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Dipole Radiation – Multiple Visual Representations to Assist Learning

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Abstract. The Hertzian Dipole is a standard topic for lectures in physics. It points to the fundamental mechanism that is responsible for electromagnetic radiation. Understanding the Hertzian Dipole is the first step toward understanding toward understanding the physics behind different antenna types, such as half-wave antennas and other types. But it is not easy to discuss the spatial and time-dependent behaviour.
Suitable illustrations and animations showing the formation of electromagnetic waves can help for teaching and learning. Moreover, a combination of multiple graphical representations can bring to light the relationships between different aspects. An HTML5-applet was written, specifically to illustrate dipole radiation. The program "DipoleRadiation" is designed to make aspects of electromagnetic radiation visible that cannot be seen directly.
In an explorative pilot study students were interviewed to find out more about their problems. Furthermore, an eye-tracker study was carried out to identify, what learners focussed on. First findings revealed some gaps in knowledge. Among them are a simple lack of prior knowledge, misunderstanding of models, invisible features, spatial imagination, and the ability to identify important details and abstractions from the superficial.

1. Introduction and theory

1.1. The content

Dipole antennas are the simplest and most widely used type of antenna to introduce the concept of dipole radiation. Understanding the Hertzian Dipole is the first step toward understanding half-wave antennas and other types of antennas. The so called “ideal dipole” was discussed in 1888 by Heinrich Hertz as a part of his pioneering investigations into radio waves.
However, the equations for the electric and magnetic fields are not simple. Thus, it is not easy to explain the spatial and time-dependent behaviour to students. Working with mathematical equations, such the one below, is highly limiting in that sense.

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\left(-\frac{\ddot{\vec{p}}}{c^2 r} - \frac{\dot{\vec{p}}}{cr^2} + \frac{3\left(\dot{\vec{p}}\cdot\vec{r}\right)\cdot\vec{r}}{cr^4} + \frac{\left(\ddot{\vec{p}}\cdot\vec{r}\right)\cdot\vec{r}}{c^2 r^3} + \frac{3(\vec{r}\cdot\vec{p})\vec{r}}{r^5} - \frac{\vec{p}}{r^3}\right)$$

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$$\vec{H} = \frac{1}{4\pi}\left(\frac{\ddot{\vec{p}} \times \vec{r}}{cr^2} + \frac{\dot{\vec{p}} \times \vec{r}}{r^3}\right) \quad \text{with} \quad \vec{p} = \vec{p}\left(t - \frac{r}{c}\right)$$

Multimedia tools can assist in teaching and learning about dipole radiation, and can offer a valuable supplement to aid into the understanding of how electromagnetic waves are generated. More than ever additional help is important for Physics in schools (as in Bavaria, where a qualitative discussion of dipole radiation is part of the curriculum). Thus, our goals are:

- Students should get a correct mental image of the radiation pattern and the spreading electromagnetic field;
- the generation of closed loops of field lines should be known as a characteristic feature;
- an adequate knowledge representation of the fact that field lines of ***E*** and ***H*** are oriented perpendicular to one another should be created; three dimensional pictures and animations should be used;
- characteristic differences between the so called "near field" and the "far field", including the changing phase relationship between ***E*** and ***H*** should be recognised;
- knowledge about the flow of energy, described by Poynting vectors should be acquired;
- students know differences between half wave antenna and the Hertzian dipole radiation;
- students should get insights about procedures how to draw electric field lines.

1.2. Dynamic illustrations

To show time-depended behaviour and the changes over time, animations are a suitable tool. They offer attractive illustrations of scientific phenomena and processes. Animations can vividly present events which change over time. According to theoretical considerations from psychology of learning animated illustrations should have a clear intrinsic superiority over static visuals if they portray change over time [1], [2]. Also Ng, Kalyuga & Sweller (2013) found an inherent advantage of animations over static graphs when presenting dynamic content [3].

