mentioned example the working memory constraints of the learner seems to inhibit the achievement of the relational level outcome.
The task for Experiment 5 (Fig. 26) demanded the deductions of two successive chemical reactions in the context of different acid-base titrations. The problem, which was associated with a familiar chemical analysing method, was open and abstract because all the possible pH-values of solutions after titrations had to be processed by deduction but data were not precisely given. Automatised schemata were not assumed as the www-links were given for solving the problem: ITC-technology as a tool and outer information sources might compensate for insufficient inner knowledge and decrease the cognitive load. The links could be superfluous for some persons because they also impose much unnecessary information which interferes with the learning process, overloading working memory.
Quite often the tutoring, the social system, was needed to concretise the problem by asking for examples of reactions and asking why-questions in order to change the quality of outcomes. Argumentations for the pH-values were not given in the links. In this task using chemical symbols was the best route to the relational level quality and also gave the possibility of generalisation, to reach an extended abstract level of learning. The students of the course, peers in chemistry, couldn’t generalise to a higher level of abstraction but some achieved the relational level, the most multistructural.

Tasks which are unfamiliar require more working memory space than familiar tasks. (218) Because the level of cognition in tasks is related to the familiarity of the learner with the particular task and its requirements, this might not have been realized in Group I. It may have led to their low motivation to perform although Group I was more interested in completing the course with tasks rather than via a test. For example, the applied style task of chemical quantitative analyses for Experiment 8 (Fig. 27) might not have been a familiar one for the most learners in Group I (Fig. 28 and Fig. 29). The material brass was familiar and a similar laboratory analysis had been worked on but the openness of this task is a feature which distinguished it from the others. To the instructor it looked like Group II used the social system quite correctly for processing: discussing chemistry with chemistry language. The discussions regarding the pH in the equivalent point of the acid-base titrations indicated that tutoring was also very important in Group II (Fig. 30 and Fig. 31). Although the students knew this titration, it was quite difficult to understand the fact that after neutralisation of the original solutions, the new reaction has an effect on the pH. Also, the use of chemistry language, reaction equations in giving a precise explanation, makes the task difficult for the cognition, requiring of the novices a lot of working memory space.

![SOLO levels in Experiment 8, Task: Analyzing of brass wire](image)

**Fig. 27.** E-learning results of the third analyzed task.

Based on the qualitative results, the groups were extremely different, which was also in some degree evident from the feedback questionnaires. Group II produced higher quality work independently. The outcomes of the group really seldom remained in the prestructural level whereas more than half of the students in Group I worked on this level in the
task of Experiment 8. Working like this says something about the surface learning style. These students received the benefit of tutoring; they were able to start learning chemistry with the help of social and virtual support. Earlier researchers have also reported weaker students being attracted to the Web site as a supplementary source to help. (229) The students of Group I improved their outcomes in these three tasks by a total of 24 steps and the students of Group II 21 steps. As a whole, Group II demonstrated a deep learning style: the self-worked and tutored outcomes had considerably higher grades than did Group I. Particularly high SOLO levels are obtained by highly intrinsically motivated learners who search for meaning and avoid surface, rote learning (230).

Here the tutoring was an effective social component for activating the cognition of students. The quality of outcomes of the learners improved from Experiment 3 to Experiment 8 as a whole (from Fig. 25 to Fig. 27), which indicates learning during the course. Specifically it can be seen in the tutored tasks of Group I (Fig. 29) and in the self-worked tasks of Group II (Fig. 30). The results indicate the students of these groups were at different levels of the chemistry learning cycle. As background, the criteria for selecting university students have been very different for the branches of study of Group I and Group II. It can also be concluded from the feedback of the course that the learning limits of Group I seem to be due to general learning process strategies; the students of this group needed tutoring to start cognition. Group II seems to improve cognition, increasing the complexity of task outcomes with tutoring.

![Fig. 28. Experiment-orientated quality of Group I.](image-url)
Fig. 29. Experiment-orientated quality of tutored Group I.

Fig. 30. Experiment-orientated quality of Group II.
6.2.4 Reliability of quality determined by SOLO levels in e-learning research

The reliability applied to the SOLO evaluation is the interjudge agreement, i.e., whether two or more judges will give the same rating to the same student response with the correlation between judges ranging from .71 to .95. (218) Biggs and Collis have studied this most crucial test of unreliability in the different areas of SOLO measuring. After individually evaluating 99 outcomes, the researcher and the tutor have agreed on 83% of the self-worked tasks and 86% of the tutored tasks. It can be regarded as adequate agreement for SOLO measurement, as statistically studied by Biggs and Collins.

<table>
<thead>
<tr>
<th>Working in tasks</th>
<th>Agreed</th>
<th>Agreed</th>
<th>Difference of one level</th>
<th>Difference of one level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of tasks</td>
<td>Self-worked</td>
<td>Tutored</td>
<td>Self-worked</td>
<td>Tutored</td>
</tr>
<tr>
<td>Percentage</td>
<td>82 %</td>
<td>85 %</td>
<td>17 %</td>
<td>14 %</td>
</tr>
</tbody>
</table>

Validity is not considered in the qualitative research. (231) In action research the theory is validated through the practise described in Section 7.2. SOLO (218) validity depends on the expertise of the rating person. Thus the experience of the researcher and instructor (nearly 30 years and 6 years) qualified the SOLO rating of the researched outcomes because SOLO definitely seems to relate to school achievement in the way instructors currently and typically assess students. In addition to this, at the same time SOLO addresses other aspects of cognitively relevant processes.
7 Discussion and conclusions

Next the achievement of the instructional aims of the research is considered with systems thinking (Section 2.1) in the a background. The focus shifts from the individual level of the research to the level of the learning environment: chemistry, (abstract system), e-environment Optima (physical system), tutoring (social system). All these three parts of the learning environments have their own effect on the activity and emotion of a learner in cognition (232). Finally the benefits of the results for an instructional use and a research are deliberated.

