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A Neurodidactical Approach to Computer Science

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Games for Learning: A Neurodidactical Approach to Computer Science

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Abstract: Games are funny but also serious. They can be a motivating and effective way of learning complex and difficult topics, especially in the subject matter of computer science, which offers a wide range of possibilities to integrate games in the classroom. This paper will describe the use of games in computer science on two levels. On the one hand, it will show how to teach core concepts of informatics in primary and secondary schools by playing games. On the other hand, some learning contents of computer science and ICT can be taught or revised by creating games for other subjects and interdisciplinary learning. Both ways of integrating games in computer science education are interesting and motivating, as it can be verified in studies about the project Informatik erLeben (Experiencing Informatics) of Klagenfurt University. The didactical principles behind the concept of game-based learning are also supported by neurodidactics, an interdisciplinary research field that combines findings of brain and memory research, psychology and other related fields. First of all, games in the classroom can increase motivation and attention, which is the key to effective learning. Apart from this necessary precondition of learning games can integrate other neurodidactical principles, like pattern recognition, social learning, or active learning. This paper will outline some important brain-functions and neurodidactical principles based on different games for computer science education and interdisciplinary learning.

Keywords: Game-based Learning, Brain-based Learning, Computer Science, Informatics, Interdisciplinary Learning, Neurodidactics

> "For whenever one plays a game, and whatever game one plays, learning happens constantly […]" (Prensky, 2001).

Introduction

Not only children play games and learn through playing. The philosopher Nietzsche said: "In every real man there is a child wanting to play." After observing pupils and students of all ages it can be said: "In *everyone* there is a child wanting to play." And that is good, because research shows that playing can be an effective learning method (e.g. Wellhousen & Crowther 2004). This is perhaps because games are very engaging and "Play is the original way of learning things", as postulated in Prensky (2001) referring to a statement of Danny Hillis. So why not use games in formal learning as well?

In regards to games for learning, the recent literature mainly involves learning by video and computer games. Contrary to that, this paper presents some ideas for integrating games for learning on two levels: the playing and the design of games. The paper shows how to teach core concepts of informatics in primary and secondary schools through animation and play. Furthermore, it presents ideas for teaching or revising some learning contents of computer science and ICT by designing games for other subjects and interdisciplinary learning.

Both these levels, the playing and the design of games satisfy some neurodidactical principles like motivation, pattern recognition or active learning and may be considered "brain-based" or "brain-friendly" learning.

This paper will outline some important brain-functions and neurodidactical principles on the basis of different games for computer science education and interdisciplinary learning. It also gives an example of the project *Informatik erLeben* (Experiencing Informatics) of the Klagenfurt University where different topics of computer science were taught with success through animation and play in primary and secondary schools (Bischof & Sabitzer, 2011).

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A Neurodidactical Approach to Games for Learning

The didactical principles behind the use of games in learning are also supported by neurodidactics, an interdisciplinary research field that combines findings of brain and memory research, psychology and other related fields. Neurodidactics shows us how the brain learns, how memory works and how we can enhance learning by considering these facts and using some automatic brain functions and cognitive effects (Sabitzer, 2011; Sabitzer & Antonitsch, 2012). Game-based learning (not only computer games) may be one possibility to do this and to make learning more effective.

Considering the twelve characteristics of games (numbered 1-12) presented by Prensky (2001) we can discover the connection to effective learning and deduce some neurodidactical principles described by different authors (Caine, 2001; Jensen, 2008; Sousa, 2006; Geake, 2009; Sabitzer, 2011). In the following paragraphs the arrow marks the neurodidactical principle behind the game characteristic.

