Scanning Probe Microscopy concepts for science communication and peer-to-peer education in Open Research Laboratories

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The concept of Open Research Laboratories is based on the idea of running an authentic research laboratory permanently within the public area of a museum or science centre. Such laboratories are installed in order to raise interest about the process of laboratory work or even to communicate aspects of scientific inquiry and scientific reasoning to visitors. Using Scanning Probe Microscopy (SPM) to implement this approach is very beneficial: The results of state-of-the-art research produce attractive images and are fascinating for the general public and pupils due to atomic resolution, three-dimensional visualization and nanomanipulation possibilities of the samples. However, principles of operation of SPMs are less intuitively understandable compared to optical microscopy.

In this contribution we describe the SPM-based concept of the Open Research Laboratory at Deutsches Museum and analyse how the less intuitively understandable operation principle of Scanning Tunnelling Microscopy (STM) and Atomic Force Microscopy (AFM) can be turned into a substantial advantage for science communication and peer-to-peer education programs. We show how explanations and a specifically developed program for young people about the generation, analysis, discussion and interpretation of SPM images and the handling of SPMs can closely be linked with communication of aspects of scientific inquiry and scientific reasoning to the general public and especially pupils. We also present results of evaluation studies of our described SPM-based educational programs.

Keywords: Scanning Probe Microscopy; Scientific Reasoning; Science Communication; peer-to-peer education; Deutsches Museum; Open Research Laboratory

1. Introduction

Science museums have a long history in which they have undergone fundamental changes in their conceptual design, mirroring changing concepts of science in society [1-3]. In accordance with this current debates about science communication with their respective ideas about science in society find repercussions in museum contexts and exhibitions. One example for this is the Centre for New Technologies, an exhibition of the Deutsches Museum in Munich, opened to the public in 2009 and host to the „Open Research Lab", a genuine university lab with a focus on Scanning Probe Microscopy. The concept of Open Research Laboratories is based on the idea of running an authentic research laboratory permanently within the public area of a museum or science center. The scientists working within it do their everyday research work in public, on museum grounds. The laboratory in the Deutsches Museum is located in the permanent exhibition about nano- and biotechnology within the Centre for New Technologies and has a two-fold role: As an authentic research lab as well as an instrument for science communication.

On an international scale, science communication was an important topic in the UK since the mid-eighties, when British Association, Royal Institution and Royal Society 1985 founded the Committee on the Public Understanding of Science (Copus). Germany did only take on this move more than 10 years later, when in 1999 the business community's innovation agency for the German science system (Stifterverband für die Deutsche Wissenschaft) held a symposium about the Public Understanding of Science (PUS). Since these beginnings numerous concepts of and approaches to science communication evolved, not the least driven by criticisms of the original PUS-idea [e.g. 4-9]. It is far beyond the scope of this article to map these varied trains of thought and courses of action; instead this contribution will concentrate on the communication concepts in place in the Centre for New Technologies to embed the communicational and educational activities of the Open Research Lab in its museological context. Instead of competing with one another, forms of science communication with different theoretical frameworks may very well co-exist [10-12] and even be required due to specifics of the science/technology in question and the stage of societal debate [10]. In practice, aspects of different concepts are very likely to mingle with each other [13], as it is true for the Centre for New Technologies as well.

2. Centre for New Technologies at Deutsches Museum

The exhibition on the whole is conceptualized as a forum for discussion and dialogue, as it is expressed in its slogan to deliver "arguments for answers" instead of the answers itself. This is on the one hand incorporated on the level of exhibits: For example "Talking Heads" ask visitors if they should do genetic testing after describing their medical problem[1]. And a Nano-Oracle[2], a series of films in comic-like style, can be questioned about future visions for nanotechnology and will deliver positive and negative scenarios about topics as diverse as immortality, perfect recycling, children made to measure, cheap goods, robots for everybody, food 2.0, clean energy and safe progress to name a few [14]. It is up to the visitors to reflect which future they wish for, though some hints on the feasibility of specific courses of events are given. On the other hand there is a dialogue board at the core of the exhibition, to be seen directly when entering the main hall of the Centre for New Technologies, that allows program formats with different degrees of engagement of participants to take place, e.g. NanoDialogues, Discussion panels, two-way video conferences with research labs or experimental games, in which pupils act as decision makers.

