Problem-Based Learning and Proprioception

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By

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FOREWORD

Teachers will not be replaced by technology,
but teachers who do not use technology
will be replaced by those who do.
—Hari Krishna Arya

Young brains come to school to learn: older brains come to school to teach them. At least, that's the ideal. The rationale for writing this book were the questions: *can cognitive neuroscience tell us anything about how young brains learn from older brains, and therefore how older brains should teach younger brains for optimal effect*? (Geake, 2009); and, additionally: *can artificial intelligence (AI) and the theory of cybernetics add something important to this process?*

The system of knowledge between younger and older brains changes in such a way as to distribute the knowledge between the two. By way of analogy, a similar thing can be said about the system of transferring the knowledge between one brain (the teacher) and several brains (students in a class), which is what goes on in traditional school settings. Since this is true of both biological as well as non-biological systems, the question may be asked, how would it be possible to optimally organize this kind of transfer even between the two, i.e. between biological and non-biological systems, that is, in an interaction between the natural (teachers' and learners') and the "artificial", AI-based brain? Further, we may ask whether the explorations in this field serve as the basis for the further development of mankind as a whole, or whether they apply only to the specific field of artificial intelligence?

Knowing that in general, the educational system at the primary level follows social change with a time lag of around fifteen to twenty years (Aberšek, Borstner and Bregant, 2014), it becomes apparent that in order to track the changes that are going to be brought about by contemporary society, we must adapt our educational systems to them as soon as possible. This is especially relevant in those fields where changes occur most rapidly, one of them being STEM (science, technology, engineering, and mathematics). Knowledge in contemporary societies of the 21st century should, in a broad outline, be based on the following:

- *Competency-based developmental knowledge* from the fields of cybernetic physical systems (robots) and the internet of things, connected to the internet of people. In short, we need specialized engineering (STEM) knowledge, upgraded through digital literacy 4.0 (communication between people, communication between man and machine, and understanding the communication between machines themselves).
- *Interoperability* requires communication competence 4.0, which does not simply refer to communication between people, but also to the skills associated with man-machine communication, as well as the understanding of artificial intelligence.
- *Competence in systems development* (for as long as this is done by humans, or until such tasks will become a matter of AI), which supports people's decision-making processes in complex situations, by means of visualization and data mining processes. At the same time, we must also develop the competence of solving complex problems in real time (critical assessment, critical decision-making, critical thinking).
- *Decentralized decision-making,* which means that the majority of decisions will be made by machines themselves by means of various algorithms and AI (as is done today by, for example, Google's filters). A person's role will be to make decisions only in "critical, poorly defined situations", when such algorithms (could) fail.

To sum up, the demands placed upon our educational system are clear and unambiguous. In this book, we will embark on the long journey of providing potential explanations of how to meet these requirements optimally. Thus, the primary purpose of this book is to shed light on issues related to teaching and learning based on contemporary trends and approaches from the field of information and communications technologies. Furthermore, our goal is to relate the above to the set-up of modern learning environments, whether they are referred to as intelligent learning materials (e-learning materials), intelligent tutoring systems (ITS), or learning management systems (LMS). With this in mind, a universal meta-model (cognitive machine) for a contemporary transdisciplinary learning strategy (transdisciplinary paradigm) will be proposed, based on cybernetic theory.

CHAPTER ONE

INTRODUCTION

It is important for an author to have in mind a setting in which readers of his or her work could benefit from having read it. I hope to be able to achieve this goal. As authors, we often spontaneously anticipate how friends and colleagues will evaluate our choices; the quality and content of these anticipated judgments therefore matters. The expectation of intelligent gossip is a powerful motive for serious self-criticism, more powerful than New Year's resolutions to improve one's decision-making at work and at home.

To be a good teacher you need to acquire a large set of different kind of interdisciplinary knowledges, each of which binds an idea of the causal relation, cause and consequences, possible antecedents and causes, possible developments and consequences, and possible interventions to the strategy of teaching. Education for teachers and trainers consists in part of learning the language of education and the appropriate skills. A deeper understanding of judgments and choices also requires a richer vocabulary than is available in everyday language. Learning is tightly linked to the body-mind relation, i.e. it is closely connected to our way of thinking. When you are asked what you are thinking about, the answer is usually not very complicated. You believe you know what goes on in your mind, which often consists of one conscious thought leading in an orderly way to another. But that is not the only way the mind works, nor indeed is that the typical way. Most impressions and thoughts arise in your conscious experience without your knowing how they got there. You cannot imagine how you came to the belief that someone loves you, or how you detected a hint of irritation in your spouse's voice on the telephone, or how you managed to avoid a threat on the road before you became consciously aware of it. The mental work that produces impressions, intuitions and many decisions goes on in silence in our minds. It is almost like our thoughts have their own thoughts and language, the language of thought.