1. Games are a form of fun. That gives us enjoyment and pleasure.
    - Learning is more effective when we enjoy it. That gives positive emotions that may have a positive impact on learning. (Jensen, 2008; Sousa, 2006; Geake, 2009; Sabitzer, 2011)
2. Games are a form of play. That gives us intense and passionate involvement.
    - Intense and passionate involvement means high attention and this is the key to effective learning (Geake, 2009).
3. Games have rules. That gives us structure.
    - Structure helps to organize and categorize learning contents. Offering structure supports the automatic brain functions of categorization and patterning and this facilitates the memory process. (Jensen, 2008; Sousa, 2006; Sabitzer, 2011)
4. Games have goals. That gives us motivation.
    - Motivation increases attention and is a necessary precondition of learning. (Jensen, 2008; Sousa, 2006; Geake, 2009; Sabitzer, 2011)
5. Games are interactive. That gives us doing.
    - Learning is always an active process. We learn better when we are active. Knowledge cannot be transferred; it must be newly constructed in the brain of each student. And this happens when we are active like in playing. (Jensen, 2008; Sousa, 2006; Geake, 2009; Sabitzer, 2011)
6. Games are adaptive. That gives us flow.
    - Flow is a state of full immersion and concentration where challenges and skills are balanced – a perfect condition for learning. In the state of flow people are fully absorbed in what they are doing and this helps to maintain motivation during the whole learning process. (Csikszentmihalyi, 1996; Paras & Bizzocchi, 2005)
7. Games have outcomes and feedback. That gives us learning.
    - Good learning outcomes and feedback may motivate for further learning. When the learner has success and, further, the result or learning product is useful for him/her also motivation is higher. (Jensen, 2008; Sousa, 2006; Geake, 2009; Sabitzer, 2011)
8. Games have win states. That gives us ego gratification.
    - Gratification is a reward and satisfies the brain's evaluation and reward system, the limbic system. The limbic system plays a fundamental role in learning, first of all, because it is in-volved in checking if the learning situation is worth the effort. (Sousa, 2006; Sabitzer, 2011)
9. Games have conflict/competition/challenge/opposition. That gives us adrenaline.
    - And "adrenaline is a memory fixative" (Jensen, 2008), certainly in an adequate dose. Like other neurotransmitters and hormones it can have an impact on the learning and memory process depending on the dose. A medium level of adrenaline supports learning, whereas a low or too high level may inhibit it. (Jensen, 2008)

10. Games have problem solving. That sparks our creativity.
    - Problem solving and creativity are important skills that everyone should have but that cannot be taught only by lecture (Weisberg, 1988). Playing games seems to foster these skills that later on can support learning (Prensky, 2001).
11. Games have interaction. That gives us social groups.
    - Our brain is social and we learn through communication and interaction (Caine, 2001).
12. Games have representation and story. That gives us emotion.
    - Emotions have a high impact on learning. They are generally processed in the limbic system that is involved in learning in many ways, e.g. in the consolidation and formation of memory. (Jensen, 2008; Sousa, 2006; Sabitzer, 2011)

Aspects of Games for Learning

Games can be used for learning on two levels: we can play games in the classroom or we can design learning games. Both ways seem to be effective as verified in different studies (Wellhousen & Crowther 2004; van Eck, 2006; Green C. S., 2012; Green & Bavelier, 2006; Hays, 2005; Kirriemuir & McFarlane, 2004). This chapter will present some ideas for both levels, for playing and designing games in computer science education.

Playing

Learning is Active – Simulation and Animation

Effective examples of learning by playing are the project “Informatik erLeben” (Experiencing Informatics and its follow-up “Informatik verstehen” (Understanding Informatics), both accomplished at the Klagenfurt University. They are the Austrian adaptation and extension of Computer Science Unplugged[1] and aim at teaching core concepts of informatics in a playful way without any computer. In all lessons, the pupils from primary and secondary school act in groups taking the role of data, parts of a program or computer components. The project and the originally prepared lessons are presented in Mittermeir, Bischof, & Hodnigg (2010).

One new example of Understanding Informatics shall be given here in order to demonstrate the connection to brain-based learning.

Simulation and animation games help to visualize difficult topics and make them more understandable. The following example of automata theory (a finite state machine) was played with children in elementary and lower secondary school.

Since we know from neurodidactics that new information must always be connected to prior knowledge, it is necessary to check and activate this knowledge or skills before introducing a new topic. We can do this by beginning with questions like “Do you know some automata / vending machines? What happens e.g. in a chewing gum vending machine? Which steps are necessary in order to get a chewing gum? What happens when we do not insert enough money?”

Based on these questions and answers, in the language of the children, the main concept and vocabulary of finite state machines are explained: “There is always a start state and a final or accept state (in this example ‘s0’ for both), an input alphabet (10 or 20 cent and the button “buy”) and one or more transition actions depending on the input and/or the actual state” (Hopcroft & Ullman, 1979).

Fig. 1 shows the state diagram of a simple chewing gum machine that accepts coins of 10 or 20 cent and cannot return money.