7.1 Achieving individuality and activity

The first research task, how the supporting functions for understanding chemical analysis are realized in the used e-learning environment, has been studied (Section 6.1) from the viewpoint of the learners. The theory of this research will next justify (validate) these experiences which they had: understanding chemistry, independent learning in an e-learning environment with its material and task interactions and a new way to complete the course.

The cognitive inspection of educational practice refers to what goes on in individual minds. An individual is described as an organisation that is autonomous, self-referring, and self-constructing. This organisation requires energy and matter from its environment in order to function. The connectivity structure, and thus also the functions of the nervous system, change as a result of interactions and individually filtering meanings. The possible situations which the individual can henceforth adopt change. This change constitutes learning to an observer. Quartz and Sejnowski have compiled studies of the neural basis of cognitive development and call it a constructivist manifesto. (233) It is a larger historical article than the theory of this research, also covering the synaptic biochemical reactions to constructive learning. These researchers arrive at a conclusion of the constructivist learning strategy which is somewhat different from the schema theory in Section 3.2.2: rather than start with a large network as a guess about the class, the schema of target concepts, the flexibility of a system can respond to the structure of some task by
building its representation schema. Could it be specifically the cognition of experts, whose knowledge is organised around core concepts or “big ideas” that guide their thinking about their domains? Cognition like that of experts comes to be an aim during the university course: increasing negative entropy, information in a brain system.

In the pilot research the basis for selecting comparable schema is the motivation defined as an inner organisation state (in Section 5.2.2). This state comprises self-referential cognition structures and functions. PET-studies indicate that the human amygdale can discriminate between stimuli solely on the basis of their acquired behavioural significance (234). The top-down alteration has an effect already in the processing of sensory information, in sensory perception. Thus, a learner in an introductory laboratory course himself reduces information in importance (also Barlett, in Section 3.2.2). In this research the learners had considered the abstract chemistry domain knowledge in the e-environment as important and useful for understanding the laboratory analyses. Greater meaningfulness information for an individual learner can translate into greater efficiency of an individual instruction because that which is selected has a higher likelihood of further cognitive processing. Authentic tasks, such as in the pilot research conducted in co-operation with society, would be useful for even more meaningful experiences of learners. In general the learners of an additional subject have to be taken into consideration in task contexts that combine chemical tasks with their main subjects. From an educational point of view there is an advantage in an intrinsic motivation: as a dynamic cognitive state it motivates a person to pay attention to a particular source of stimulation (235). This active and subjective attention directed by a learner’s memory schemata speaks more commonly in favour of individual instruction: decreasing external direction and increasing the self-referring of a learner in the studying process.

The students were highly committed to the new way of studying. At the end of the course hardly any students remembered to mention an extrinsic motive, i.e., no test, though according to the tutor at the beginning of the course it was the most important reason for choosing the new way of completing the course. Afterwards it seemed that the students placed more significance on their self-regulation of time, place, information and interactions. This intrinsic motivation, the organisation of earlier dynamic knowledge with embedded emotions, seems to have, in the e-learning process, both an energizing (bottom-up) and a directing (top-down) function which results in understanding, deep learning (in Section 6.1.2). Increasing learning substantially increases satisfaction with learning (236). Many more students of other contemporaneous groups would have wanted the e-learning instead of the test; this was not possible in this limited virtual project.

The feeling of understanding after e-learning (Section 6.1.2) is evidence of quality learning by an individual: a high level of cognition translated into an active analysing in a laboratory. Taking into account the level of learner’s activity in the e-environment (Section 6.1.1) a high efficiency of individual learning seemed to be achieved. Quality and quantity together provide the effectiveness of brain processes. Learning activity with emotion can also modify the motivation functioning, to produce acquired motives, motives which are not intrinsic but rather are acquired by certain special types of experiences. For example one learner of the chemistry course changed his attitude to ICT as a tool. These changes are often unconscious and remain unspecified by students. In contrast to these research results the effect can also be a negative feedback for learning. The best-known positive effect in synapses dopamine has also been studied with a cholinergic
system in Behavioural Inhibition. (237) As a neuromodulator, dopamine plays a central role in brains as we form value judgements and make choices, and also includes in cognitive disorders (238). Synapses conduct signals between neurons in an ever-changing manner. The effect of a signal transmitted synaptically can vary enormously depending on the recent history of activity at either and both sides of the synapses, and such variations can last from milliseconds to months. The role of synapses is to control and filter neuronal firing within a neural circuit. Given that there are many more synapses than neurons in a typical circuit, the state of a neural network might better be described by putting neurons and synapses on a more equal footing in cognition. (239) Pre-existing knowledge with emotion caused by these known (dopamine, serotonin, NO, CO...) and still unknown molecules has its meaning in brain networks in a learner’s cognition. How can teaching institutions influence these learning systems of an individual learner? The focus has to be changed from teaching to learning. What students do is more important than what a teacher does. Teaching aimed at quality learning at university means creating the intrinsically worthwhile and valuable tasks and a versatile learning environment with feedback interactions. Then trusting a learner’s motivation and his/her enhanced activeness in learning leads to understanding, to deep approaches, in contrast to surface approaches in learning. (240)

Personalized meaningfulness in contents and a feeling of safety in laboratory working gave positive emotions and activated learning. The learning activity of the researched groups was not only what had appeared in the statistics of the e-environment (Section 6.1.1). Primarily the most important activity for individual learning was the activity in a learner’s brain achieved during this learning situation. The experience of understanding analyzing methods and chemistry theory (Section 6.1.2) indicated the activation of LTP and an adaptation: working in the laboratory took place days, even a week after e-learning. The tutor’s observation was of better self-controlling and concentrating laboratory working in two groups of this research compared to other groups parallel with these. True understanding shows in how one behaves. Being responsible for their studies allows students to develop as human beings, which is one of the major aims of their whole lives, especially modern working life.