Origins

There are only three major monopolies in the world:

- food,
- energy, and
- technologies.

Societies always have been, and still are, formed on the basis of the above. Each segment of society requires appropriate means in order to function, and the added value (the required means) comes from the real (economy) sector, which is based on the above three inextricably linked monopolies. The ratios between them may have changed during the course of history, but through time they always had to keep up with the generally accepted current social trends. The trend regarding the development of our society, indicated around 2012, is called Industry 4.0, commonly referred to as the fourth industrial revolution. It is a trend of automation and data exchange in manufacturing technologies, which roughly includes the following:

- physical cybernetic systems (PCS),
- the internet of things (IoT), and
- cloud computing.

All three pillars of Industry 4.0 are based on contemporary technologies and modern-day knowledge. The fourth industrial revolution creates what has become known as "smart factories". Within these modularly structured smart factories, cyber-physical systems monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Through the *internet of things*, cyber-physical systems communicate and cooperate with each other and with humans. In real time and via the *internet of services,* users can access individual and globalized services and use them in their work – along the entire *value chain,* which is a set of activities that a firm operating in a specific industry performs in order to deliver a valuable product or service for the market.

In the context of societal development and progress, these technologies take on a double role, they are both a cause and a consequence of our increasingly fast-changing society. While we may well understand the connection between technology and society, we are no longer in a position of being able to shape our future entirely on our own; we are increasingly only able to react to events, and are less and less able to direct them, manage them, or control them. There are several diametrically opposed theories exploring the connections between technology and society. Jacques Ellul and Herbert Marcuse believe that technology is becoming man's master rather than his tool. Contrary to this, others believe that technology is neutral, for example Lynn White, who suggested that *"technology opens doors; it does not compel man to enter".* However, even if we support White's view, which seems more comfortable (Aberšek, Borstner, Bregant, 2014a) in our technology-oriented society, several questions arise:

- Who decides which doors to open?
- If or when we decide to enter, does technology determine the contours of the chamber into which we have stepped?
- If we consider technology simply as a thought, the following question also arises: who determines the end of this thought, and, last but not least, is there a danger of *thought* becoming its own as well as our own end?

All these questions are not just historically relevant; they are real-life problems of our time, which is apparent form the directions and trends in the development, usage, and control of all these technologies that are increasingly based on artificial intelligence principles. Many issues related to modern-day technologies primarily require general knowledge and answers about the nature of the world, society, and people – the debate, therefore, is a *global philosophical problem,* and hence it is important in any decision-making process to *understand* the general and basic mechanisms of intelligence: the philosophy of reason, the principles of natural (human) intelligence and how it can be measured, etc. Only then can we begin to understand how the society as a whole (as well as AI-based technologies within the society) functions, or how it *could* function. As we have already pointed out regarding communication competence 4.0, people must learn, among other, to understand the principles of machine-machine communication. The question of whether man can ever *truly understand* artificial intelligence, however, is left open and unanswered for future research.

So, in the same way that most technological systems do, intelligent tutoring systems, too, must have the possibility of learning and organizing themselves. And what do "organization" and "order" mean? *"Order was usually considered as a wonderful building, a loss of uncertainty. Typically, it means that if a system is so constructed that if you know the location or the property of one element, you can make conclusions about* *the other elements. So order is essentially the arrival of redundancy in a system, a reduction of possibilities".* (von Foerster, 2003: preface, vii)

Von Foerster's (2003) second preliminary proposition deals with the problem of a complete and closed theory of the brain. If any one of us mortals ever deals with this problem they will, without any doubt, use their brain. This observation is at the basis of von Foerster's second preliminary proposition:

> *"The laws of physics, the so-called "laws of nature," can be described by us. The laws of brain functions – or ever more generally – the laws of biology, must be written in such a way that the writing of these laws can be deducted from them, i.e., they have to write themselves"* (von Foerster, 2003: 230).

In short, on a systemic level the education system needs to take into account the individual as the basic building block of society, and further take into account the individual's consciousness related to their emotional intelligence (EI). Because a person's consciousness is something entirely singular and inherent to the individual, some kind of generalization will have to be constructed, which will be better than nothing and still contribute enough in terms of novelty and progress, to make it innovative enough for the purposes of teaching and learning, i.e., for the formalization of automated processes of individualization and differentiation within intelligent tutoring systems. Ultimately we are talking about the *cybernetic organization of systems*.