In this regard the conceptualization of the exhibition is in line with the "*dialogic turn*" of science communication: Moving from the classic dichotomy of the scientist informing 'the' public and understanding on part of 'the' public to new forms of communication and a larger diversity of voices and roles for different kinds of publics[3]. Underlying the dialogic turn is a reassessment of the science-society relation, in which science is no longer a world apart and separated from its societal context: Science *in* Society instead of Science *and* Society, acknowledging the huge impact of science in all aspects of our every-day life as well as its effects on global and local levels (even though this is sometimes viewed as merely rhetorical [e.g. 10].

Nevertheless, the introduction of dialogue into the exhibition does not rule out more traditional forms of museum communication such as interactive exhibits, models and objects, all of which you will find in the Centre for New Technologies. Within the exhibition, there is also a heavy emphasis on the museum as a learning centre with two student labs offering programs for school classes on a nearly daily basis in addition to other educational programs for school classes and young people.

Throughout the exhibition and in the work of the different labs making research visible figures as a prominent communication approach, which is for want of a better word still called Public Understanding of Research (PUR). Initially the PUR-initiative began with a focus on *current*, cutting-edge research with its social, ethical and political implications, also described as "*research into the unknown*" ([15], p. 4). Stating the profound impact of current developments in research for "both personal decisions and larger policy issues" ([15], p.3), Field and Powell regarded it central to take up these issues in contrast to "*established science knowledge*" ([15], p. 4), which for them seemed to be the predominant thread in informal science education until then ([15], p. 1). As the term "Public Understanding of Research" suggests, Field's initiative is very similar to the PUS-concept in various aspects, e.g. with regard to the distinctions of experts and public, the focus on enhancement of literacy and understanding instead of participation, and in its expectations to generate continued public support for research instead of opinion-forming or independent contributions of different publics. However, the vital decision to communicate "*unfinished science*" ([1], p. 53) was taken up by several institutions, among them renowned museums as the London Science Museum, the Museum of Science in Boston, the Citè des Sciences et de l´Industrie in Paris and, following in this wake, the Gallery of Research in Vienna [16] and is still very influential. You could probably argue that the essential idea to concentrate on *science-in-the-making* finds continuation as well as enormous expansion in today's ideas about Open Research and Open Science though these ideas are framed completely differently (compare [17]). Regarding the Open Research Lab it would these days be more appropriately named as "Visible Research Lab" or "Dialogic Research Lab" as "Open Research" now refers to forms of participation of "lay" people in the actual research process.

Lewenstein & Bonney [18] introduced a relevant differentiation to the original PUR-concept: They distinguished between PUR approaches with emphasis on *current* research and PUR approaches with emphasis on *processes* of research. Processes of research refer to "the scientific method" ([18], p.64), "processes of inquiry, questioning, evidence gathering, logic and exploration" ([18], p. 64).

[1] http://www.deutsches-museum.de/en/exhibitions/new-technologies/nanotechnology/biotechnology/

[2] http://www.deutsches-museum.de/en/exhibitions/new-technologies/nanotechnology/nanosystems/

[3] It should be noted that the dialogic turn and the move to public engagement with science in itself are still disputed (Stilgoe et al. 2014) and that there are a lot of different opinions what counts as 'real' dialogue or 'real' engagement (Irwin 2008, Stilgoe et al. 2014).

3. The Open Research Laboratory and its SPM-based science communication concepts

Fig. 1 Students doing AFM based research in the public section of the Open Research Lab at Deutsches Museum. The AFM is installed inside an acoustic protection box.