Though much of a human’s cognitive ability may be genetic, many of these genetically determined processing capacities do not show substantial individual-differences or variation. Thus these differences between learners are not deemed to be important determinants of later intelligent functioning. The differences in learning of the learners of elementary laboratory course are mostly due to their living and learning environments. (241, 242) An e-learning environment with its materials and interactions can help the learner of a lower level in chemistry learning cycle (Section 7.2) to develop individually and to reach the desired LTM-schemata. This brain process uses a working memory with limited capacity and a long-term memory with unlimited capacity. For this, instructional processes can be made more flexible, rich, and individualised by multimedia and networks. However the simple assumption that using multiple forms of displaying information and providing multiple opportunities to interact with a learning environment generally results in better learning doesn’t take into account working memory constraints. The effects of a multimedia context on an individual’s cognition have been studied very little. (243) In this study the development of individuals in chemistry learning was verified by the experiences of the learners and by SOLO taxonomy in the e-environment of texts and figures
with tutoring. The self-selected time and interactivity between these elements produced the conceptual changes of many learners in most tasks (Section 6.2.1). This environment can be interpreted as supporting working memory rather than to overloading it because the verbal and visual store of working memory can function simultaneously.

### 7.2 Benefits of e-instruction

The second research task, how the individual learning of theoretical topics (theme, subjects) of this course was facilitated by network interactions, has next been studied as the implementation of the tools: tutoring and Optima. Tutoring is the tool of human activity systems as a social system at the university and Optima is the tool of designed physical systems (Section 2.1.2 and Section 4.1, Fig. 8).

The realisation of the e-learning course was assessed from the perspective of learning chemistry by SOLO-taxonomy. The results (Section 6.2) of getting most students to use the higher cognitive level processes indicate that the supporting of learners in the understanding of chemical concepts and laboratory methods succeeded: the adaptation has happened in the learner’s brain. It also looks promising when we generalise the results of the analyzed tasks for all of an individual learner’s 41 tasks concerning chemical bonds, reactions and analysing methods. Students are at different levels of learning processes in chemistry especially at the beginning of university; there are even great differences between course groups. Despite the fact that Piaget’s developmental stage is formal at about the age of twenty, the structures of responses in domain knowledge could nevertheless be seen developing in university from prestructural to extended abstract in SOLO levels; from the response level in which they have no need for consistency to the response level of resolved inconsistencies and logical alternatives. Even in the content of one domain theory they have at first only separate objects, then classes, systems and theories of increasingly higher orders. (244) These learning cycles (218) in chemistry could be practically supported by embedding formal e-learning into concrete laboratory working. Then a learner may develop to function from a sensorimotor mode to a higher order of formal thinking at least in some sub-domain of chemistry during one laboratory experiment. Without e-learning the understanding and then development of chemical thinking might have been unrealised, as opposed to what happened in these research groups. This effect on understanding can be argued partly with the support of working memory. When a learner was working in the laboratory he/she had already in his/her memory some chemical schemata of an experiment that were no more greatly loading the limited capacity of this memory type but rather activating him/her to think. For example in pre-tasks the understanding of chemical reactions in the precipitation of Ni\(^{2+}\) ions (Fig. 21) was started by thinking of the chemical circumstances of a gravimetric method and the properties of Ni using why questions. The concept of chelate used in preliminary tasks and laboratory working, was furthermore applied in post-tasks. One aim of the present research came then true during the laboratory course; the interaction cycle of theoretical and experimental chemistry.

The tutor’s observation of the students’ better self-control and concentrating laboratory working in two groups of this research is in parallel with the NSF (National Science
Foundation) project of Web-based prelaboratory tutorials. (245) The project has had some similar bases and aims with the present research: familiarising students in general chemistry with the concept, procedures, and technical skills associated with the experiments. The statistical data of student and faculty perceptions of the effectiveness of the prelaboratory tutorials also indicate many similar advantages:

- More time in the laboratory for additional data analysis and expanded studies
- Replace a lengthy prelab lecture
- Students come to the laboratory more confident and ready to begin work.

The self-referring of a learner is based on the metacognition (246–248) of one’s own ability to accomplish experiments. In their feedback, students commented that they had got from e-learning the confidence to work in a laboratory. This cognition area might be a good object to develop by doing SOLO levels (Section 5.3.2) known for students before a course in Optima. Thus learners could use their self-referring effectively in processing problems and improving their knowledge of cognitive skills. Sharing the criteria of assessing learning quality with learners can also save a great deal of time and trouble in tutoring. (249) Taxonomy may thus be used as an instructional as well as an evaluative tool, thereby shifting the focus of e-learning to students more than is done in this present research.