As is generally known (and as will be discussed in more detail later on in this book), there are a number of different definitions and development stages of cybernetics that exist. From the idea that cybernetics dealing with sociological issues is a cybernetics of cybernetics, i.e. second-order cybernetics (von Foerster, 2003), to the idea that it is in fact fourth-order cybernetics (Zangeneh and Haydon, 2004, Mancilla 2013). Although there is resonance between Zangeneh and Haydon's (2004) and Mancilla's (2013) notion of fourth-order cybernetics and the one advanced in this study (second-order 4.0 cybernetics), the main difference between them lies in their approaches: the former adopts a psychological, post-modern approach, as well as requirements of the industry 4.0, which assimilate cybernetics into this discipline and school of thought respectively, while the latter attempts not an interdisciplinary approach, but a transdisciplinary one, i.e., it attempts to develop a model that does not fit within the boundaries of a specific branch of social sciences, but one that respects the basic tenets of cybernetics. In this sense, cybernetics as a whole could be defined as an attempt to build a *universal meta-model (cognitive machine)* that would help us to build concrete object models for any specific system or situation.

When we discuss cognitive machines we will be referring to intelligent teaching/learning environments, and usually we will use the term intelligent tutoring system (ITS). Two questions are to be asked in order to understand our model-ITS as a universal meta-model or cognitive machine:

- First, what are the elements that constitute such mechanisms? (We are talking about the architecture or structure of such systems.)
- Second, what are the defining features of a cognitive system? (We are talking about the function of such systems.)

As it was already mentioned, there are three requirements to be fulfilled in order for a machine to be considered as cognitive:

- it must store and retrieve information.
- It must help to understand received information.
- It must create new information.

The defining features of cognitive machines can be expounded by analysing their relation to their inputs and outputs. Cognitive machines receive, create, transform and transmit information, which is both their input and output, and which can be used either to create new data, different from that received, or to broaden the existing information storage in the brain, which can result in the expansion of the cognitive domain. This means that cognitive machines are omniscientific because they can produce both their own components and information other than itself; omniscience, the ability to create all kinds of output (internal and external to self), is the distinguishing feature of cognitive machines, which are the subject of study of our second-order 4.0 cybernetic systems.

This book presents my current understanding of the teaching and learning process based on cognitive machines: apart from being driven by my own curiosity, the judgments and decision-making were inspired by cognitive and neuroscientific discoveries made in recent decades. I can trace the central idea for the book back to one lucky day in 2009, when I asked my colleagues Bojan Borstner and Janez Bregant from the Department of Philosophy, University of Maribor, to act as mentors for my second PhD. They agreed – and immediately I knew this was going to be an extremely useful and valuable experience for me, and I could already see that we would spend some very interesting times together, which was only confirmed by the lively and productive debate between us that followed. The goal of my study (our study) was to examine whether other researchers "suffered from the same affliction", so to speak. For the next ten years, our collaboration was the focus of my life, and the work we did together during those years was the best I ever did. We quickly adopted a practice that we maintained for many years. Our research took on the form of conversation, in which we invented questions and jointly examined our intuitive answers. Each question was a little experiment, and we would often carry out many experiments in a single day. We were not *really* looking for the correct answer to the statistical questions we posed: rather, our aim was to identify and analyze the *intuitive* answer, the first one that came to mind, the one we were tempted to make even when we knew it to be wrong. We assumed – rightfully so, as it was later proven – that any intuition that we shared would be shared by many other people as well, and that it would be easy to demonstrate its effects on judgments.

The use of contemporary learning strategies connected with information and communication technologies has provided scholars from diverse disciplines – notably philosophers, economists and engineers – with an unusual opportunity to observe possible flaws in their own thinking. Having seen themselves fail, they became more likely to question the dogmatic assumption, prevalent at the time, that the human mind is rational and logical. The choice of method was crucial in the case of my own research: if I had reported results of only conventional (standard) methods, our work would have been less noteworthy and less memorable. However, I did not choose demonstrations over standard methods because I wanted to appeal to the widest possible audience: I preferred demonstrations, problem-based and research-based methods because they were more fun, and, as it turned out, I was lucky in my choice of method as well as in many other ways. A recurrent theme of this book is the idea that proprioception and emotional intelligence play a major role in every successful learning story; it is almost always easy to identify a small change in the story that would have turned a remarkable achievement into a mediocre outcome. Our story was no exception.

Where we are now

This book is not intended as an exposition of the early research that Bojan, Janez and I (Aberšek, Borstner, Bregant, 2014a) conducted together, a task that has been ably carried out by many authors over the years. My main aim here is to present a view of how the mind and the learning processes inside it work, drawing on recent developments in cognitive and social psychology. One of the more important developments is that we now understand the marvels as well as the flaws of intuitive thought (and of learning processes) much better.

Structure of the book

This book is divided into seven parts, which are outlined below.

