NEURODIDACTICS -

A NEW STIMULUS IN ICT[1] AND COMPUTER SCIENCE EDUCATION

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Abstract

Neurodidactics, a relatively young discipline, represents an interface between neuroscience and didactics. Based on the findings of brain research neurodidactics provides principles and proposals for effective (brain-based) teaching and learning. This paper shall present the most important principles and give an impetus for using them in ICT (Information and Communication Technology) and computer science education.

Keywords: Neurodidactics, technology, brain-based learning, ICT, information and communication technology computer science education, progressive pedagogy.

1 INTRODUCTION

Due to the progress in neuroscience and brain research in the last decades, a new interdisciplinary research field was created, called Neurodidactics. It is an interface between neuroscience, didactics, pedagogy and psychology. It tries to work out principles and proposals for effective learning and teaching based on the findings of brain research. Not all of the findings are new, but they confirm the theories and principles of progressive pedagogy like Maria Montessori's "Help me to do it alone" and prove why they are effective.

This presentation shall summarize the main principles of neurodidactics and describe how to influence the memory process by considering some functions and mechanisms of the memory system in the human brain.

By now there are various concepts and proposals from the field of neurodidactics. There are methods like discovery learning or learning by teaching, which integrate some of the neurodidactical principles. However concrete suggestions for the practical employment in the classroom and the evaluation of these methods are missing.

This paper will present some ideas for the practical use of neurodidactical principles by giving examples of ICT and computer science education. The benefit of this way of teaching will be evaluated in a future study.

2 NEURODIDACTICS – BASICS

2.1 Neurodidactics – An Interdisciplinary Research Field

The term "Neurodidactics" (translation of the German "Neurodidaktik[2]") was proposed in 1988 by Gerhard Preiss, a specialist in early childhood mathematics education, to emphasize the interdisciplinarity of this new research field. It tries to combine research findings of neuroscience, didactics, psychology, education theory and other related disciplines. These findings will be used to work out principles and proposals for brain-based teaching and learning. Neurodidactics may be compared with two terms that are better known in the English-speaking world: "Educational neuroscience" or "brain-based learning".

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[1] ICT – Information and Communication Technology

[2] http://www.zahlenland.info/de/leitgedanken/

Thanks to imaging methods, such as fMRI (Functional Magnetic Resonance Imaging) and PET (Positron Electron Tomography), we know much about structure, development and functioning of the human brain. They allow us to observe the learning brain in different circumstances and to detect factors and conditions which may influence teaching and learning.

Many of the research findings are not definitely new, but confirm the principles and methods of progressive pedagogy like the following key-sentence of Maria Montessori (1870 –1952):

"Help me to do it alone!"

Learning is a very complex process that cannot be influenced directly [10], but only through circumstances. Certainly, we cannot change biological facts, such as gender-specific differences in brain structure and development or the hormone status which may have an effect on aptitudes and performance. But we can take them in consideration and try to understand the difficulties in learning and concentrating of our students in their adolescence.

Some unconscious processes, such as some memory processes or the valuation of new situations and information by the limbic system, can be influenced indirectly. We can take them in consideration by offering appropriate circumstances and conditions in the classroom. And that is what researchers in neurodidactics are integrating in their different principles and proposals.

2.2 Neurodidactical principles and proposals

Two of the pioneers of brain-based learning – Renate and Geoffrey Caine – summarized the research findings about the learning brain in the following 12 principles of nature learning:

1. Learning engages the physiology.
2. The brain/mind is social.
3. The search for meaning is innate.
4. The search for meaning occurs through patterning.
5. Emotions are critical to patterning.
6. The mind/brain processes parts and wholes simultaneously.
7. Learning involves both focused attention and peripheral perception.
8. Learning always involves conscious and unconscious processes.
9. We have at least two ways of organizing memory: A spatial memory system and a set of systems for rote learning.
10. Learning is developmental.
11. Complex learning is enhanced by challenge and inhibited by threat.
12. Each brain is uniquely organized. [3]