Tutoring was a social support for the internal, desired high quality thinking of students, which was activated by learning tasks in the e-environment. Having a new understanding of learning, the tutor was very motivated for this research. Like Hodson (250) she criticised the laboratory course, which had traditionally been successfully completed by memorising the material rather than understanding it. She and the researcher created the tasks which took the place of the final test and changed learning into an active working period through out the laboratory course. In addition to being tutored for the tasks in Optima, the students received messages both individually and together. The tutor could also answer sensibly and effectively to an individual message so that all students could read it. For students, the network with messages created a feeling of safety, a feeling that a tutor is always “present”. The tutor was of the opinion that intervention and feedback for tasks was easy to do in the learning environment but laborious due to the quantity of interactions. She observed that many students chose functioning at the lowest cognitive level of recalling knowledge and they continued developing their outcomes only after her feedback and further questions. The tutor’s own view, based on her experience, is that interactions between a teacher and a student is essential to achieve the necessary learning skills and standards needed at the university level. Relief from laborious tutoring could be partially gained by making the aforementioned Solo known to students and partially by the collaborative team working mentioned next.

Discussions with the tutor revealed ideas and plans for new types of tasks and activities in Optima but they couldn’t be realised as an experimentation. (251) The ideas included more open method tasks (203) of modern, real world chemistry as collaborative working carried out for a virtual university:

- Finding the problem
- Representing the problem
- Planning a problem solution
- Executing the plan
- Checking the solution
Reflecting to consolidate learning

It is important to think of this six-stage problem-solving model (252) as a spiral system (Section 3.2.1), not as linear stages in a top-down process and each phase most likely the result of distributed cognition of a team in the environment. The learning goal includes then more higher order strategies and patterns of chemistry discipline than only content-level knowledge – facts and procedures – facilitating multiple levels of expertise (Pilot results in Section 5.2.3). Experts solve complex problems considerably faster and more accurately than novices do: they immediately recognise familiar features in a situation, and these turn out to be the principal relevant features for correct handling of the situation (253). Approaches to teaching and learning such as cognitive apprenticeship (169) focus on the authenticity in which knowledge is developed as well as the dialogue processes between students and adult guides or more experienced peers. (254) Chemistry problem solving can benefit from these approaches first by using these methods for placing students’ learning in an authentic, real world community, (137, 204) and second by using a new, rational e-environment tool for peer and mentor interactions. Thereby studying is developed into a cognitive apprenticeship, and working interactions into collaborative ones. Employing a method comparable with this teaching method but without e-learning, the experiment of a sophomore organic course has been reported to have successfully put this into practice, without a traditional lecture, working face-to-face cooperatively and reaching a deeper understanding. (255)

The present research project has been realised in parallel with the strategy for the educational use of the information and communication technologies at the University of Oulu. (256) The efficiency of the action research at this university level, i.e., relevance (20) for practise, has been held up to the light of acceptable students in the final test of the contemporaneous and same laboratory course. About 54% of these 103 students failed and 6.8% (7 students) didn’t even try to complete the course after the laboratory period. Yet by next autumn six of the students, or 5.8%, hadn’t completed the test. In addition, four students hadn’t even tried but they might have also left some laboratory work undone.

Table 4. Test results of the contemporaneous laboratory groups.

<table>
<thead>
<tr>
<th></th>
<th>Test 12.12.02</th>
<th>1. Repeat 11.2.03</th>
<th>2. Repeat 8.5.03</th>
<th>3. Repeat 4.9.03</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passed</td>
<td>38.8%</td>
<td>41.7%</td>
<td>9.7%</td>
<td>–</td>
</tr>
<tr>
<td>Failed</td>
<td>54.4%</td>
<td>5.8%</td>
<td>1.9%</td>
<td>–</td>
</tr>
</tbody>
</table>

An optional way to complete the course, e-learning helped all research students to leave the course behind during the autumn of 2002. In addition to having significance at the university level, this surely means an increase in intrinsic learning motivation for the individual learner as feeling that chemistry is comprehensible: As a result of the required acceptable points, usually 50% of the points of the test, failure at the end of the laboratory course often sends the wrong message to students about their possibilities in studying chemistry. There is also criticism of students’ study activities as a perspective; students learn what they think they will be tested on, thus often only studying the questions of the earlier tests and getting into surface learning. The test doesn’t teach skills for managing
as experts in real life. (257) Interactions with social systems and abstract chemistry system are forbidden. In the test you answer only from memory. During e-learning, feedback was given individually and the evaluation by SOLO taxonomy showed evidence of deep learning. The learning situation of this study proved right for the efficiency of the university: both an increased quantity of students who passed the course and development of the learning quality of the individual (Section 7.1) were achieved in the desired time.

On the whole the Optima environment satisfied examiners as a tool for this e-learning project well even though it was only in a development stage and some failures caused difficulties and extra work for the tutor and the researcher. Help was available from many directions via e-mail and the action research was powerfully realized here as a social process. Optima has changed to become more reliable and its functions have been diversified after the research year through attentively listening to the users; from the perspective of the research, the laborious transfer of data to Excel has changed. Learning environments like this are necessary tools for individualising active learning in a cost effective and high quality manner. The university has invested in virtual teaching but this has not yet effectively been used in science education. This research course was the first one in the chemistry department and it is also possible to see and to use it as an open Internet version with e-mail interaction. Working like this will, without doubt, overburden a tutor if there are many groups. For example, messages are not organized here as they are in a closed system. The researcher and the tutor do not have other experience in supporting learning virtually and they didn’t try to use the properties of Optima environment very extensively. The object called “task”, which was used very much, could also be in their opinion a closed one that can be selected in order to avoid the copying of certain kinds of tasks by students. The open one could be for the collaboration of teams, which is a necessary element of science learning at university level and teaches the ability to communicate cognitive concepts and investigative procedures. In this e-learning environment a common understanding and report of the collaboration can be created. Researchers (258) recommend that the communication of science should be taught clearly and together with the procedures and concepts of science, with laboratory investigations because it reflects and develops understanding of measurement. For the purpose of motivating students and assisting them in relating instructional chemistry to the wide world, tasks may be presented in a socio-cultural context close to students (137). One student could have a low directing motive for science but will become involved in the task when doing a particularly interesting lab activity in chemistry. The e-environment provides versatile probabilities for this kind of collaborative working that utilises Vygotsky’s zone of proximal development of participants (Section 3.2.1).