Nevertheless, the higher effectiveness of animated presentation compared to static visualizations is not generally evident [5], and research on learning effects of animations did not result in conclusive findings (e.g. [4], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19]). Prior knowledge as well as individual abilities have an influence, and information is only available for a limited time span. Cognitive load can become a problem when using animations about complex subject matters. As a result, Wouters, Paas & Merriënboer (2008) specified the following guidelines. Firstly, overall complexity must be limited. Secondly, activities that obstruct learning must be prevented. Finally, learners should be engaged in active and relevant processing of a given subject matter [20]. Furthermore Ryoo & Linn (2013) point to the value of prompting students to generate explanations [4]. Several design criteria for additional information have to be considered.

Thus, a combination of static visuals and animations, backed by additional information and learning tasks sounds promising, and will be implemented here.

1.3. Multiple Representations

In particular for complex subject contents, multiple representations are a means to reveal different important perspectives. Furthermore, this means that essential concepts are based not only on one single form of representation.

According to Savelsbergh et al. (1998), experts use internal representations for problem solving more flexibly than beginners [23]. Kozma (2003) also identified differences between experts and novices. While experts specifically use different representations, novices have difficulties using and linking multiple representations. The considerations and arguments of novices are restricted to superficial characteristics. In addition, novices stick closely to one presentation, while experts use a variety of representations and can switch between them easily. They also use them with different intentions, to improve their own thinking about the content and to communicate with other scientists [24].

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Thus, three possible reasons for using multiple representations are:

- Specific information can be best communicated in specific representations.
- Differing representations can set different accents.
- Availability of several representations supports cognitive flexibility.

It is essential that learners see connections between multiple representations and the subject content. Only the availability of various representations enables building a comprehensive knowledge structure.

Such integration processes have been examined by Seufert (2003) [27]. She distinguishes between the following two types: The first type concerns the construction of links between different elements, while the representation remains the same (e.g. linking of iconic representations). The second type deals with representations in certain forms and compares them with corresponding relationships in another form (links between different types of representation).

The combination of multiple graphical representations can focus on relations between different aspects, e.g. between a field distribution and its corresponding flow of energy. According to Ainsworth (1999) multiple representations can "provide complementary information", "constrain possible (mis)interpretations" that arise from one illustration in the use of another, and help learners to "construct a deeper understanding" [28].

2. Concept and Implementation

An HTML5-application was designed to provide dynamic illustrations in order to visualise characteristics of dipole radiation. It is even suitable for smartphones, and can be used in lectures as well as by individual studies. Static pictures and/or animations elucidate the development of electromagnetic waves. Several types of images are used to highlight different features of dipole radiation. They can clarify what is included in the mathematical equations and illustrate some of the essential characteristics of electromagnetic fields more evidently. Spatial characteristics, temporal progress, and relations between different aspects can vividly be displayed.

The implemented visualizations are listed below and give an overview of what the students had to work with.

2.1. Structure of the electromagnetic field

The radiation pattern is displayed using field lines in two and three-dimensional drawings (see figure 1 and figure 2). Zooming in and out, it is possible to show one or more wavelengths. Dynamic presentations (animations) as well as static pictures are available via mouse or finger-tips. They are intended to give impressions of the distribution in space and also of the temporal characteristics of starting electromagnetic waves (via animated visuals).