Chapter One: Introduction

Part I summarizes the trends and guidelines in societal development, and provides a historical overview of "advanced" learning strategies. This part of the book introduces the evolution of the education process, and the mind as an information processor, by sketching out some of the key moments in the history of education and the science of mind. It highlights how the foundations for sciences of education and mind were laid in psychology, cognitive science, neuroscience, mathematical logic, artificial intelligence and linguistics, pointing out that theories of *what a mind does* have to co-evolve next to theories of *how the brain works*.

Chapter Two: Cognition, teaching and learning

In part II we will be dealing with the core philosophies of education, such as cognitivism and constructivism; we will explore dialectical and social constructivism, social competences and emotional intelligence and try to connect constructivism and cybernetics. At the end of this chapter we will analyse learning, intelligence and consciousness, and point out paradigms for successful learning. I wanted to provide a sense of the complexity and richness of the automatic and often unconscious processes that underlie systematic models of teaching/learning, and an idea of how these automatic processes explain the heuristics of judgment. One of the goals is to introduce a language for thinking and talking about the mind.

Over the last few decades, tremendous progress can be observed in the field of developing cognitive competences through the use of ICT- and AI-supported learning environments. The paradigm of individualization and differentiation has become firmly established through the use of such environments. However, most developers that create such learning environments have neglected the school's educational component, i.e. the idea that schools must also develop social skills and/or social competences in students. With the use of problem-based and research-based learning and collaborative learning, as well as many other innovative approaches, such as role playing, lively online debates, or short educational computer games, teachers can help to enhance the sensory stimuli in their students, to raise their blood pressure and epinephrine levels, which ultimately reduces sleepiness, tiredness, or restlessness, and increases the ability to memorize information. This allows students to interact with their colleagues, to carry out research and exercises independently, and enhance their cognitive competences as well as their social skills.

Chapter Three: Problem-based and research-based learning

As part of this chapter, I developed contemporary learning strategies related to ICT-supported learning environments, where problem- and research-based methodology serves as a platform for successful learning. Collaborative learning and proprioception play the central role in these strategies. All of the proposed models are practically oriented, with numerous tips and proposals which help the readers understand the essentials of how the brain learns. This section of the book discusses some of the key principles of neuroscience, and provides additional tips that allow the teacher to create an effective e-learning development.

In this chapter we also discuss cognitive science and its relation to the cognitive learning theory and information processing approaches and models. Apart from consciousness and free will, learning and acquiring new knowledge and skills is one of the key factors separating intelligent systems from non-intelligent ones. This is why the previous chapter focused mainly on the methods of acquiring new skills from the perspective of neuroscience and how it interprets learning and memory. It was stressed that both neuroscience and cognitive science are distinctly interdisciplinary, and that a view from a single perspective, i.e. from the perspective of a single discipline, cannot yield accurate results, in fact, most often that kind of research provides entirely inaccurate and misleading results. It is not enough to possess a certain kind of knowledge, or to have the possibility of empirical research; what is crucial is an in-depth and interconnected understanding of all these phenomena as a whole.

Chapter Four: Symbolic and connectionist models

As indicated in the introduction, a distinction can be made between *discrete* and *continuous* cognitive process modelling theories. In this chapter, I point out three separate approaches to modelling the human mind, namely *cognitive symbolic* systems, *cognitive connectionist* systems, which use neural networks as the basis for their model, and *modelling systems based on dynamic systems theory*. In addition, especially over the last few decades, various mixed models, called hybrid systems, are increasingly emerging. Since symbolic systems have already been exhausted as an independent area of research, our focus is primarily on connectionist and dynamic systems, while symbolic systems are only considered in relation to connectionist systems, i.e. as part of hybrid systems.

Each of these approaches to cognitive architecture emphasizes specific features of cognition and can be viewed as a suitable architecture for its interpretation. Thus, traditional symbolic models make up a relatively successful approach to modelling higher cognitive functions that require the use of language, while connectionist models are useful in understanding the mental logic behind pattern recognition. Principles of dynamic systems theory and 'embodied cognition' remind us that we must first understand biological solutions for human simple tasks.

As this chapter reveals, the near future is neither black nor white; it is neither connectionist nor symbolic, but a necessary combination of both.

Chapter Five: Consciousness, learning and proprioception

Consciousness remains one of the greatest still unresolved philosophical (and commonplace) mysteries, and many believe that it is indeed consciousness that makes the mind-body problem so intractable. The secret lies mainly in the fact that we do not know how to align consciousness with the rest of our knowledge; how to answer questions such as: why does consciousness exist? What is its function? How can it emerge from the neurological processes inside the brain? How to connect consciousness, learning and proprioception? In this chapter I attempt to provide some basic solutions and answers to these questions, but also some more sophisticated ones, such as the idea of quantum consciousness.