7.3 Implication for use and future research

Enhancing teaching through socio-cultural constructive alignment is consistent with the aim to take into consideration the individual cognition of natural sciences. It is even more important in future studies when learning is pointedly seen as the process and function of a self-referring organisation. In that case the understanding of learning with the more neu-
rochemically-oriented accounts of the neural basis of memory (259) actually emphasises an active operational quality. It is, therefore, no longer the task of education and learning to reveal the fundamental unity of cognition by schemata. These schemata are available in scientific research based on theories of open systems, non-linearity (Section 2.2), and learning reactions (Section 3.1). Though the function of the brain, here learning, isn’t observed with PET or other scientific methods (Section 3.1.4.2) all noticeable results must be in accordance with these scientific measurements.

To sum up chemistry learning as the different levels of systems thinking

- Learning doesn’t exist without the active function of a learner’s brain system
- Meaningful learning doesn’t exist without the functions of brain paths of synapses and networks that have been traversed earlier
- Learning is highly tuned to interactions with an environment; physical, social, and abstract

Specifically, meaningfulness (Section 3.2.2) comprises emotional intrinsic motives (See Fig. 11). First the abstract chemistry content has significance through earlier knowledge and a relevance in laboratory. Second the resulting experience with controlling the learning process and achievability of aims is a known way to awaken/energise learning on the molecular level too. Emotion and activity tune learning to interactions with the environment. An extrinsic learning situation, both the social and physical, doesn’t need to be “nice” but to feel meaningful and safe for the learner in interactions. This focus of meaningfulness and laboratory safety in the produced web-materials of the present study can and will be exploited in future courses. Besides improving the quality of chemistry achievement, potential collaboration also creates the essential high-level skills of cognitive processes needed in the information society. (260) The above-mentioned individually-rooted processes play a key role in collaborative learning as well (261) and these have to be understood and taken into consideration in the planning of teaching.

In parallel with the cognition concept from the natural sciences, learning can be discussed using more qualitative than quantitative terms. The measure of quality needs, however, a new kind of assessment. For example Solo taxonomy was indicated as one useful tool to evaluate the quality of cognition outcomes in addition to the quantity of stored knowledge; to evaluate when learners have achieved higher order thinking skills to formulate, hypothesise, draw conclusions or solve some chemistry problem but not achieve these skills generally. As an active system, a functioning brain connects knowledge internally, integrating concepts in its processing into a meaningful whole.

An individual learner is an active, goal-oriented student in an instructional system: in a university or at school. This system has its own curriculum that essentially directs teaching and studying. The Finnish National Framework Curriculum has been authorised in 2004 and will be in use in 2005. The principles of the curriculum of upper secondary school (262) are based on the socio-cultural learning theory (Section 3.2.1) and, as a result of this, make it necessary to create such learning environments where students can set own goals, learn to work individually and collaboratively in different groups and networks. The curriculum’s contents emphasise taking into consideration in teaching methods a student’s own ability to study, the individuality of a student. In addition, the curriculum of chemistry emphasises experimentation which enables learning science knowledge, information acquisition methods, and understanding of chemistry as an experimen-
tal natural science. These kinds of versatile environments, which are similar to socio-cultural and situational learning, have been created and researched as a pilot project in chemistry from 1998 to 2000 (Section 5.2). The result was that authentic laboratory problems guided by an expert created meaningfulness for understanding chemistry, improved activeness and emphasised the emotional component in the cognition of students. After these years, ICT has also been used as a tool in the same laboratory course; activity for educational development has continued in this upper secondary school. An e-learning environment with authentic laboratory situations acquaints students with modern technology in industry and environmental technology and connects chemistry to everyday phenomena and to the well-being of humans and nature. The results (Section 5.2.3) indicated that the goals of the curriculum to awaken and deepen interest in chemistry and its studying were achieved by the pilot students’ experiences. The mode of networking activity during the pilot project as a whole provides one way to realise most of the new chemistry teaching goals of the curriculum principles, and the theory of the current research: scientific and educational theories together explain why these goals are achieved.