[1] http://csunplugged.org/

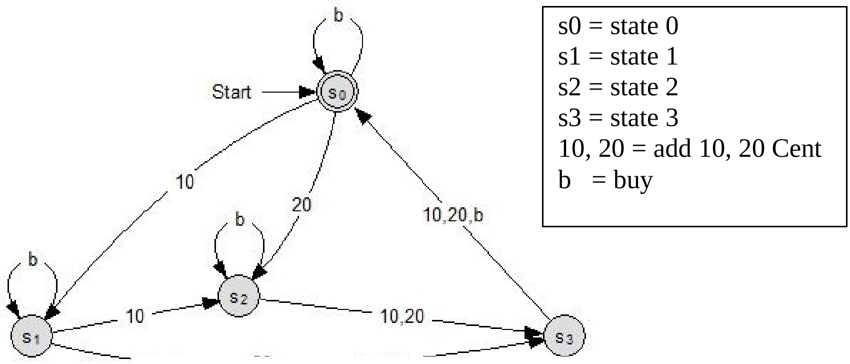

Fig. 1 State diagram of a chewing gum machine

On the basis of this diagram (on a poster or in the program "AutoEdit"[2]) the way of inserting money to receiving a chewing gum, is slowly shown to the children by following the transitions accompanied by questions and instructions like: "What happens when we insert 10 cent? We 'go' to state one (s1). Which state follows when we now insert 20 cent? – State two (s2). How much do we have to insert now? Nothing, we have to press the button 'buy (b)."

After the simulation, that allows the children to discover the concept of automata theory, the pupils are asked to animate the diagram, to play all steps of the chewing gum machine. The children representing the states (s0, s1, 12, s3) get a label and are placed at the front of the classroom according to the diagram on the poster. Those who don't want to act observe the animation and give instructions to the actors. One child gets some coins and "buys" a chewing gum by following the correct way from the start state (s0) to the accepted final state (s0) according to the coins he/she "inserts". (Bischof & Sabitzer, 2011)

The neurodidactical principles behind this game (besides motivation, flow and attention) are the following:

- *New information must be connected to prior knowledge*: All children know a chewing gum machine and the necessary steps for getting a gum. The new information (states, input alphabet, transitions) can be connected to their existing knowledge and hence better anchored in the long-term memory.
- *Patterning = Automatic brain function in discovery learning:* The brain automatically generates rules and patterns when it gets good examples. By simulating and animating the processing of the chewing gum machine the children extract the pattern and rules by observing and playing.
- *Observing and the mirror neurons:* Mirror neurons are responsible for empathy and enable social learning by imitation as well as learning without having to go through trial and error (Geake, 2009). They are a special class of brain cells that fire not only when we perform an action, but also when we observe someone else making the same movement. That is what we are doing while observing simulations and animations.
- *Modality effect supports memory*: The children can follow the steps with their eyes while hearing the instructions. By providing information for two senses, more synapses for one topic are activated in the brain, the processing of the new information is deeper and it is saved in more brain regions than a simple lecture or explication.
- *Movement supports learning*: Animating the states and transitions of the chewing gum machine means also movement, which may be fun. It may also spur the nerve growth factor, further synapses are activated in the brain and the information is

[2] (Hielscher, 2006)

saved in more brain areas and hence better anchored in the long-term memory (Jensen, 2008; Roth, 2009).

- *Learning has to be active – knowledge must be newly constructed*: Besides the actors in the animation the pupils who observe are also active because they have to think about the topic and give the correct instructions for the actors. They help to "construct" the finite state machine and make it work. This form of learning by doing is very effective compared to other teaching methods. The following figure shows the average retention rate of different methods after 24 hours.