The Open Research Lab in the Deutsches Museum (Fig. 1) operates on both of the aforementioned levels: Visitors can enter a dialogue with scientists in the lab while these are conducting their current research and discuss the relevance of their research projects as well as the social, ethical and policy implications of the "*unfinished science*" of nanotechnology. Instead of mere co-existence this PUR-approach interlocks very well with the fore-mentioned dialogue-orientation as visitors can voice and discuss their concerns, hopes and fears in face-to-face communications with the researchers. A not to be neglected effect of this is an increasing awareness on behalf of the scientists for the social, ethical and political context of their research as visitors tend to ask more questions about these issues than about details of the research of the respective scientist [19]. This might not meet the expectations of the researcher, especially one newly introduced to this kind of lab, for whom these details will be in much sharper focus and represent a much higher proportion of his or her own work.

Open Research Labs in general are installed in order to raise interest about the process of laboratory work or even to communicate aspects of scientific inquiry and scientific reasoning to visitors [20]. Regarding the *processes* of research, the daily works of the laboratory give visitors a chance to observe how an authentic research lab functions and to get an impression of routine tasks of scientists. This makes visible scientific procedures normally hidden away behind closed doors and therefore provides a quite unusual access to the processual part of science-in-the-making. Yet, visitors watching the Open Research Lab and measurements with the Scanning Probe Microscope situated within it will not necessarily inquire, question, gather evidence, use logic or explore in the same way as the scientist in the Open Research Lab does. In a program specifically designed for young people, christened "Be a scientist for a day", the participants themselves are asked to use scientific practices: To work with a Scanning Probe Microscope they need to develop a hypothesis how this instrument functions and to demonstrate this using a model, to explore how the Microscope can be put into operation, to make their own measurements with it and come to conclusions about the samples they analysed. By using the method of inquiry-based learning, the pupils are allowed to implement aspects of a research cycle [21] in an active and as far as possible self-regulated manner. Of course, this in itself might be a very seminal experience for the pupils with regard to scientific processes and therefore a valid approach to the communication of the *making of science*.

Now, why is it beneficial to use SPM as the basic research tool for an Open Research Lab? The key issue of such a laboratory is its authentic character. Thus, real scientific work with current research topics has to be carried out. At the same time, experimental results should be able to attract museum visitors. Experiments which exclusively produce spectra or graphs have less potential to draw visitors' attention compared to images. A promising way to meet the requirements of both authentic, current research and producing attractive experimental results is opening up by using SPM. Instruments such as Scanning Tunnelling Microscopy (STM) and Atomic Force Microscopy (AFM) represent modern analytical technologies used for many different fields of current research in physics, chemistry, biology and materials science. They have the potential to fascinate the general public and pupils due to atomic resolution, nanomanipulation capabilities and the possibilities of three-dimensional reconstruction and visualization of the sample topography [22].

The Open Research Lab at Deutsches Museum was initially planned as a pure PUR approach with emphasis on current research based on SPM. It aims to tap the described potential of STM and AFM for science communication. STM research of the Open Research Lab is based on the effect of Organic Solid/Solid Wetting Deposition (OSWD). This recently discovered effect [22,23] enables to grow supramolecular monolayer of insoluble semiconductor molecules on graphene, graphite or other substrates under ambient conditions and without the need of toxic chemicals. OSWD is used for developing easy and low energy demanding fabrication processes for carbon-based electronics. Therefore, a highly complex STM laboratory to establish e.g. ultra-high vacuum conditions, extremely low temperatures or a sophisticated wet chemistry section is neither necessary nor desirable for this current field of research and thus all steps of sample preparation and STM investigations can be done within the public area of a museum. These advantages make OSWD-based STM investigations highly compatible with the initial PUR approach of the Open Research Lab. The same applies to AFM investigations in the Open Research Lab. Current AFM-based research topics are in the context of restoration and preventive conservation of exhibition pieces of the museum. These investigations can also be done within the public area of the museum and the relevance of the results are instantly comprehensible for museum visitors.