Based on these principles some advice for effective and brain-based learning is given. Renate and Geoffreiy Caine postulate that all students learn more effectively when

- they are involved in experiences,
- their needs for social interaction and relationship are engaged and honored,
- their interests, purposes and ideas are engaged and honored,
- they can use their innate capacity of patterning,
- their learning is accompanied by positive emotions,
- details are embedded in wholes, that they understand, such as a real life event,
- their attention is deepened and multiple layers of the context are used to support learning,
- they have time to reflect on,
- immersed in experiences that engage multiple ways to remember,
- individual differences in maturation, development, and prior learning are taken in consideration,
- the environment is supportive, empowering, and challenging,
- their individual talents, abilities, and capacities are engaged. [3]

Further neurodidactical proposals are given by Brand and Markowitsch [2], two researchers in the field of memory and cognition:

- The reduction of requirements during the perception of new topics may increase the efficiency of learning and memory.
- An overview at the beginning of the lesson prepares the so called priming, an implicit memory effect, that facilitates the recognition of a stimulus implicitly perceived before.
- Students shall also structure and organize their material on their own.
- The teacher should always refer to well-known topics.

- They also propose to integrate teamwork and projects as well as multimedia.
- At last teachers shall show enthusiasm for their subjects. So they can motivate their students.

Kraus [6] refers to another important principle, which is also part of the progressive education: the active role of the students. A fact that can be considered using the method of “Learning by teaching”.

Many of these neurodidactical proposals are not new, but – and that is important – they can now prove some well-known principles of various approaches of progressive education, like Montessori, Dalton or Freinet and others.

Considering all the principles mentioned above and many other suggestions for brain-based learning as well as the knowledge about brain and memory the following points are essential:

Knowledge cannot be transferred, but:

- We can try to facilitate the learning process in all steps from perception of new information over the working memory and the long term memory by using various teaching methods, varied material etc.
- Creating appropriate environment in our lessons (room, positive atmosphere, confidence, enthusiasm, good relationships…) we can help the students to motivate themselves and to learn more effectively.

2.3 How to Influence the Memory Process

If we want to improve the learning of our students it is good to know something about the memory process and how to influence it.

Our memory (see Fig. 1) is a very complex and dynamic system including also many unconscious processes. Even though the long-term memory seems to be a static data memory, it is dynamic, too. It is rather a data generator which organizes the storage and linking of information and creates new meanings [10]. Each recall of the long-term memory causes a re-encoding and therefore also a new storage.

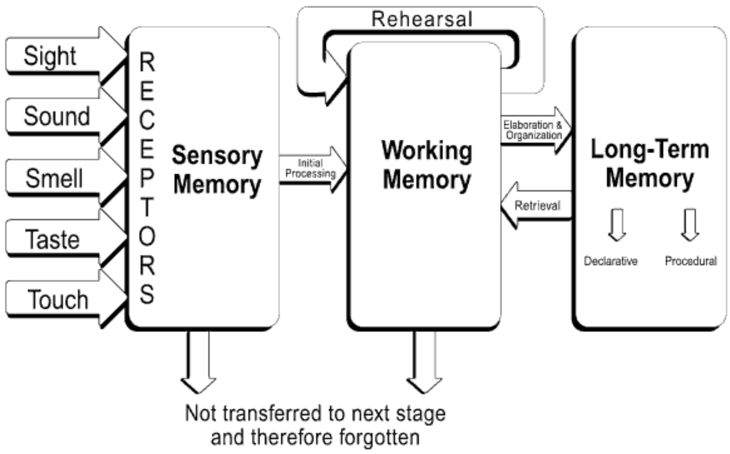

Fig. 1: An information processing model [14].

The main steps from receiving new information until a permanent storage in the long-term memory are the following.