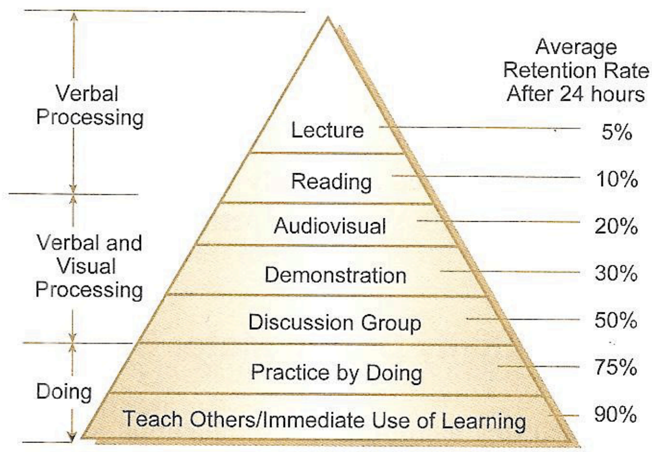

Fig. 2 Retention after 24 hours for different teaching methods (Sousa, 2006)

- *Limbic system is satisfied*: As just mentioned, the limbic system, seat of emotions and reward, is strongly involved in learning. When it considers new information (learning contents) as good and worthwhile it supports the learning process by activating the right neurotransmitters and hormones. Dopamine controls curiosity and stimulates motivation and the brain's pleasure centers. It passes the mesolimbic system, one of the dopaminergic pathways of the brain, and cares for reward. The neurotransmitter serotonin ensures good feelings, a precondition for further learning in the same context.

Like this example of automata theory all tasks of the projects "Experiencing Informatics" and "Understanding Informatics" consider several neurodidactical principles. Therefore it is not surprising that the evaluation results of the projects were convincing (Bischof & Sabitzer, 2011).

This is not a single case as described in Seay (1997) who examined 68 studies on the difference between simulations/games and conventional instruction in student performance. Simulations and games show greater retention over time than conventional classroom instruction.

Adrenaline and Dopamine – Competitions

Both dopamine and adrenaline support learning as already mentioned. Dopamine is released when we expect reward and it stimulates motivation. Adrenaline can serve as "memory-fixative" and is released e.g. in competitions or games where we want to win. This situation can be offered also in classroom by integrating quiz games and other competitions in order to revise and practice different skills and competences.

The website Quia[3] offers some different types of quiz games for all school subjects, like *challenge board* (Fig. 3 and 4) or *rags to riches* (Fig. 5) that can be integrated in the classroom.

[3] http://www.quia.com

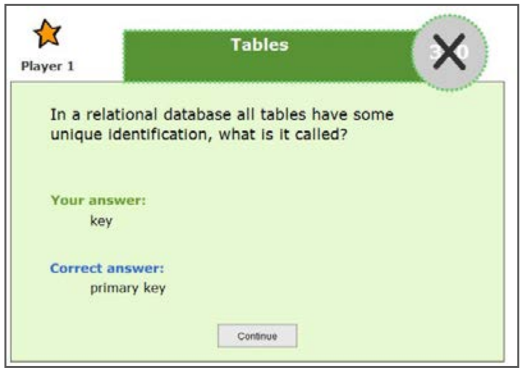

Fig. 3 Challenge Board and Fig. 4 Question of the challenge board
(http://www.quia.com/cb/32212.html)

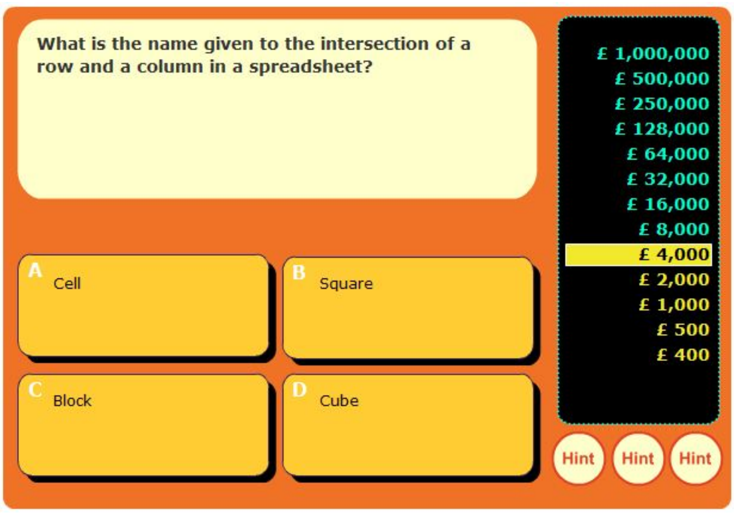

Fig. 5 Rags to riches http://www.quia.com/rr/89239.html

Patterning Recognition – Puzzles and Discovery Learning

A good way to benefit from the automatic brain function of patterning is discovery learning in the sense of inductive learning. Students get different examples, examine them and extract respectively “discover” the structure or rules behind them. Discovery learning can be effective, as described in Baldwin (1996) because it causes active involvement of the students and leads to an active and hence deeper processing of the learning contents in the memory. Discovering new and important information may give a feeling of satisfaction (positive emotion), which also supports the learning process, as already described.