However, while images produced by SPM can be very attractive for visitors, the principles of operation of SPM are less intuitively understandable compared to classical optical microscopy: SPM images are the product of highly sophisticated reconstructions from signals generated e.g. by quantum tunnelling of electrons or by deflections of tiny cantilevers measured by laser beam reflections. This makes the generation, analysis, discussion and interpretation of SPM images as well as the handling of SPM more complex compared to classical optical microscopes.

4. Peer-to-peer education in training AFM operation and scientific reasoning

It seems paradoxical, but the challenge of higher complexity in gaining and interpreting SPM images is very beneficial for PUR approaches with emphasis on processes of research: if intuition and everyday life experience doesn't help very much for achieving proper results, the relevance of basic aspects of scientific inquiry can be communicated more convincingly. As a consequence, the importance of gaining competence in scientific reasoning becomes clearer. We put this benefit into practice by developing an AFM based course for pupils as a peer-to-peer education concept.

The main objective of the course “Be a scientist for a day” is to train pupils on how to systematically become familiar with complex scientific instruments in general (with AFM as an example, see Fig. 2) and to let them experience the relevance of scientific methodology. Instead of giving lectures the course instructors create situations where the participants find the solutions by themselves and apply scientific methods such as “1. observe, 2. describe, 3. interpret” or “classify”.

We chose peer tutoring [24] as educational concept because it is described as “one of the most effective educational interventions” [25]. The primary idea behind this concept is that pupils teach each other. So there are tutors who teach and tutees that are taught. By using this method the focus shifts from the learner to the subject matter. In other words, this concept offers additional chances to learn for both sides. On the one hand, the tutors learn by explaining and answering questions because they have to control, arrange and reflect their knowledge. They also have to deal with the curricular substance regularly. By being asked questions they can control and extend their knowledge. By giving examples, analogies and using a language that is more easily understandable than explanations given by grown-ups, they organize their own knowledge and add new knowledge structures [25]. Tutees, on the other side, show similar social and sociographical characteristics. They learn from their tutors not only about curricular topics but also about social, personal and methodical competencies. In other words the tutors also act as „role models“. In a peer-to-peer course tutors and tutees interact as equals which makes asking questions easier than in a teacher-pupil course because there are no hierarchies. In order for peer-teaching to work however, tutors need to be trained. In doing so, they don't only learn about the subject but also acquire key qualifications as discipline, teamwork, rhetoric and didactic competencies [26].