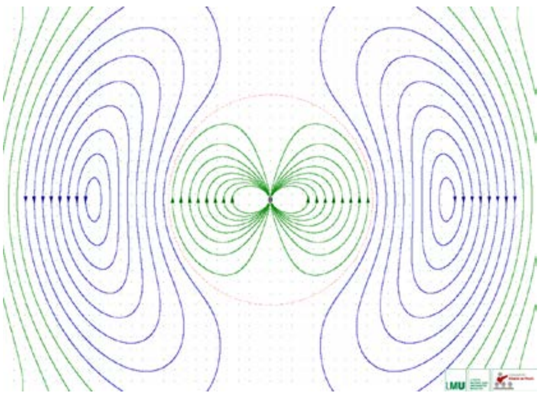

Figure 1. Snapshot of field lines of a Hertzian dipole

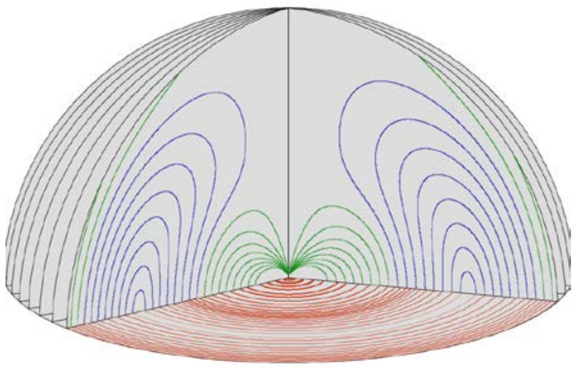

Figure 2. Electric field lines with the magnetic field in the equatorial plane (perpendicular to the electric field lines)

Watching a whole period also shows the detachment of field lines and the generation of closed loops, which is not possible in electrostatics (see figure 3 and figure 4).

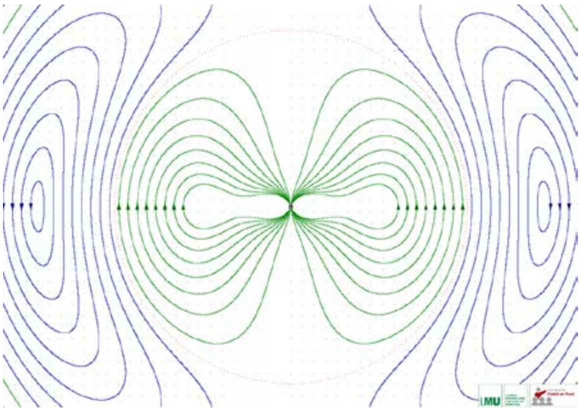

Figure 3. Electric field lines starting from the dipole and already closed loops detached from the Hertzian dipole.

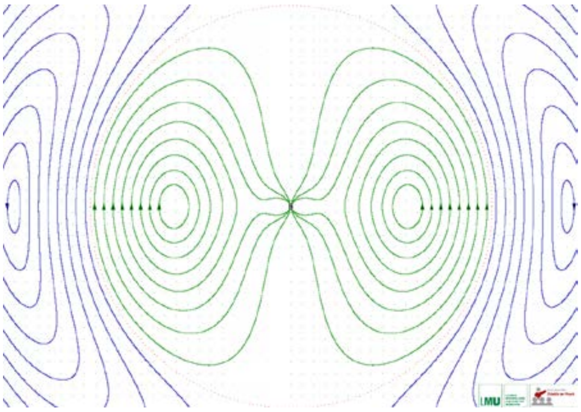

Figure 4. Electric field lines one twelfth of a period later.

2.2. Changes with increasing distance from the dipole

How strong is the electric field in the equatorial plane? This is shown in a special animation. A line graph shows how the strength of the field decreases with increasing distance (see figure 5). To make it easier to connect this to the illustration above a combination of two different graphical representations is used. The allocation where the field is zero at a certain moment is evident.

Also, figure 6 combines multiple representations. The electric and magnetic field and the phase relation for the equatorial plane is displayed.

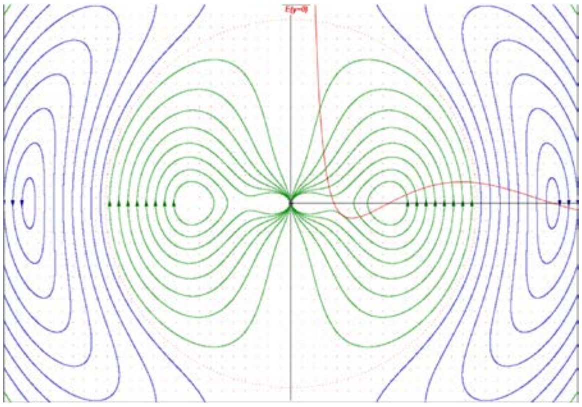

Figure 5. A line graph and field lines are combined to give an impression of the development of the electric field with distance from the dipole (a snapshot).