Chapter Six: Cybernetics and society

This part of the book translates the general dynamic systems theory and the theory of cybernetics into the cognitive dynamic systems theory. It provides an explicit description of new cognitive models based on the theory of cybernetics, analysing the roots of cybernetics and connecting the theory of cybernetics to society, education, learning and artificial intelligence (second-order cybernetics). Finally, on the basis of the above, this section of the book demonstrates how to develop a cyber-based learning environment. The new cognitive models are associated with two different research programs proposed by cognitive scientists, partly moving beyond the basic assumption that the mind is either a symbol manipulator or a connectionist network. The first is a combination of two traditional approaches to mental architecture, the symbol system hypothesis and the connectionist network hypothesis, called the hybrid model; the second is associated with the dynamic systems hypothesis in mathematics, including the situated/embodied cognition movement; it is referred to as the dynamic model.

Chapter Seven: Education 4.0 and the learning environment

This chapter defines the proper architecture of the teaching and learning process. It draws on methods from cybernetics and artificial intelligence and is associated with the dynamic systems hypothesis. On the basis of the belief that a school system with its educational process is a dynamical system, it shows how to build an intelligent tutoring system (an intelligent tutor), an intelligent teaching and learning material, and/or an environment based on gamification and game-based learning. In the final stage, a cost-benefit analysis is performed, to observe what was gained and what was lost through all these advanced and contemporary teaching/learning strategies in comparison to traditional, established, well-known teaching/learning methods and strategies.

Chapter Eight: Concluding remarks

This part of the book provides concluding observations on the proposed approaches to the mind-body relation, which allows us to reduce our cognitive capacities to a physical brain using mathematical algorithms, i.e. differential equations, and, on the basis of this, to design a proper intelligent teaching/learning environment LE_LMS_AI, taking into account the cognitive and social aspects of human beings.

Historians of science have often noted that at any given time scholars in a particular field tend to share basic assumptions about the subject of their study. Social scientists are no exception. Social scientists in the 1970s broadly accepted two ideas about human nature. First, people are generally rational, and their thinking is normally sound. Second, emotions such as fear, affection, and hatred explain most of the occasions on which people depart from rationality. This book challenged both assumptions without discussing them directly. Ideas of heuristics and biases have proven useful, i.e. they have been used productively in many fields, including intelligence analysis, philosophy, statistics, computer science, information and communication sciences, etc. – and I strongly believe they were also useful in the realm of general education, particularly with regard to the specifics of the teaching/learning process.

Much of the discussion in this book is related to our thoughts, our judgements, our brain and its plasticity, and especially focused on the learning processes and the methodology of *how* to learn effectively. Let us take a step on this path towards new knowledge.

CHAPTER TWO

COGNITION, TEACHING AND LEARNING

2.1 Learning and human personality

Just like with any kind of complex system, society, too, is defined by the interrelations between its basic elements, i.e., the individuals that constitute it. These interrelations are highly intricate and therefore cannot be addressed in their entirety, which is why social reality can never be understood fully. In order to be able to understand society at least partially, however, we need to examine how it is influenced by the physical environment, culture, and interpersonal relations – since each of these generates social values and institutions that in turn change society; for example, education affects one's attitudes towards their surroundings (it ultimately also affects economy), and thereby affects cultural relations and the society as a whole. In this context, we are mostly concerned with the social development of an individual and their behaviour in the specific cause-and-effect relationship between a teacher and student, as is shown in the process of education.

Figure 2_1 schematically shows the cause-consequence effects, with a focus on how the social development of the individual – in our case, the teacher and the learner – affects the internal and external responses of the individual in society.

In order to balance our behaviour, human beings have developed a sophisticated nervous system that informs us of the following:

- the needs of our *internal environment,* and
- what goes on in our *external environment*.