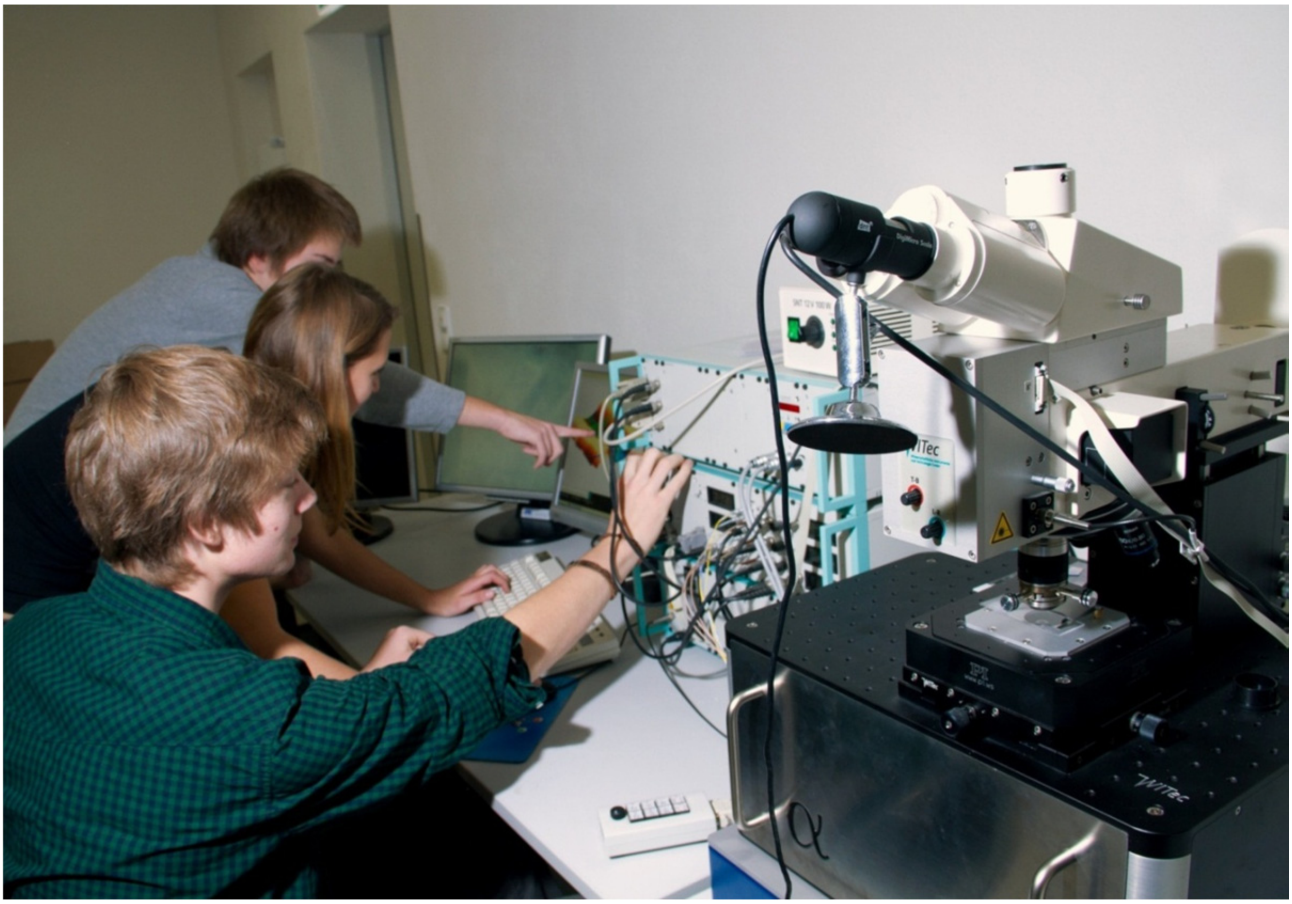

Fig. 2 Pupils in front of an AFM of the Open Research Lab. The image shows a tutor training tutees in operating the AFM during the course "be a scientist for one day".

The instructors (tutors) of the AFM-based peer-to-peer course are trained and supervised by a scientist and an education researcher. The course instructors learn about nanomaterials, how to operate the AFM and about rhetoric. For each course there are two course instructors responsible and they guide the course by themselves. The course itself takes four hours and consists of three parts. At the beginning, before obtaining an introduction into the topic, participants (not more than 4 persons) fill out a questionnaire about nanomaterials The pupils fill out the same questionnaire at the end of the course which on the one hand gives us insight into the amount of knowledge they absorbed and on the other hand provides a good possibility to evaluate our course. Through the introduction into nanomaterials close to everyday life examples, the pupils learn how these materials affect their lives and why they are so important. We also raise awareness of the benefits and risks that come with these materials. Through this process we can show them why research is important. In the second part, which is also the main part, the pupils get to interact with the AFM. The course instructor shows with text, pictures and a model how the microscope works. The participants are expected to take notes so they can subsequently carry out AFM measurement of a CD or DVD by themselves. In the third part the pupils have to analyse their pictures. The course instructor shows the participants how they determine how much memory capacity is available on the CD or DVD.