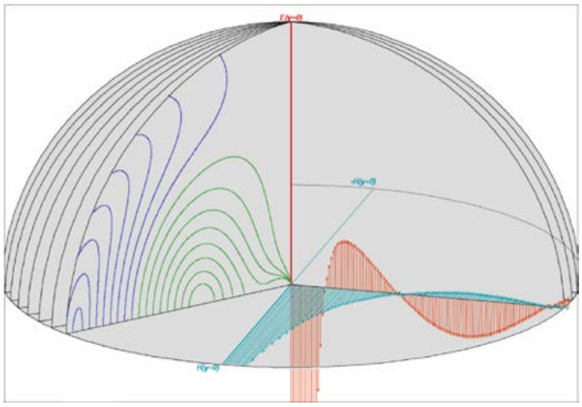

Figure 6. Line graphs and field lines are used to show relations, especially the phase relation, between the electric and magnetic field in the so called near zone.

While different representations help users to take into account different aspects of a topic, the informative value of the representations has to be explained to unexperienced learners.

2.3. Flow of energy

As is seen in figure 6 the phase shift between ***E*** and ***H*** is 90 degrees close to the dipole. But there are no differences in phase at greater distances. This can be explained by Lenz's Law or, more

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interestingly from a physicist's point of view, by looking at the flow of energy. The Poynting-vector reveals the meaning of phase relations.

$$\vec{\boldsymbol{S}} = \vec{\boldsymbol{E}} \times \vec{\boldsymbol{H}}$$

If there is a phase shift between $\boldsymbol{E}$ and $\boldsymbol{H}$, the Poynting vector will flip to the negative direction at a certain time. The consequence is that the flow of energy changes its direction. This is illustrated in figure 7 and figure 8. The flow of energy is shown by arrows, symbolizing Poynting vectors. Colours from blue (weak) to red (strong) indicate the magnitude, and the directions of the arrows show the momentary energy flux.

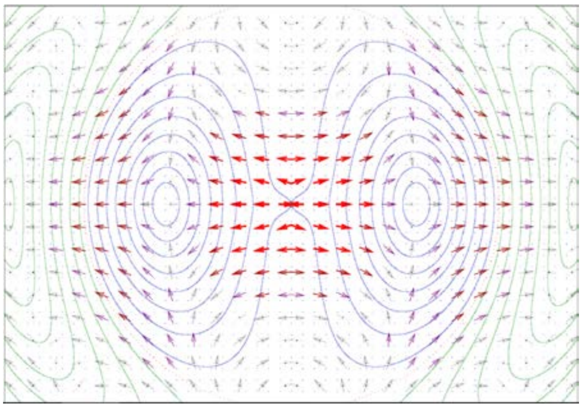

Figure 7. The energy flux is shown. To show relations between different representations, electric fields lines are displayed in a transparent overlay.

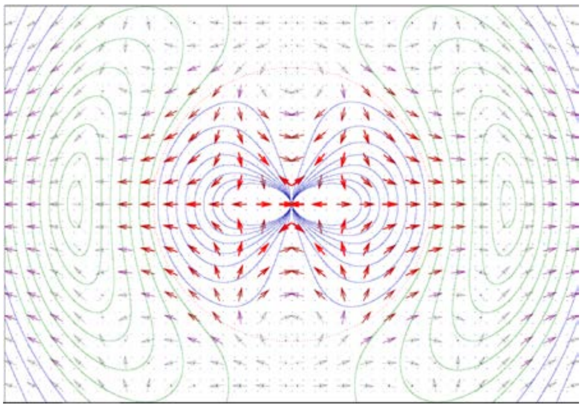

Figure 8. The energy flux sometimes points back towards the dipole (only in the near field zone).