The website Quia offers different Java games that allow discovery learning like flashcards, memory or matching (Fig. 6) where the students have to indicate the two cards that fit together one right after the other.

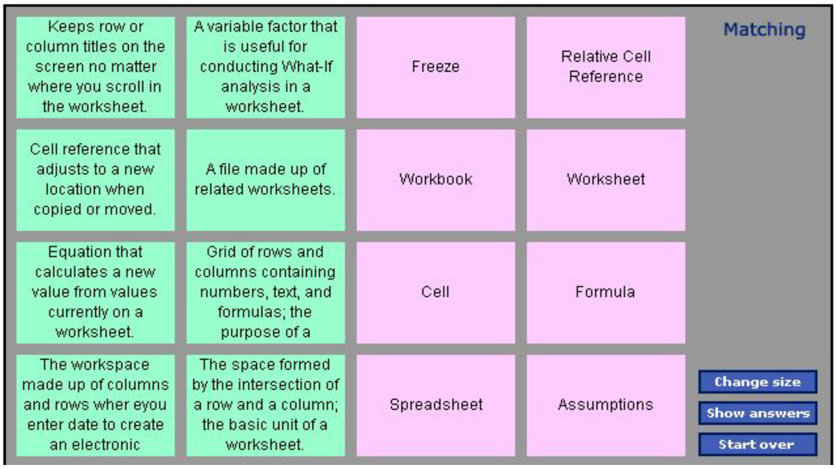

Fig. 6 Spreadsheets http://www.quia.com/mc/669031.html

Another example of discovery learning is the following puzzle presented in a Java programming course at the University of Klagenfurt. It contains the jumbled Java code of a recursive binary search and the visualization of the steps and meantime results (Fig. 7).

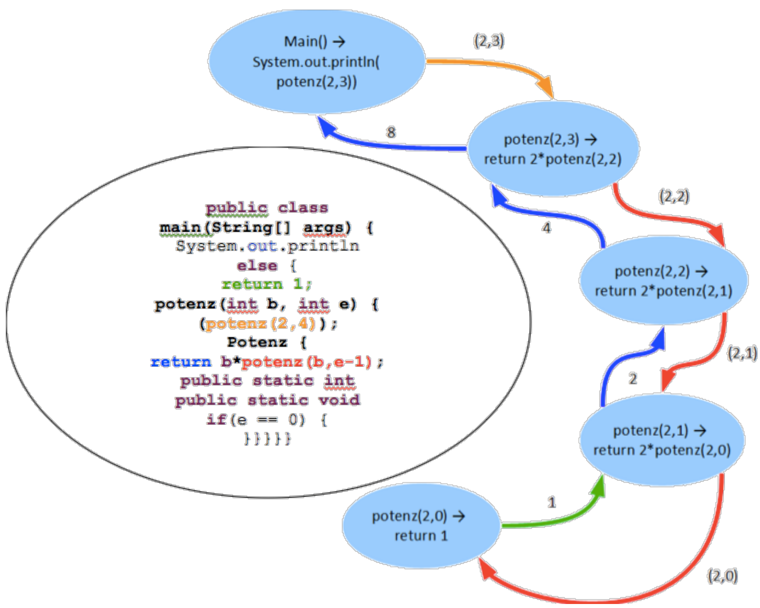

Fig. 7 Puzzle „Binary search“

Game Design

Not only playing but also designing games can enrich learning. “Games can aid in the understanding of a difficult concept or idea” is postulated in Cliburn (2006) who studied the effectiveness of games as assignments in programming courses. Most of his students preferred game assignments to non-game assignments. Even though the game assignments didn’t seem to improve the student scores overall, the effect on learning was positive: motivation was higher and the students enjoyed the type of tasks.