To pedagogically evaluate the quality of the course and to get an impression of the personal development of the course instructors we used learning protocols. Learning protocols aim to encourage self-regulated learning [27]. Characteristic of learning protocols are the learner's planning, documentation and reflection of their learning activities [28]. This process is called "Self-Monitoring" and is shown in a „cyclical-interactive model [29]. The learning protocol was filled out once a month during a period of 8 months by the course instructors and the evaluation focused on learning motivation, knowledge about scientific inquiry and awareness of didactic knowledge. The qualitative study also examined the acceptance of the learning protocol by the pupils and an evaluation of the peer-to-peer course.

The results of this study indicate that the learning journal had positive effects in all ranges. Particularly the knowledge about scientific inquiry and the awareness of didactic knowledge was significantly improved. However, to get more significant results we recommend a quantitative survey with modified prompts [30].

5. Summary

SPM can be used as an ideal tool for science communication within the context of Public Understanding of Research. In our approach to communicate both *current research* and the *process of research* via the concept "Open Research Lab" we use SPM in two different ways. On the one hand, SPM images are highly capable to draw museum visitor's attention to current research on materials science, surface physics and nanostructures. This helps to initiate discussions between museum visitors and scientists working in the Open Research Lab. On the other hand, the characteristics of SPM are very beneficial for communicating aspects of scientific methodology via peer-to-peer education. A positive pedagogical effect of our AFM-based course "be a scientist for one day" for pupils has been proven by an accompanying social scientific research project. The concept has recently been adopted with only very minor modifications by the Physics Department of the Technische Universität München.