The objectives of the researched introduction laboratory course at the university have been written into a study guide as an initiation to laboratory working. The person in charge said it also means, of course, an understanding of the chemical ideas of working, then an action both in physical and abstract systems for students. In her opinion the theory and practice of chemistry remain, however, different “packages” for students, and minor teaching recourses result in teaching traditionally though groups are very heterogeneous. The individuality of students’ cognition can’t be taken into consideration. (263) According to the new comprehension of learning, students nevertheless have different pre-existing knowledge and individual learning strategies and these require a new mode of action by the same resources in teaching. With these problems as a background, current e-learning research has been a topical question. At universities the curricula (264) had to be deliberated and worked both because of the new learning comprehension and the international mobility of staff and students within a European higher education area. The Bologna Process, which began at the end of the last millennium, is currently the major process of higher education in Europe with the aim of putting the diversified national systems into a common frame. The most important development of all is a change of attitudes toward recognition. “Instead of making detailed comparisons of reading lists and curricula, the assessment of foreign qualifications is increasingly seeking to determine whether applicants have a comparable level of skills and competence as they would have had if they had held a degree of the home countries. This shift is also reflected linguistically, in that there is less talk about ‘equivalence’ and more about ‘recognition’. ” (265) This means a shift toward appreciating the quality of learning, and there will be an increasing number of applications for non-traditional learning. More education will be supplied through the Internet, and through a combination of traditional and non-traditional learning. The latter way has been reported in Sections 5.3 and 6.1, with Section 6.2 combining traditional laboratory working with modern e-learning. The observation and active working in a laboratory with reflection beforehand and afterwards increased the level of understanding of chemical methods and theory. The objectives of theory and practice could also be achieved at the university level by changing teaching methods: activating and tutoring students by means of new learning comprehension and using new learning tools. The teachers of e-learning courses would start primarily with real-life problems scaffolding by
the experts of e-learning. (266, 267) Future instructions for e-learning will be conceived in parallel with curriculum and pedagogical reforms based on informed research.

The Solo taxonomy method, a new way for measuring the quality of tutored chemistry learning outcomes, has been used successfully. Starting from these results it is possible to develop teaching and to assess these changes on the strength of the skills and competencies and on quality, like the above report of the Bologna Process requires: “If we are to move further toward a direct assessment of learning outcomes and competencies, alternative standards will have to be developed.” It is not ideal to assess only the traditional objectives of the curriculum quantitatively. This is valid both at the school and university level.

The challenges of elementary chemistry education are:

- socially distributed learning, thereby expanding beyond active individual cognition to include features of both the social environment (tutors/chemists and peers) and the tools or cultural artifacts employed, e.g., partnerships with technology (e-learning)
- learning as constituted by cultural practises, i.e., authentic applications of modern chemistry.

On the basis of recent studies on collaborative learning, it seems evident first that human beings acquire knowledge patterns of reasoning from one another and second that learning is situated in the local context or culture. The present research shows there are ways to integrate both a focus on internal cognitions of the learner as well as the contextual dimensions of chemistry learning contexts, authentic science. This is a very valid approach that goes beyond limited cognitive models that attempt to describe all thinking with one model either stressing internal knowledge structures or the importance of context or culture. It reflects the general social-cultural idea that students must come to use and understand the disciplinary language and terminology used by a functioning member or expert in a disciplinary community. Researching socio-cultural learning in authentic institutional situations is challenging work and it must not be overly simplified. Instructional improvement involves thinking clearly and deeply about the nature of the discipline and the desired knowledge and thinking processes. Then designing instruction to facilitate and encourage the use of knowledge and processes requires an expert of both discipline and learning and also the institution as a supporting background. Perhaps the best way to put the aim into practice is, as also in the present study, action research because it helps people to change realities in order to investigate it and, on the other hand, to investigate realities in order to change it. At least as important as the dominant features of the self-reflective spiral (Fig. 9), there are six other useful key features of an approach to up-to-date action research; they are social process, participatory, practical and collaborative, emancipatory, critical and recursive. (268, 269) This research approach would be sophisticated and developable not only for the researcher but also for the whole institution. It is a process of learning by doing and learning with others by changing the ways of interactions in a shared social world, growth as a human being.
7.4 Conclusions

The present study was interested in conducting research in an actual learning setting. New knowledge and conclusions were generated through intervention by changing learning environments of the introductory laboratory course while nonetheless keeping the entire learning activity system, as much as possible, as the background unit of analysis. The research has aimed at triangulation in using diverse data, qualitative and quantitative methods, and both the learning theory of natural sciences and the learning theory of education. The designed Optima e-learning environment of chemistry seemed to be working and effective to the students. The e-learning environment has also been adapted to the open www-version but has to be developed for more authentic contents and collaborative functioning.

According to the pilot findings (Section 5.2.3) authentic laboratory working gave individual activities and meaningfulness for students’ cognition. Two learning theories, socio-cultural and neurocognitive, were used for verifying these results. Next individual cognition was improved, transferring these positive findings of physical systems into a designed e-learning environment of abstract chemistry systems. Students studied the skills and theory of chemistry together working in a chemistry teaching laboratory and in this tutoring e-environment. They felt that working like this had a considerable affect (78.6%) and at least some affect (96.4%) on the understanding performance of the analysis during the laboratory session. The levels of understanding in theoretical topics were measured by Structure of the Observed Learning Outcomes, SOLO Taxonomy. This was found to be a powerful tool for following students' development in their understanding of particular chemistry concepts and analysing methods. Specifically new in this study was comparing the students’ own outcomes before and after tutoring in the e-environment. As a result, the most remarkable change in cognition was to think several aspects simultaneously (55.3% of changes to multistructural level of SOLO Taxonomy) which is an essential, but difficult precondition to achieve for the coherent whole in cognition (relational level of SOLO Taxonomy). Empirical working in a laboratory and conceptual change in the cognition of the student were integrated together to encourage deep learning and order in cognition.

The results of the empirical study indicate that Optima-supported learning leads to a higher level of an individual learner’s understanding: the remarkable higher SOLO levels of task outcomes were achieved after e-learning, higher than outcomes worked alone by learners (Section 6.2.1). However only 19% of the analysed outcomes reached the ‘relational’ level in the SOLO level, which means great comprehension difficulties in the theoretical topics of the instructional chemistry course.