- Encoding[3] (converting perceived information and putting it into memory)
- Storing (the first storing after encoding),
- Consolidation,
- Storage (in the long term memory),
- Recall,
- Re-Encoding [2] [translated by the author].

[3] Encoding is the cognitive process that applies attention and associates context and existing knowledge to sensory data to make it more easily remembered [7].

Every step needs certain time and can be supported by the teacher and/or the learner by considering the following functions and mechanisms of the memory system:

Encoding can be influenced by *activating current knowledge and competences.* Teachers should check existing knowledge and create a learning path to the world of the students, for example, by beginning the lesson with questions. This would also arouse curiosity.

Priming: As mentioned in chapter 2.2 this implicit memory process can be prepared by giving an overview at the beginning of a lesson or unit. That will also help the pupils to structure the new information themselves.

Cognitive effects: To facilitate the receiving and encoding of information we can use some cognitive load learning effects:

- Serial position effects: the first and the last unit(s) are remembered best (primacy, recency effect).
- Modality (multimedia) effect: Information is remembered easier when dual coded (spoken text combined with pictures).

Patterning and *extracting rules* can be forced by giving many examples and using discovery or exploratory learning.

Chunking: Grouping and categorizing little (meaningless) units to larger (meaningful) ones facilitates to hold and memorize data. *Magical number 7*: When chunking we shall also consider that we can hold 7±2 units in our working memory.

Linking: Learning is always linking new information to existing knowledge. It can be facilitated by using *mnemonics* (the funnier the better!) or by embedding learning data into situations with practical or personal orientation.

Consolidation: After receiving and processing new information the brain needs time (breaks, sleep) for the unconscious process of consolidation. This works best in all forms of self-organized learning where students can learn following their own rhythm and have a break when they need it.

Re-Encoding: The recall of information from the long-term memory causes always a new re-encoding and storing. We can use this mechanism by using cooperative learning forms (teamwork, interviews…) or "learning by teaching". Of course we have to correct immediately mistakes of the students to avoid the new storing of false information.
[2], [9], [14]

How the different steps of the memory-process can be integrated in the classroom is shown by applying the educational model of "Learning under Self-Control" (LUS), like the bilingual private school "formatio" in Liechtenstein. In this teaching concept an ideal lesson is divided into the following six phases:

1) *Activation* (10 minutes): At the beginning relaxation exercises prepare the students for the learning process and focus their attention.
2) *Presentation* (5-10 minutes): The key-information of the new learning contents is presented.
3) *Consolidation* I (5 minutes): A little break of 5 minutes shall facilitate the consolidation of the new contents.
4) *Repetition* I (5 minutes): Now the key-information is repeated for a first time.
5) *Consolidation* II (10 minutes): A second break shall foster the consolidation of the repeated contents.
6) *Repetition* II (10 minutes): A second repetition shall lead to a better and deeper memory-processing and storage.

This concept of LUS seems to be faster than other teaching methods as it could be confirmed in two long-term studies in primary schools [13]. It would be interesting to repeat these studies in other school types and with elder pupils and students.

3 NEURODIDACTICS IN THE CLASSROOM

"Brain-Based" Ideas for ICT or Computer Science Education

Particularly ICT (Information and Communication Technology) and Computer Science Education offer a lot of possibilities to integrate neurodidactical principles. There are not only the contents of the subject “Computer Science Education” like programming languages or hardware components. You can see ICT also from an interdisciplinary point of view: You teach the required contents of the curriculum using contents of other subjects like history or languages for your examples and exercises. So you can introduce the functions of a relational database creating a multilingual dictionary.

Considering both points of view allows teachers to organize varied lessons which also integrate the principles of individualization and differentiation which are proposed not only by researchers of neurodidactics. This will be necessary particularly in the ICT and computer science education because there is hardly any other subject with such a wide variation concerning the knowledge and capabilities of the students [4].