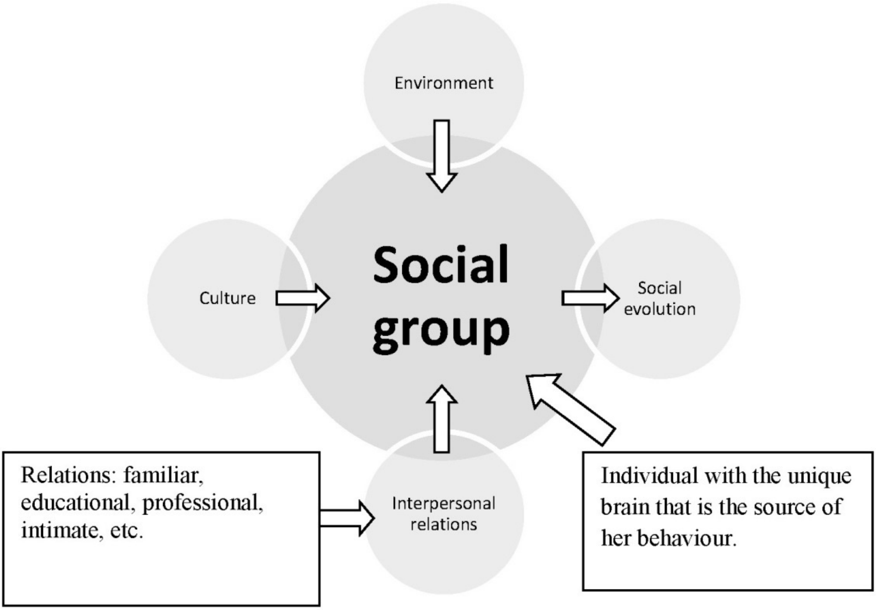

Figure 2_1: Society as a social system (Aberšek, Borstner, Bregant, 2014a)

Some of our behaviour types are very elementary and do not need to be adapted, since adaptations already occurred in the past and these behaviours have simply become an automated way of responding to internal and external stimuli, or are part of our historical memory. Other, more sophisticated types of behaviour require the recall of pleasant or unpleasant past experiences and the development of a suitable reaction based upon them. These represent the majority of one's obtained social and cultural knowledge. The third type of behaviour requires more elaborate planning, which also includes imagination and abstract thinking, whereby a strategy that ensures a less unpleasant or painful action is developed.

We are quite capable of simulating and describing the external environment, using this or that kind of human or computer language, of a symbolic or AI system. However, this becomes much more difficult, or even impossible, when we wish to do the same in terms of our *internal environment,* which is related to the individual's *consciousness*. Chalmers (1996) divided this problem into two parts:

- *the easy problem* – how do our conscious acts cause the activation of neurons that, in turn, cause our behaviour; and
- *the hard problem*[1] – are these acts conscious at all?

Let us not deal with the hard problem (and leave it to philosophers) and, instead, focus on the easy problem and explore what can be done from the viewpoint of the goal of our book. For this purpose, we will imagine the individual – in our case a teacher and/or a student – as (according to cybernetics) a *regulated system*; in the sense that the social group in which these individuals operate (an education system) creates an external control, which places different values (prescribes social norms) on the behaviour of teachers and students within this social group (Müller, 2008, 2011). The understanding of an education system in this way means that it is a cybernetic system which *can be* formalised (Aberšek, Borstner, Bregant, 2014b); we will reinforce this assumption by means of our own arguments later on in this book.

Throughout human history, our nervous system has adapted and adjusted according to the existing needs and possibilities in our environment. Humans are indeed the most adaptable species on the planet, as we are able to work and live in all kinds of environments, even the most inhospitable ones. The environment, however, is also capable of adapting, and its most important property is the *ability to learn*. Modern-day education with its methods of schooling and studying no longer provides youth with a competitive advantage, i.e., employability. In today's society, therefore, young people must be equipped with some fundamental competences that are general in character (e.g. learning how to learn, learning how to solve problems, critical thinking) and are thus transferable between different areas (generic competences). Skills and technical-vocational knowledge also need to be added to this (UNESCO, 2007). The results of the *Progress in International Reading Literacy Study* (PIRLS) suggest that the model of quality teaching be composed of three fundamental *dimensions,* each of them consisting of six *elements*:

- *intellectual dimension* (elements: deep knowledge, deep understanding, problematic knowledge, higher-order thinking, metalanguage, and substantive communication);
- *learning environment* (elements: explicit quality criteria, commitment, high expectations, mutual support, students' self-control, and student-teacher joint decisions), and

[1] Also called *the explanatory gap*.

– *making learning meaningful* (elements: prior knowledge, cultural sophistication, knowledge integration, inclusion, and narration).

Therefore, in an attempt to build an e-learning environment, all of the above dimensions and elements must somehow be incorporated in that learning environment, through the use of different learning management systems (LMS).

2.2 Cognitivism and connectionism

In *structuralism* it is common belief that the same organisation and laws apply to human thinking as for the world of machines; critics consider this as ignoring the differences between the distinctive psychological and pedagogical features of mental operation on one side, and the characteristics of technical systems on the other. If we wish to overcome this criticism, and take into account the modelling of higher cognitive processes, the distinctive features of the educational field – where the student is not only the object of teaching, but also the subject of its own control and change – structuralism must be replaced with modern *cognitive and neuroscience* as the fundamental premise. (Bermudez, 2010; Winograd and Flores, 1986; Markič, 2010)

The interdisciplinarity of cognitive science originates in two cognitive revolutions, which not only changed the type of cognitive disciplines, for example psychology and neuroscience, but also led towards interdisciplinary research groups within them (Bechtel, 1998). The first cognitive revolution was the rise of *cognitivism* in psychology in the 1950s. Cognitivism offers unique research strategies and approaches to study our mentality. They consist of deduction, remembering and language. Later on, perception and motor control were added, which led to the idea that cognition also includes manipulation of symbols. It was thought that the symbols which describe the outside phenomena certainly have their own meaning, their own *semantics*. They are permanent entities which can be stored by a system and brought back to memory. They can, under certain rules, also be changed. Rules that determine how symbols are combined are systems' *syntax*. They direct the systems' cognitive characteristics by determining how their symbols should be transformed; this is called symbol manipulation, and represents the core of symbol models.