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References

[1] Durant, J. The Challenge and Opportunity of Presenting "Unfinished Science". In: Chittenden D, Farmelo G, Lewenstein BV, editors. Creating Connections: Museums and the Public Understanding of Research. Walnut Creek :Altamira Press; 2004. p. 47-60.
[2] Graf B, Noschka-Roos A. Lernen im Museum. Oder: Eine Kamerafahrt mit der Besucherforschung. Zeitschrift für Erziehungswissenschaft.. 2009; 12:7-27.
[3] Schiele B. Science museums and science centres. In: Bucchi M, Trench B, editors. Handbook of public communication of science and technology. London & New York: Routledge; 2008. p. 27-39.
[4] Felt U, Nowotny H, Taschwer K. Wissenschaftsforschung: eine Einführung. Frankfurt a. M., New York: Campus; 1995.
[5] Gregory J, Miller S. Science in Public. Communication, Culture, and Credibility. New York: Plenum Press; 1998.
[6] Hilgartner S. The Dominant View of Popularization: Conceptual Problems, Political Uses. Social Studies of Science. 1990; 20:519-539.
[7] Irwin A, Wynne B. Misunderstanding science? The public reconstruction of science and technology. Cambridge: Cambridge University Press; 1996.
[8] Miller S. Public Understanding of Science at the crossroads. Public Understanding of Science. 2001; 10:115-120.
[9] Wynne B. Public Understanding of Science. In: Jasanoff S, editor. Handbook of Science and Technology Studies. Thousand Oaks: Sage; 1995. p. 361-388.
[10] Bucchi M. Of deficits, deviations and dialogues: theories of public communication of science. In: Bucchi M, Trench B, editors. Handbook of public communication of science and technology. London & New York: Routledge; 2008. p. 57-76.
[11] Bucchi, M. Style in science communication. Public Understanding of Science. 2013; 22:904-915.
[12] Irwin A. Risk, science and public communication: third-order thinking about scientific culture. In: Bucchi M, Trench B, editors. Handbook of public communication of science and technology. London & New York: Routledge; 2008. p. 199-212.
[13] Lewenstein BV. Changing our ideas. International Journal of Science Education, Part B: Communication and Public Engagement. 2011; 1:17-21.
[14] Breitsameter F. Das Nano-Orakel. In: Breitsameter F, Hauser B, editors. Nano- und Biotechnologie im Zentrum Neue Technologien, München: Deutsches Museum; 2009.
[15] Field H, Powell P. Public Understanding of Science versus Public Understanding of Research. Public Understanding of Science. 2001; 10:421-426.
[16] Yaneva A, Rabesandratana TM, Greiner B. Staging scientific controversies: a gallery test on science museums' interactivity. Public Understanding of Science. 2009; 18:79-90.
[17] Grand A, Wilkinson C, Bultitude K, Winfield AFT. Open Science: A New „Trust Technology"? Science Communication. 2012; 34:679-689.
[18] Lewenstein BV, Bonney R. Different Ways of Looking at Public Understanding of Research. In: Chittenden D, Farmelo G, Lewenstein BV, editors. Creating Connections: Museums and the Public Understanding of Research. Walnut Creek :Altamira Press; 2004. p. 63-71.
[19] Hix P, Schüßler P, Trixler F. Kommunikation des Forschungsalltags: Das Gläserne Labor im Deutschen Museum. In: Dernbach B, Kleinert C, Münder H, editors. Handbuch Wissenschaftskommunikation. Wiesbaden: Springer VS Verlag; 2012. p. 133-139.
[20] Brunner M, Gast N, Heckl WM, Trixler F. Scientific research in a public environment: benefits for science and communication. International Conference on Science Communication JHC2012. 2012; A24, p. 14-16. [cited 2014 May 11]. Available from: http://www.jhc2012.eu/images/partenaires/brunner.pdf
[21] Mikelski-Seifert S, Duit R. Naturwissenschaftliches Arbeiten. *PIKO-Brief Nr. 6*. 2010. [cited 2014 May 11]. Available from: http://www.ipn.uni-kiel.de/projekte/piko/pikobriefe032010.pdf
[22] Trixler F, Heckl WM. Various approaches to control solid/solid wetting self-assembly of organic semiconductors with STM. In: Mendez-Vilas A, Diaz J, editors. Modern research and educational topics in microscopy. Badajoz: Formatex; 2007. p. 534-541.
[23] Trixler F, Markert T, Lackinger M, Jamitzky F, Heckl WM. Supramolecular self-assembly initiated by solid-solid wetting. Chem. Eur. J. 2007; 13 (27), p. 7785-7790.
[24] Gartner A. Children teach children; learning by teaching (1st ed.). New York: Harper & Row; 1971.
[25] Roscoe RD, Chi MTH. Tutor learning: the role of explaining and responding to questions. Instructional Science. 2008; 36:321-350.

[26] Geyer C. Museums-und Science-Center-Besuche im naturwissenschaftlichen Unterricht aus einer motivationalen Perspektive: die Sicht von Lehrkräften und Schülerinnen und Schülern. Berlin, Logos; 2008.
[27] Nückles M, Hübner S, Glogger I, Holzäpfel L, Schwonke R, Renkl A. Selbstreguliert lernen durch Schreiben von Lerntagebüchern. In: Gläser-Zikuda M, editor. Lerntagebuch und Portfolio aus empirischer Sicht. Landau: Empirische Pädagogik e.V; 2010. pp. 35–58.
[28] Ziegelbauer S, Noack J, Gläser-Zikuda M. Förderung von Lernkompetenz auf der Grundlage des Portfolioansatzes. Zeitschrift Für Didaktik Der Naturwissenschaften. 2010; 19:355-359.
[29] Nückles M, Hübner S, Renkl A. Enhancing self-regulated learning by writing learning protocols. Learning and Instruction. 2009; 19:259-271.
[30] Brunner, M. Das Lerntagebuch als Förderinstrument bei tutoriellen Lernumgebungen im außerschulischen Kontext. Ludwig-Maximilians-Universität, München. 2013.