In this case (but not only) *open learning* may be a good method to respect and integrate the individual talents and competence. In Austria there is a network for COOL (cooperative open learning[4]) schools that practice this form of instruction in various subjects and have just had good experiences. Open learning offers the possibility to integrate individual interests and knowledge by using obligatory and voluntary tasks. One part of open learning is discovery learning, which may allow better learning results than traditional lessons [1].

The following points shall offer some ideas for putting in practice neurodidactical principles.

3.1 Knowledge cannot be transferred

Knowledge cannot be transferred; it must be newly created in the brain of each student. [10]

This is, in my opinion, one of the most important principles of neurodidactics. It may surprise and contrast with the traditional view of school education and the traditional active role of the teacher (teacher-centred instruction). But meanwhile another form of education (student-centred learning) is well substantiated in neuroscience and cognitive psychology. According to Maria Montessori’s “Help me to do it alone!” neurodidactics proposes an active student role, too, because effective learning is always an active process. That may lead to other ways of education: self-regulated, self-organized or open learning which satisfy nearly all requirements of a pedagogy that has learned from brain research [5].

Self-organized or open learning allows the students to follow their own interests and work rhythm, two very important aspects for motivation and memorizing. Firstly, we learn better when we are motivated and it is easier to memorize things we are interested in. On the other hand self-regulated learning allows the students to have breaks when they need them – and when their brains need them for consolidation and storage of the new contents in the long-term memory. Unfortunately the traditional timetables in our schools with 50- or 45-minutes-lessons and always changing subjects and teachers are sometimes counterproductive. So a part of the contents learned in one lesson is “overwritten” or cancelled by the new contents in the following lesson. To avoid this negative effect we could try to integrate a concept like “Learning under Self-control” (see also chapter 2.3) in our lessons, at least when we introduce a new topic.

3.2 Patterning and Categorizing

The brain recognizes and generates patterns, categories and rules itself [5].
Manfred Spitzer [11] calls the brain a “rule-extracting machine” because the function of patterning and categorizing is innate and works automatically. The students don’t need rules, but many examples, which help them to recognize the included structures. This brain-function is the base for exploratory or discovery learning, which is also one of the basic principles of progressive pedagogy.
The following illustration (Fig. 2) shows two patterns (a decimal and a binary number) that I present in my classes as introduction into the binary system.
Depending on the age-group I give more or less information. For younger pupils (elementary school) I calculate two or three examples like the following on the black-board and explain what I’m doing. For elder pupils and students it is not necessary to explain the way of calculating. They are able to discover the structures and rules on their own on closer examination of the examples.

[4] Further information: http://www.cooltrainers.at/

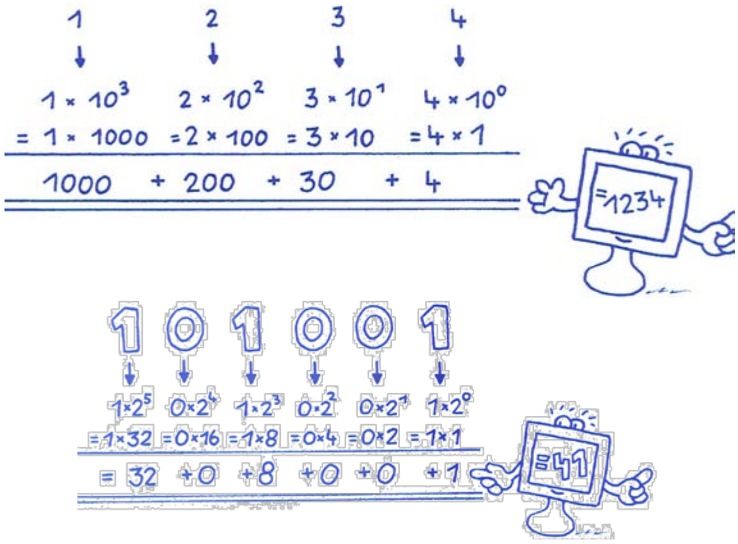

Fig. 2: Examples of decimal (above) and binary numbers [12].