In closing, the major points proposed earlier are reiterated:

1. Changes in learning environments are a prerequisite for the learning of chemistry, which is ascribed to the brain processes of learning and the knowledge society; good alternatives are the authentic and e-learning environments researched here.
2. Contents of experiments and tasks have to be meaningful for an individual student, which is ascribed to the fact that earlier knowledge energises cognition and is an explanatory principle of the development of higher brain functions.
3. Learning activities ought to enable volitional control and self-reflection for students, ascribed to the active adapting, but, among other things, relatively slow chemical reactions and brain process of learning.

4. Emotion is a component in cognition emphasising positive feelings in metacognition (feeling that I know) and the safety of learning activities in chemistry.

5. E-learning has to be seen not only as distance learning but also as a good support to learning generally, which was presented as a challenge in parts 1–4.

6. SOLO Taxonomy is an alternative worthy of consideration for the evaluation of the learning quality of the chemistry conceptions of an individual student.

The examination of students’ learning in authentic and e-environment settings demonstrates that active learning is a joint emotional product of processing abstract instructional, social, and physical environmental goals. With these goals as a background, the concluding remarks enable conversely the consideration of the reasons behind the learning difficulties in an introduction chemistry laboratory course: the lack of relevance knowledge for the cognition of an individual student, the exiguity of self-regulation in learning activities, and abstract chemistry lecture topics and laboratory experiences don’t relate without tutored pre- and post-tasks in the present curriculum. Although this study of the student-centred learning environment has yielded some answers, many questions remain for future research. How do collaborative problems improve the cognition of chemistry students in e-learning? How could a curriculum associate, via e-learning, a conventional passive lecture and laboratory working, i.e., learning the facts and skills of chemistry actively and effectively together? Does e-learning make possible a student’s metacognition for the expertise of chemistry laboratory skills? Is SOLO Taxonomy a good tool for students to develop metacognitive skills? These and other questions remain to be answered by science educators and researchers.
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Appendices
Appendix 1 Experiment 3

DETERMINATION OF NICKEL CONTENT

In basic solutions nickel forms a very insoluble complex with dimethylglyoxyme, which is called bis-dimethylglyoxymatenickel. There is one nickel ion (central atom) and two dimethylglyoxyme-molecules (ligands) in the complex. Nitrogen atoms in the dimethylglyoxyme-molecule act as electron donors (they donate a pair of electrons in a bond) and nickel acts as an acceptor (accepts electron pairs). The dimethylglyoxyme-molecule has two pairs of electrons and that’s why it is called double dentate ligand. Bis-dimethylglyoxymatenickel complex is called a chelate. The bis-dimethylglyoxymatenickel complex is a cyclic complex where the ligand is bound with the central atom from more than one location.

Bis-dimethylglyoxymatenickel complex is soluble for example in hot HCl solution and to some extent also in ethanol. When dimethylglyoxyme is used in this work as a 1% ethanolic solution, no more than 75 ml for 100 ml analyzing-solution should be used.

**Purpose:** The amount of nickel is determined as a bis-dimethylglyoxymatenickel using gravimetric method.

**Equipment and reagents:** Beaker (400 ml), tripod, wire gauze with ceramic center, thermometer, desiccator, sintered glass funnel, measuring cylinder, glass rod with rubber head, 1% dimethylglyoxyme ethanolic solution, 2 M ammonia, ethanol.

**Procedure:** Wash the sample from the test tube to beaker (400 ml) and dilute it to 200 ml. Warm the solution with Bunsen burner to 80-90 °C and turn the heat off. Add (60 ml) 1% dimethylglyoxymate ethanolic solution and mix the solution with the glass rod. Add finally 2 M ammonia, until the moisture coming from the solution is basic. Check the pH by setting one drop of solution to moisturized pH-paper. Let the precipitate stand for about 20 minutes, and separate it by filtration (use suction and sintered glass funnel).

Sintered glass funnel has been tared before. It has been kept in oven at 110 °C, cooled in a desiccator and weighed. Before separation, wash the sintered glass funnel with deionized water using suction. Move the precipitate to the sinter using the glass rod. Wash the precipitate well with water and finally with few millilitres of ethanol. Dry the precipitate in oven for 30 minutes at 110 °C. Let the precipitate cool down in desiccator for 15-20 minutes and measure the weight.

Calculate the amount of nickel in the sample. Record the amount of nickel (mg) in the sample.

After approval of the result wash the sintered glass funnel according to the following instructions: At first, remove the loose precipitate and put it to a waste container. Wash the funnel with water and brush. Red precipitate in a sinter is dissoluble to strong acid. Fasten the sintered glass funnel again to the filtering flask and dissolve red precipitate with few drops of concentrated hydrochloric acid. Add finally plenty of water until the filtrate is neutral.
Appendix 2 Analyysiohje / raudan määritys tioglykoli-ferroziini menetelmällä

1 PERIAATE

2 KÄYTTÖKOhteet
Voimalaitoksen prosessivesien valvonta

3 VÄLINEET
-mittapulloja 100 ml
-annostelijoita
-vesihaude
-fotometri aallonpituutena 530 nm ja 5 cm kyvettäjä Käyttävät astiat pestään 20 %:lla suolahapolla ja huuhdellaan ionivaihdetulla Fe-vapaalla vedellä vedellä.