2.4. Half wave dipole in contrast to a Hertzian dipole

A half wave dipole, the classic radio dipole antenna, can be seen as a sum of many Hertzian dipoles. This is also the basic framework for numerical calculations. In the so called near field, there are major differences between the ideal Hertzian dipole and a half-wave-dipole. However, those differences become smaller with increasing distance (see Figure 9 and Figure 10).

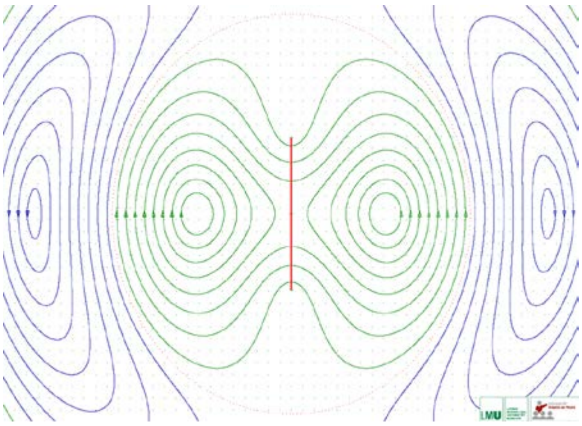

Figure 9. Electric field lines of a half wave dipole in the near field.

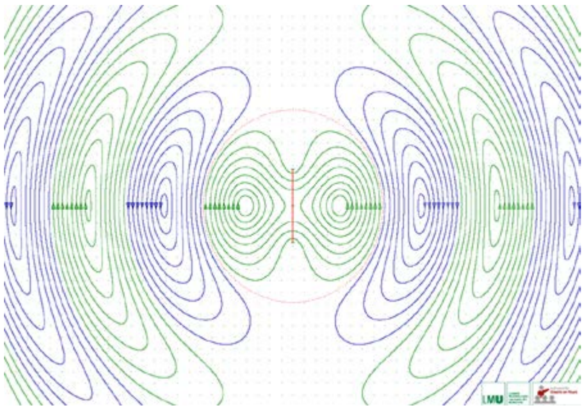

Figure 10. Electric field lines of a half wave dipole for a wider range.

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3. Learning Studies and Assessment

The subject content is not easy to understand, even for university students. Thus, a first explorative pilot study was carried out to identify the obstacles for students when learning about dipole radiation. The intention is to find guidelines for additional help and for the design of adaptable worksheets. The derived teaching strategies will then be compared, and further tests will help to get empirical evidence for what is effective for learning. Here, for the first insights, several methods were applied to get information from university students.

Twenty students from Ludwig-Maximilians-University Munich participated in the study. All students had passed experimental introductory courses in mechanics, electrodynamics and thermodynamics. Only a few already had passed a course in the theory of electrodynamics.

3.1. Methods

A multiple-choice test, interviews and eye-tracking methodology were chosen to assess students' factual understanding of the illustrations of Hertzian Dipole, learning difficulties with the program, and visual attention.

3.1.1. Test of factual knowledge and interviews

20 students completed the written multiple-choice test. The test consisted of 18 questions. All questions included an illustration from the learning program (see figure 11).

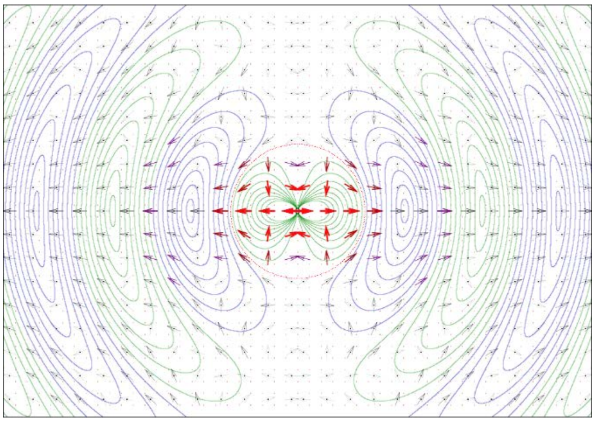
		The arrows show the...
		direction of the energy flux density.
		direction of the electric field vector.
		direction of the magnetic field vector.
		direction of the electric dipole moment vector.