3.3 Connections and Practical Orientation

We cannot learn effectively, when there is no base where we can connect new information. Teachers should check the current knowledge and competences of their pupils and start the learning path from there because we are always learning by making associations and linking new information to existing knowledge. That can be facilitated by using *mnemonics* (the funnier the better!) or by embedding learning data into situations with practical or personal orientation.

Our internal valuation-“software”, the limbic system, checks all new information whether it is new / meaningful / good or old / meaningless or bad for us [10], [11]. It is obvious that we memorize better what’s good and meaningful for us. So learning is especially effective, when it makes sense, when we need the contents in our (every day) live. We are more motivated and learn more easily when we know why we do it, when we have a reason. Teachers can consider this principle by giving the students references to their personal life and environment like in the following worksheet “Hardware components”. The neurodidactical principles are given in brackets and italics.

Hardware components, IPO-Principle (Input-Processing-Output)

In this task pupils shall learn about the components of a computer and the IPO-principle (functional model of hardware components)

The first thing to do for the teacher before introducing new topics is to check the current knowledge of his / her students. So you can start the lesson with questions that also may arouse curiosity, such as: “Would you like to buy a computer? Have you got any idea, where to pay attention to? What can we actually do with a computer? Is there perhaps just a computer expert in this class?” This beginning will consider a pedagogical proposal, postulated by Stern [12] [translated by the author]: “Good instruction, at least in natural sciences, begins with a question.”

The pupils receive a work-sheet with the following instructions, of course without the neurodidactical principles.

> Your parents want to buy a computer or a notebook, but do not know a lot about technology (*practical orientation, path to personal world of the students, sense*). They ask you to compare different offers and to explain the possibilities, advantages and disadvantages (*learning by teaching, re-encoding*). Your parents also want you to help them to choose the appropriate offer (*social context, sense*). To choose the right one you will have to know, of course, how the computer will be used. Do your parents want to work on it, write or calculate? Or do you like painting or hearing music or would you like to register even your own songs? (*priming for IPO-model – Input – Processing – Output*). You choose an appropriate offer that you discuss perhaps with your friends (*re-encoding*). Then you write it down with all necessary information (*integrating current knowledge, individual interests and talents - pupils with higher knowledge can just give more details about processor, memory size etc.*) and explain it to your parents (*learning by teaching, re-encoding*).

To carry out these instructions the students need good and varied material, such as advertising leaflets or websites of computer shops. If the school is situated near a computer shop, the best choice would be a short study trip inside it (*practical orientation*).

After discovering the different components of computers and other hardware the students have to perform part two of the work-sheet:

> Now you have seen some offers of computers and other hardware. Before explaining them to your parents and giving them advice, can you first group the hard-ware components according to their function (*priming, patterning, structuring*)? Remember what you can do with them! (*Question thrown in to facilitate structuring*)

3.4 Practice makes perfect!

Linking new data to existing one alone doesn't guaranty the storage of the information in the long-term memory. The more often we use the same association the better we can memorize the learned issues. So the brain research proves another very old saying: Practice makes perfect! That doesn't mean doing only many stupid exercises of the same type. It means especially using the learned contents in different context and transferring them into new and different situations.
The following example of a multilingual dictionary shows how to practice not only the contents of computer science education but also to learn and/or repeat vocabulary necessary for the students.

A Multilingual Dictionary: An interdisciplinary project

Interdisciplinary tasks and projects are a good way to integrate neurodidactical principles in classrooms. They refer e.g. to the students' world with their individual knowledge, talents and interests (my students wanted to collect and repeat useful vocabulary in 5 languages), support associative learning and social competences etc.