4 REAGENSSIT
Tioglykolihappo p.a.
Reagenssipuskuriliuos: 2g ferroziinia liuotetaan puhtaaseen veteen ja lisätään 250 ml väkevää etikkahappoa. Lisätään HITASTI (kuumenee) 210 ml 25 % ammoniakkia koko ajan sekoittaen. Liuoksen jäädyttävää laimennetaan 1000 ml:ksi puhtaalla vedellä. Liuosken pH on 5.1 ja se säilyy 2 kk.
Fe-perusliuos:
1000 mg Fe/l perusliuos valmistetaan ampullista
Mittaliuossarja:
Valmistetaan Fe-perusliuoksesta laimentamalla puhtaalla vedellä väliainemokset 10 mg/l ja siitä 1 mg/l. Mittauskäyrää varten välilaimennokset 1 mg/l valmistetaan mittaliuossarja alueella 0,005 – 0,100mg/l. Lisäksi valmistetaan reagenssinolla

5 MÄÄRITYS
Puhtaisiin mittapulloihin otetaan 100 ml näytettä sekä yhteen pulloon puhdasta Fe-vapaasta vettä, josta valmistetaan reagenssinolla. Lisätään pulloihin 1 ml tioglykolihappoa, suljetaan korkilla ja ravistellaan. 
Pulloit siirettäen lämpökaapiin puoleksi tunniksi 90 °C ± 1 °C. 
Liiuokset jäädytetään kylmässä vesihauetteessa, jonka jälkeen lisätään pulloihin 10 ml reagenssipuskuriliuosta. 
Mittataan välilläsmästä absorptio spektrofotometrilla käyttäen aallonpituutta 530 nm ja 5 cm kyvettä.
Vertailuluokseena reagenssinolla

6 TULOS
Tulokset luetaan fotometriltä ja näytteen rautapitoisuus ilmoitetaan korkeintaan yhden g/l tarkkuudella.
Appendix 3 Kysely verkostotumuksesta laboratoriokurssin yhteydessä keväällä -99

(Kysely 24.5.99)

Vastaa kukin kohteesi (kolme) erikseen!

Kohde: IVO ( ) Ympäristölaboratorio ( ) Apteeki ( ) Terveyskeskus ( ) YO ( )

I KOULUSSA ANNETTU INFORMAATIO

1. Saitko taustatietoa omaa työtäsi varten: liikaa 1 2 3 4 5 liian vähän
2. Ymmärsitkö, mikä on tutkimuskohteenasi olevan työn merkitys laitoksen tai ympäristösi kannalta:.............................................................. hyvin 1 2 3 4 5 huonosti

II YLEISTÄ KOHTEESTA

3. Miten mielenkiintoisena pidit kohdetta: ……..mielenkiintoinen 1 2 3 4 5 pitkästyttävä
4. Millaisen kokonaiskuvan sait laboratorion toiminnasta: selkeän 1 2 3 4 5 sekavan

III KOKEELLINEN OSA

5. Millaiset mielestäsi olivat kirjalliset työohjeet ..................................................................selvät 1 2 3 4 5 epäselvät
6. Millaiset mielestäsi olivat työsi ohjaajan antamat suulliset ohjeet ..........................................................selvät 1 2 3 4 5 epäselvät
7. Työn tekemiseen varattu aika..............liian pitkä 1 2 3 4 5 liian lyhyt
8. Työn vaikeusaste..........................liian vaikea 1 2 3 4 5 liian helppo

IV RAPORTOINTI

9. Oliko raportin kokoaminen mielestäsi a)..................................................tarpeellista 1 2 3 4 5 turhaa
   b)...........................................mielenkiintoista 1 2 3 4 5 ikävää

V LABORATORIOSSA TYÖSKENTELYN HERÄTTÄMIÄ AJATUKSIA

10. Käynti ja työskentely laboratoriossa antoi tietoa
    kernian teoriasta.................................paljon 1 2 3 4 5 vähän
    kernian sovellusmahdollisuuksista.....paljon 1 2 3 4 5 vähän
    laboratoriosta työpaikkana.................paljon 1 2 3 4 5 vähän
    kernian alan ammateista......................paljon 1 2 3 4 5 vähän
    ympäristön suojelusta.......................paljon 1 2 3 4 5 vähän

11. Tekikö tämä työskentely - ympäristö kernian opiskelun mielekenkointimäärä
    …………………………………………………....ehdottomasti 1 2 3 4 5 ei yhtään

12. Oli sitä ollut valmis osallistumaan useampiin muualla kuin koulussa tehtäviin laboratoriotöihin
    …………………………………………………....erittäin mielessäni 1 2 3 4 5 en olisi

13. Kolme tärkeintä mieleesi jäänyttä kokemusta laboratoriosta
Give feedback of the Chemistry introductory laboratory course. In particular, comment on the significance of its network activity on learning.

1A. In your experience, how significant was networking with regard to completing the course?

<table>
<thead>
<tr>
<th></th>
<th>very significant</th>
<th>significant</th>
<th>no significance</th>
</tr>
</thead>
</table>

1B. What motivated you to work in the network, what prevented you?

Did you work at home or at the university?

2A. Did the network material motivate you to study chemistry?

<table>
<thead>
<tr>
<th></th>
<th>very motivating</th>
<th>motivating</th>
<th>no motivating</th>
</tr>
</thead>
</table>

2B. What in particular supported your studying? What felt frustrating?

3A. In your experience, how did doing the exercises affect the knowing completion of analysis?

<table>
<thead>
<tr>
<th></th>
<th>helped a lot</th>
<th>helped somewhat</th>
<th>no effect</th>
</tr>
</thead>
</table>
3B. Which pre-/post-tasks were good in your opinion? Which were bad?

4A. Did you get help and guidance for your working on the network when you needed it?
- always
- most of the time
- too rarely

4B. What support was especially valuable and helpful?
In what issues would you have needed more support? Did you get enough instructions for working on the network?