Figure 11. Sample knowledge question from the multiple-choice test.

Nine students were interviewed in detail to get a list of what they thought caused problems when learning with the presented program and its illustrations.

3.1.2. Eye-tracker-studies

An eye-tracker was used to register computer activities and the eye movements of several subjects. It helped to identify whether students selected proper presentations and whether they focused on areas with essential information.

3.1.3. Communicative Validation

Striking events were noticed. Then their classification was discussed together with the subject and with another evaluator. Only a set of frequent occurrences with a consistent interpretation were used for defining the categories of problems which will be described in the subsequent section.

3.2. Findings

The following factors often caused problems:

- Prior knowledge which is transferred in an inappropriate way (e.g. Many students falsely believe that electric fields can never form closed loops, since this is as concept that is applied in electrostatics).
- Misunderstanding of models because of confusing features (the Hertzian dipole is only an infinitesimal small dipole, actually only a dipole vector; field lines cannot be divided into sections with a defined motion speed)
- Properties which cannot be seen directly are not very familiar to students (e.g. the flow of energy is symbolized by discrete Poynting vectors – however there is a complex propagation of a continuum which cannot be seen with naked eyes)
- Spatial visualization (e.g. despite there being several 3D-illustrations, the spatial distribution of electric and magnetic field lines was not always clear)
- Consideration of important details – The illustrations offered a plenitude of spatial information. A cognitive overload is possible, especially when using animated visuals.
- Abstraction from superficial attributes - A selection of important aspects and an abstraction from superficial features is not easy for novices. It takes time to find out what is important and what can be neglected.

4. Conclusions

Multimedia theory helps to design attractive tools for visualisation and illustration of an abstract subject matter like dipole radiation. Nevertheless, students have to understand what is shown. Furthermore, they have to process the presented information, and work-with their new knowledge. To make this effective, common obstacles have to be removed. Several difficulties for learning were found. Based on these findings additional help and auxiliary worksheets will be designed, and their efficacy for learning will be tested.

References

[1] Betrancourt, M. (2005). The animation and interactivity principles in multimedia learning. In R. E. Mayer (Ed.), Cambridge handbook of multimedia learning (pp. 287e296). New York: Cambridge University Press.

[2] Tversky, B., Bauer-Morrison, J., & Bétrancourt, M. (2002). Animation: can it facilitate? International Journal of Human-Computer Studies, 57, 247-262.

[3] Ng, H. K., Kalyuga, S., & Sweller, J. (2013). Reducing transience during animation: a cognitive load perspective. Educational Psychology, 33(7), 755-772.

[4] Ryoo, K., & Linn, M. C. (2014). Designing guidance for interpreting dynamic visualizations: Generating versus reading explanations. Journal of Research in Science Teaching, 51(2), 147-174.

[5] Brucker, B., Scheiter, K., & Gerjets, P. (2014). Learning with dynamic and static visualizations: Realistic details only benefit learners with high visuospatial abilities. Computers in Human Behavior, 36, 330-339.

[6] Park, O.-C., Hopkins, R (1993) Instructional conditions for using dynamic visual displays: a review. Instructional Science. 21, 427-449.

[7] Rieber, L. P. (1994) Computers, graphics, & learning. Dubuque, IA: Brown & Benchmark.

[8] Mayer, R. E., & Anderson, R. B. (1992) The Instructive Animation: Helping Students Build Connections Between Words and Pictures in Multimedia Learning. Journal of Educational Psychology. 84(4), 444-452.