Building Knowledge

Besides motivation, further neurodidactical principles may be involved in game design. It may foster creativity, active learning and building new knowledge e.g. when the students themselves create the puzzles and games, presented in the previous section. From own experiences and informal feedback letters of my students in a vocational school, it can be said that most of them enjoy it. These feedback letters are not statistically analyzed but they reflect what we could observe in the classroom. The students seem to like making their own learning games, to find them useful and more attractive for repeating the learned knowledge or competences than other traditional exercise types. Furthermore, they appreciate bringing in their individual needs and interests when they can chose the type and the learning contents for the game they shall design. It may also be interesting for them to make games for other subject matters, perhaps in the form of interdisciplinary projects that may have further benefits. These interdisciplinary projects may foster important skills that are not explicitly part of the subject curriculum: cross-linked thinking, self-responsibility as well as team and communication skills (Sabitzer, 2011).

Sense and Meaning

Learning is more effective when it makes sense and has meaning. This is the case when the students can bring in their individual needs, interests and talents, e.g. when they create games in computer science for contents of other subject matters that they have to learn or repeat. In Sabitzer (2011 & 2012) some ideas for the design of language learning games are presented. They extend from the design of quiz cards, game boards and tandoku[4] etc. in spreadsheet analysis software to the tasks for a Java programming course at University-level; like the vocabulary learning game *Jumbled Words*, a review exercise for the use of arrays. The worksheet for the students contains the following description of the program: “The letters of a word selected from a vocabulary list (by entering a number or randomly) shall be shaken and the new ‘word’ shall appear on the screen. Then the language learner has to enter the correct word and shall get feedback. If his/her answer is false it shall be possible to enter another word.” The following figure shows an example output of this game.

```
Which word shall be shaken?
(Enter a number or -1 for a random
word): 3
Your word is: mianla
What is the correct word?: animan
That is not correct! Try it once
again!: animal
Super! This word is correct!
```

Fig. 8 Output of the Java program Jumbled Words

The vocabulary learning game *Jumbled Words* is one part of a complex language learning program that shall be developed in the course of the whole semester and will contain some other language learning games like flashcards, tandoku or hangman as well as a dictionary and a vocabulary trainer. The embedding of single tasks (games about data types) in one complex program satisfies another neurodidactical principle, already postulated by Aristotle “The whole is more than the sum of its parts.” Details shall always be embedded in a whole because “The experience of the whole provides a story, a model, or a fascinating example of what can be achieved” (Caine & Caine, 2001).

These and other programming tasks (not only games) are part of the project “COOL Informatics” described in Sabitzer (2012) that aims at designing learning material based on neurodidactical principles. These excercises as well as some brain-based learning methods are

[4] A tandoku is a sudoko with words instead of numbers

now tested and evaluated in a university programming course with a high failing rate that. Unfortunately the results are not yet available.

Conclusion

We can use games in computer science education on two levels: we can play games in order to learn as well as repeat computer science competences or we can design games for computer science and other subjects. Both ways offer benefits that may be explained by neurodidactics. First of all, games in classrooms can increase motivation and attention, which is the key to effective learning. Apart from this necessary precondition of learning, games integrate other neurodidactical principles, like: pattern recognition in discovery learning, social learning and imitation, or active learning through animation.

This paper should draw a connection between the characteristics of games and neurodidactical principles and brain-functions to show how and why learning can be supported by playing or game design. Both methods seem to be effective, as verified in different studies.

The results of the project Experiencing Informatics, that teaches informatics by playing and the subsequent evaluation of the project COOL Informatics, containing assignments of game design; show that both ways are motivating and seem to consider some neurodidactical principles. But further research in this field is definitely required. In recent years, some literature about brain-based learning and neurodidactics or neuroscience for education has appeared but empirical studies are still missing. Some aspects are considered in the project COOL Informatics and the detailed results of the current evaluation will be published in a further paper.

REFERENCES

Baldwin. (1996). Discovery Learning in Computer Science. ACM SIGCSE Bulletin, 28/1, 222-226.

Bischof, E., & Sabitzer, B. (2011). Computer Science in Primary Schools - Not possible, but necessary?! In I. Kalas, & R. T. Mittermeir (Hrsg.), Informatics in Schools (S. 94-105). Heidelbert: Springer.

Caine, R., & Caine, G. (2001). Caine Learning Center. Retrieved May 7, 2012 from Overview of the Systems Principles of Natural Learning: www.cainelearning.com/files/Summary.pdf

Cliburn, D. C. (2006). The Effectiveness of Games as Assignments in an Introductory Programming Course. Proceedings of 36th ASEE/IEEE Frontiers in Education Conference.