The multilingual dictionary of one of my classes with emphasis on foreign languages had two aims (besides the aims of the language lessons):

1) the revision of the basic functions of spreadsheet analysis and database and
2) the introduction of new contents, such as complex functions and queries as well as the data exchange between the two applications.

The data – vocabulary in five languages – were collected with the respective language teachers according to thematic suggestions of the students (*sense, practical orientation, individual interests→ motivation*) and then entered in the spreadsheet analysis software Microsoft Excel.

For the revision of the basics the method of "group-puzzles" was used: The students formed panels of experts for particular topics, such as *filtering and sorting* or *functions* (*integrating existing knowledge, individualization, and differentiation*). These expert groups had to revise their topics by sharing their own knowledge and competences as well as rereading their scripts and books. The instructor had a passive role and was there to help and answer eventual questions. After this first new panels were formed, each of them including one representative of each former expert group who had to help his/her colleagues by "teaching" the own topics (*learning by teaching, re-encoding, re-storage*). The result should be the multilingual dictionary with a search form like the following and a vocabulary trainer:

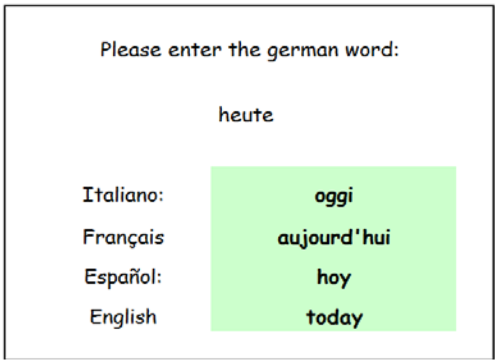

Fig. 3: Multilingual dictionary, search form

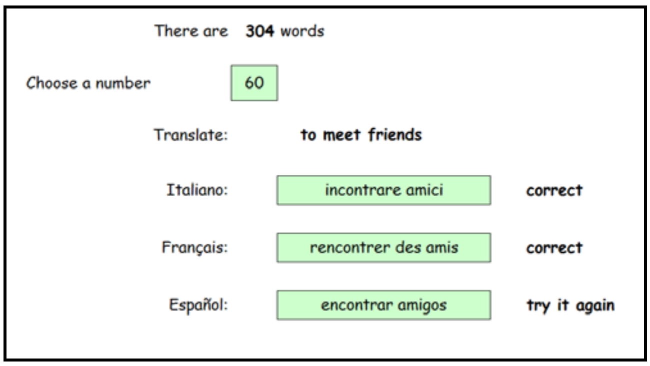

Fig. 4: Vocabulary trainer

The vocabulary lists where then imported in the database Access, where the students revised the basics of tables, forms and reports. Then they created a search form based on a query which should look up the entered word in all available languages.

4 CONCLUSION

Based on the findings of brain research the young interdisciplinary science of neurodidactics has worked out different principles and offers some useful proposals for effective and “brain-based” teaching and learning. Not all of the findings are new, but they confirm the theories and principles of progressive pedagogy and prove why they are effective [4]. Therefore an integration of neurodidactics just in the training of teachers would be desirable.

By now there are various concepts and proposals from the field of neurodidactics. The central message is that we cannot transfer knowledge, but it must be newly created in the brain of each learner. There are proposed methods like discovery learning or learning by teaching, which integrate several neurodidactical principles. However concrete suggestions for the practical employment in the classroom are still missing.

That was the idea of this paper. It tried to give some suggestions of how to

- influence the learning process by using and activating innate brain functions like patterning or associative learning,
- support memorizing by integrating cognitive learning effects and unconscious memory processes like priming or consolidation,
- foster associative thinking and connecting or combining different subjects and pertinent factors.

What is needed now is an evaluation study in order to check the effectiveness of a consequent employment of brain-based teaching and learning methods.

Especially the ICT (Information and Communication Technology) and computer science education may contribute to integrate neurodidactical principals because it can also support the learning success of other subjects by offering interdisciplinary examples and projects.

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