However, in 1980 an alternative way of understanding cognition, the second cognitive revolution, appeared; known as *connectionism*, *parallel distributed processing (PDP)* or *neural network models*. The two Bibles of this process were written by Rumelhart and McClelland, titled *Parallel Distributed Processing – Part 1 and 2* (1986). This was a new approach to study our mentality and could not be possible without certain theoretical contributions (Gardner, 1987). Of vital importance were the achievements of mathematics and logic (Turing), the development of the information theory (Shannon) and cybernetics (Weiner), the discovery of neurons (Ramón y Cajal) and their modelling (McCulloch and Pitts), and the research of cognitive disorders as a result of a brain damage (Luria, 1987).

Connectionism (Bechtel and Abrahamsen, 2002; Anderson, 2007; Horgan and Tienson, 1996) is an alternative computer paradigm based on an analogy between a digital computer and the mind – according to which thinking constitutes a special kind of symbol calculation. The connectionist model of the mind is a discreet dynamic system, with the same kind of learning algorithms. Their main characteristic is that they are composed of simple units, i.e., idealised neurons, which are interconnected. Each unit has a certain activation value that is forwarded to other units via bonds of varying degrees of strength, and thereby contributes to an increase or decrease in their value. The entire process is performed in parallel, and does not need a central part for its control. Such a network learns the selected cognitive tasks in the learning process by changing the strength of the connections between units on the basis of a learning rule (algorithm). The choice of the network's architecture, and the learning algorithm, depends on what kind of cognitive task we would like to model using the network, or how neurologically credible we would like the model to be.

2.3 Connectionism and cybernetics

It seems that cybernetics is many different things to many different people. It may be argued that over the centuries since Aristotle, physicians and philosophers have tried again and again to develop theories of the brain. So, what's new of today's cyberneticists? What is new is the profound insight that a brain is required to write a theory of a brain. From this follows that a theory of the brain, that has any aspirations for completeness, has to account for the writing of this theory. Translated into the domain of cybernetics; the cyberneticist, by entering his own domain, has to account for his or her own activity. Cybernetics then becomes a cybernetics of cybernetics, or *second-order cybernetics*. This perception represents a fundamental change, not only in the way we conduct science, but also in the way we perceive teaching, learning, the therapeutic process, organizational management, and so on and so forth; and I would say, of how we perceive relationships in our daily life. One may see this fundamental epistemological change if one first considers oneself to be an independent observer who watches the world go by; as opposed to a person who considers oneself to be a participant actor in the process of mutual interaction of the give and take in the circularity of human relations. In the case of the first example, as a result of independence, we can tell others how to think and act, “Thou shalt...” or “Thou shalt not...”. This is the origin of moral codes. In the case of the second example, because of our interdependence, we can only tell ourselves how to think and act, “We/I shall...” or “We/I shall not...” This is the origin of ethics, and the basis for an analysis of the contemporary teaching/learning process, which is the subject matter of this book.

2.4 Education

With regard to human learning, the specification of stages of development from Jean Piaget’s cognitive psychology was picked up by designers of curricula, and the notion of the role of biological maturation in the ontogeny of mental development became a kind of dogma for educators and educational researchers. The epistemological core of Piaget’s theory, however, was largely disregarded. Not until around 1970 did a number of researchers focus on the idea of self-regulation. By then Piaget himself had become aware of the affinity of his theory and basic concepts of second-order cybernetics. Above all, they shared the principle that whatever we call knowledge has to be actively constructed by the knowing subject.

From then on, this principle of self-organization gained some attention among educators. By now, it has a firm foothold in the areas of mathematics and science education. An extensive literature concerning the individual and social construction of knowledge has been produced and there is considerable evidence that its practical applications are successful, but it is still far from being universally accepted. Among the points stressed by advocates of constructivism are the following:

- if knowledge consists of conceptual structures learners have to form in their own heads, verbal communication (by teachers’ speech or textbooks) does not guarantee a positive result. What is required is thought, i.e. reflection on both practical experiences and whatever teachers and books try to communicate.

- Two excellent ways for teachers to foster students' reflection are the imposition of collaboration with others and the persistent demand that students verbalize their thinking in their attempts to solve a problem ("team problem-solving" or collaborative research- and problem-solving strategy).
- The implementation of the constructivist approach requires two things of teachers: they have to credit students with the ability to think and they have to provide the students with opportunities to discover that they are able to solve problems without the teacher providing a ready-made solution.
- And, perhaps most importantly, the insight that linguistic communication *cannot replace students' active abstraction of knowledge* from their own experiences.