Csikszentmihalyi, M. (1996). Creativity: Flow and the Psychology of Discovery and Invention. New York: Harper Collins.

Geake, J. G. (2009). The brain at school: Educational neuroscience in the classroom. Berkshire, New York: Open University Press.

Green, C. S. (2012). Research. Retrieved May 7, 2012 from http://vision.psych.umn.edu/users/csgreen/Research/research.html

Green, C., & Bavelier, D. (2006). The Cognitive Neuroscience of Video Games. (P. &. Messaris, Hrsg.) Retrieved May 7, 2012 from http://vision.psych.umn.edu/users/csgreen/Publications/csg_CNofVGP.pdf

Hays, R. T. (2005). Defense Technical Information Center. The Effectiveness Of Instructional Games: A Literature Review And Discussion. Retrieved May 7, 2012 from http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA441935%26Location=U2%26doc=GetTRDoc.pdf

Hielscher, M. (2006). AtoCC Projekt. AutoEdit. Retrieved May 7, 2012 from http://www.michael-hielscher.de/cgi-bin/atocc/site.cgi?lang=de&site=main

Hopcroft, J., & Ullman, J. (1979). Introduction to Automata Theory, Languages, and Computation. USA: Addison-Wesley.

Jensen, E. (2008). Brain-based learning: The new paradigm of teaching. Thousand Oaks: Corwin Press.

Kirriemuir, J., & McFarlane, A. (2004). Literature Review in Games and Learning. Retrieved May 7, 2012 from Telearn: http://telearn.archives-ouvertes.fr/docs/00/19/04/53/PDF/kirriemuir-j-2004-r8.pdf

Mittermeir, R. T., Bischof, E., & Hodnigg, K. (2010). Showing Core-Concepts of Informatics to Kids and Their Teachers. Teaching Fundamentals Concepts of Informatics 4th International Conference on Informatics in Secondary Schools - Evolution and Perspectives, ISSEP 2010. Proceedings, (S. 143-154). Zurich, Switzerland.

Paras, B., & Bizzocchi, J. (2005). Game, Motivation, and Effective Learning: An Integrated Model for Educational Game Design. Proceedings of DiGRA 2005 Conference: Changing Views – Worlds in Play. Vancouver.

Prensky, M. (2001). Fun, Play and Games: What Makes Games Engaging. In M. Prensky, Digital Game-Based Learning (S. 05/1-05/31). California: McGraw-Hill.

Roth, G. (2009). Warum sind Lehren und Lernen so schwierig? In U. Herrmann, Neurodidaktik: Grundlagen und Vorschläge für gehirngerechtes Lehren und Lernen (S. 58-68). Weinheim, Basel: Belt.

Sabitzer, B. (2011). Informatics + Foreign Language(s) = COOL (Cooperative Open Learning). In: I. Candel Torres, L. Gómez Chova, A. López Martínez (eds.): International Conference of Education, Research and Innovation, ICERI Proceedings. Barcelona: IATED, 1373-1381.

Sabitzer, B. (2011). Neurodidactics: Brainbased Ideas for ICT and Computer Science Education. The International Journal of Learning , 18 (2), S. 167-177.

Sabitzer, B.; Antonitsch P. (2012). Of Bytes and Brain. – Informatics Meets Neurodidactics. In: L. Gómez Chova, I. Candel Torres, A. López Martìnez (eds.): INTED 2012 Proceedings. Barcelona: International Association of Technology, Education and Development (IATED), pp. 2003-2012.

Seay, J. (1997). The effectiveness of games for educational purposes: a review of the research. Retrieved May 7, 2012 from http://seayj.people.cofc.edu/cb/findsim.html?referrer=web cluster&

Sousa, D. A. (2006). How the brain learns. Thousand Oaks: Corwin Press.

van Eck, R. (March/April 2006). Digital Game-Based Learning: It's Not Just the Digital Natives Who Are Restless. EDUCAUSE Review , vol. 41, no. 2, S. 16-30.

Weisberg, R. W. (1988) Problem solving and creativity. In: Sternberg, R. J. (ed.): The Nature of Creativity: Contemporary Psychological Perspectives. Cambridge University Press.

Wellhousen, K., & Crowther, I. (2004). Creating Effective Learning Environments. New York: Thomson Delmar Learning.

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