[9] Dahlqvist, P., (2000) Animations in Physics Learning. In Proceedings of MSET, Mathematics/Science, Education and Technology (ed. R. Robson). San Diego. Retrieved 20/4/05 from http://www.dsv.su.se/~patricd/Publications/Animations_in_Physics_Learning.pdf

[10] Steinberg, R. N. (2000). Computers in teaching science: To simulate or not to simulate? Phys. Educ. Res., Am. J. Phys. Suppl. 68 (7), 37–41
[11] Bétrancourt, M. & Tversky, B. (2000). Effect of computer animation on users' performance: A review. Travail Humain, 63(4), 311-329.
[12] Mayer, R. E. & Moreno, R. (2002). Animation as an Aid to Multimedia Learning. Educational Psychology Review, Vol. 14, No.1, March 2002, 87-99
[13] Bogacz, S., Trafton, G. J. (2002). Understanding Static and Dynamic Visualizations. In M. Hegarty, B. Meyer, N. H. Narayanan (Eds.): Diagrammatic Representation and Inference, Second International Conference, Diagrams 2002, Callaway Gardens, GA, USA, April 18-20, 2002, Proceedings. Lecture Notes in Computer Science 2317 Springer 2002, 347-349.
[14] Lewalter, D. (2003) Cognitive strategies for learning from static and dynamic visuals. Learning and Instruction 13, 177-189.
[15] Lowe, R. K. (2003) Animation and learning: selective processing of information in dynamic graphics. Learning and Instruction. 13, 157-176.
[16] Höffler, T. N., & Leutner, D. (2007). Instructional animation versus static pictures: a meta-analysis. Learning and Instruction, 17, 722-738.
[17] Mayer, R. E. (2009). Multimedia Learning (2nd ed.). New York: Cambridge, University Press.
[18] Mayer, R. E. (2010). Unique contributions of eyetracking research to the study of learning with graphics. Learning and Instruction, 20, 167–171.
[19] Meyer, K., Rasch, T., & Schnotz, W. (2010). Effects of animations speed of presentation on perceptual processing and learning. Learning and Instruction, 20, 136–145.
[20] Wouters, P., Paas, F., & van Merriënboer, J. J. (2008). How to optimize learning from animated models: A review of guidelines based on cognitive load. Review of Educational Research, 78(3), 645-675.
[21] Bétrancourt, M. & Tversky, B. (2000). Effect of computer animation on users' performance: A review. Travail Humain, 63(4), 311-329.
[22] Ainsworth, S. (1999). The functions of multiple representations. Computers & Education 33, 131 – 152.
[23] Savelsbergh, E. R., De Jong de, T. & Ferson-Hessler M. G. M. (1998). Competence-Related Differences in Problem Representations: A Study of Physics Problem Solving. In M. W. van Someren, P. Reimann, H. P. A. Bushuzien & T. De Jong (Eds.). Learning with Multiple Representations. Amsterdam: Pergamon, 263 - 282.
[24] Kozma, R. (2003). The material features of multiple representations and their cognitive and social affordances for science understanding. Learning and Instruction 13, 205 - 226.
[25] Blake, C., & Scanlon, E. (2007). Reconsidering simulations in science education at a distance: features of effective use. Journal of Computer Assisted Learning, 23(6), 491 – 502.
[26] Seufert, T, Brünken, R. (2004). Supporting Coherence Formation in Multimedia Learning. In P. Gerjets, P.A. Kirschner, J. Elen & R. Joiner (Eds.) (2004). Instructional design for effective and enjoyable computer- supported learning. Proceedings of the first joint meeting of the EARLI SIGs Instructional Design and Learning and Instruction with Computers (CD-ROM), 138 - 147.
[27] Seufert, T. (2003). Supporting coherence formation in learning from multiple representations. Learning and Instruction, 13, 227 - 237.
[28] Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. Learning and Instruction, 16, 183 – 198.