These four points are sufficient to indicate the need for a radical change of educational attitude: namely the concession of a great deal of autonomy to the student in order to develop their own capacity for *thinking and learning*.

A serious argument against such a change is that it would require formative assessment that is very different from the tests given to students now. This is indeed a problem. Testing for understanding is far more difficult than testing for the correct repetition of verbal statements heard from the teacher or read in a textbook. On the other hand, there is sufficient evidence by now, that the motivation to learn grows by itself once students realize that learning is not a passive but an active process and that the ability to solve problems by one's own thinking yields satisfactions that are at least as enjoyable as winning a game.

2.5 Successful competence-based learning

Four types of learning based on research, with different names but the same underlying philosophy, will probably prevail in competence-based teaching in the 21st century: *project-based*, *problem-based (team problem solving*), *inquiry-based,* and *research-based* learning (Aberšek, 2012, Aberšek, 2013). These will provide students with more comprehensive learning processes in order to be able to use competences obtained in school (knowledge, skills, etc.) for problem solving in real life. Research-based approaches are important for nurturing communication, collaboration, creativity, and critical thinking. It should be noted, however, that research-based learning is greatly dependent on well-structured assessment and testing for understanding, as regards defining learning tasks and the evaluation of learned content. *This will be discussed in detail later.* The success of different research approaches is, of course, very much dependent on the knowledge and skills of those performing them. It is therefore not amiss, or out of place, to note that all such reforms must include teacher training before they commence work in schools.

Dreyfus and Dreyfus (1986) introduced a nomenclature for the levels of competence in competency development. The process of competency development is a lifelong series of doing and reflecting. As competencies apply to careers as well as jobs, lifelong competency development is linked with personal development as a management concept. The four general areas of competency are:

1. *Meaning competency*: the person assessed must be able to identify with the purpose of the organisation or community, and act from the preferred future in accordance with the values of the organisation or community.
2. *Relation competency*: the ability to create and nurture connections with the stakeholders of the primary tasks must be shown.
3. *Learning competency*: the person assessed must be able to create and look for situations that make it possible to experiment with the set of solutions that make it possible to complete the primary tasks, and reflect on the experience.
4. *Change competency*: the person assessed must be able to act in new ways when it will promote the purpose of the organisation or community, and make the preferred future come to life.

The first two areas are particularly important in real working situations. They were discussed in detail in our previous works (Aberšek et al., 2017), while the focus of this book will be on the last two, i.e. the *learning competency* and the *change competency.* In this framework, we will also place special attention on two social competencies which are very important in schools, the *attribute* and the *awareness competency*, as shown in Figure 2_2 (Aberšek et al., 2017).

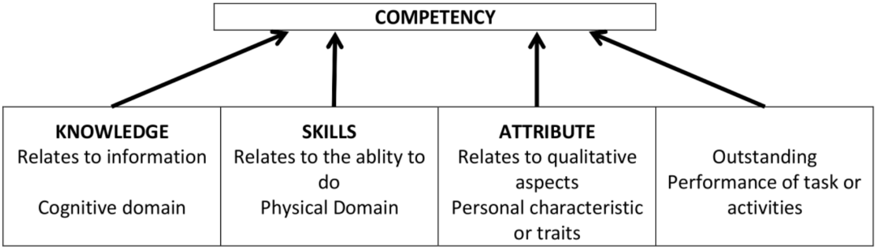

Figure 2_2: Elements of competency

These four areas of competences entail the need for the skills in today's schools, as shown in Table 2_1 (Anderson, 2010, Aberšek et al., 2017).

Table 2_1: Competencies for the 21st century

Competencies for the 21st Century				
Analytical skills	**Interpersonal skills**	**Ability of realizing**	**Information processing**	**Ability of changing/ learning**
Critical thinking	**Communication**/ Messaging	Initiative, self-regulation	Information literacy	**Creativity/ innovation**
Problem solving	**Collaborating**	Productivity, efficiency	Media literacy	**Adaptability/ learning to learn**
Decision-making	Leading and responsibility		Digital citizenship	**Flexibility**
Research and development			ICT procedure and concepts	

The implementation of 21st century skills requires the development of *core subject knowledge* and understanding among all students. Those who can think critically and communicate effectively must build on a base of core academic subject knowledge. Within the context of core knowledge instruction, *students must also learn the essential skills for success in today's world, such as critical thinking, problem solving, communication, and collaboration*. In the presented book, the development and evaluation of life and learning, and innovation skills, will be the subject of research attention, as shown in Figure 2_3.