Science Education
Review Letters

Teaching Patterns of Scientific Inquiry: A Video Study of Chemistry Lessons in Germany and Sweden

Jaana Björkman[a*] and Rüdiger Tiemann[a]
[a] Department of Chemistry, Chemistry Education, Humboldt-Universität zu Berlin, Berlin, Germany

[*] Corresponding author: jaana.bjoerkman@chemie.hu-berlin.de

Received 17th December 2012, Accepted 5th March 2013

Abstract
Despite the central role of *Scientific Inquiry* within science education, this topic is rarely focused upon during science lessons in Germany. A comparison with a school system that emphasises *Scientific Inquiry* in a stronger way (such as the Swedish system) would enable the identification of culture-specific teaching patterns in terms of the instruction of *Scientific Inquiry*. For this reason, such a comparison has been made within this study.
This study has been undertaken as a low- and middle-inferent video analysis. The study provides information concerning culture-specific teaching patterns in Germany and Sweden on the level of general (organisational) teaching processes and of the phases of *Scientific Inquiry*. The study was carried out with ten German und nine Swedish video-recorded chemistry lessons. The results, presented in this paper, show that German chemistry lessons are organised in a more product-oriented way than the Swedish chemistry lessons.

Keywords
Scientific Inquiry, video study, international comparison, Chemistry Education

Framework

Today one of the most important goals in science education is to provide basic scientific understanding – *Scientific Literacy* – in terms of socially and politically relevant issues. This enables students to participate critically in the discussion of these issues (e.g. Sadler & Zeidler, 2009; Gräber & Nentwig, 2002; DeBoer, 2000). The concept of *Scientific Literacy* not only focuses on the acquisition of technical skills, but also on abilities such as methodological, problem solving and evaluation skills. Within the ability of problem solving the central dimension – *Scientific Inquiry* – plays an essential role (Chen & Klahr, 2008; Mayer, 2007; Simon, Langley, & Bradshaw, 1981).

Scientific Inquiry, which illustrates one kind of the *Scientific Thinking* (Mayer, 2007), consists of five major stages (e.g. Hofstein, 2004; NRC, 2012):

1) Formulation of scientific questions
2) Formulation of hypotheses
3) Planning of investigations
4) Performing of investigations
5) Analysis of the survey data

A lot of different international studies investigated and recommended the instruction of *Scientific Inquiry* (e.g. Anderson, 2002; Furtak, 2006; Gyllenpalm, Wickman, & Holmgren, 2010; Minner, Levy, & Century, 2010), but the question if and how *Scientific Inquiry* is really implemented within science classroom situations has been considered infrequently.

Up to now, culture-specific teaching patterns in science education were mostly investigated in large-scale studies such as the TIMSS Video Study (Stigler, Gonzales, Kawanaka, Knoll, & Serrano, 1999). The investigation of teaching patterns in terms of *Scientific Inquiry* occurred mostly within German physics education. So, Reyer (2004) was able to show that in the 8th and 9th grade in grammar school classes the process of *Scientific Inquiry* occupies less than 10% of science lessons, although the five steps of this process have a central meaning in science education (Hofstein, 2004; Höttecke, 2001; NRC, 2012). Furthermore, experiments in physics lessons are not often integrated within *Scientific Inquiry* (Tesch & Duit, 2004). These results point to an increased need for research on *Scientific Inquiry* in other science subjects.

In order to get an enhanced impression of how *Scientific Inquiry* is taught, investigations of teaching processes have to be initiated. To compare the organisation and the way of instruction of *Scientific Inquiry*, a comparison of a country with a stronger emphasis on *Scientific Inquiry* (for example within the curriculum) is necessary. Internationally, there are considerable differences in the integration of the concept of *Scientific Inquiry* into different school systems (Strobl, 2008). There are European countries such as Sweden which integrated this concept much earlier into their curricula than Germany (Kungliga Skolöverstyrelsen [Royal National Board of Education], 1955; Skolverket [The Swedish National Agency for Education], 2008; Skolverket, 2011). It can be assumed that this difference leads to the identification of different patterns of teaching and learning processes within these countries in general (Seidel, 2003) and in terms of *Scientific Inquiry*.

Purpose & Research Questions

The aim of the project is to analyse the organisation of chemistry lessons in Germany and Sweden in general and in terms of the organisation of *Scientific Inquiry* in chemistry lessons.

The following questions are addressed in the context of this project:

1. What are the general teaching processes in German and Swedish chemistry lessons?

2. How is the process of Scientific Inquiry in chemistry lessons in Germany and Sweden organised?

Design and Methods

To investigate the organisation of general teaching processes and of the process of *Scientific Inquiry* in a holistic way, in the study information concerning national teaching patterns of Germany and Sweden in chemistry have been collected. This descriptive and exploratory study has been designed as a low-and middle-inferent (Gais & Möller, 2006) video analysis. It was done with a convenience sample of videos of German and Swedish chemistry lessons.

Single chemistry lessons of both countries have been video-recorded, where one single lesson takes 45 minutes (in Germany) and 40-60 minutes (in Sweden). The study has been carried out with ten German 10th grade grammar school classes (aged 15/16) in North Rhine-Westphalia and nine Swedish 9th grade primary school classes (aged 15/16) in Växjö and Stockholm. While the German students leave their primary school after the 4th respectively 6th grade to secondary schools (grammar schools are the most academic), Swedish students stay in primary schools until they finish the 9th grade (Möhler, 2008).

In order to answer the research questions, the video-recorded chemistry lessons were analysed on two levels: First, the analysis of the *surface structure* depicts the general organisation of classroom teaching processes such as the *general occurrence of teaching*, the *organisation of classroom interaction* and *instructional phases*, as well as the t*eachers' and students' statements* (Seidel, 2005). Second, the process of *Scientific Inquiry* within the lessons was analysed – on a level of *deep structure* (Table 1). The variables and categories of each coding manual were developed and tested in previous investigations (Seidel, Prenzel, Duit, & Lehrke, 2003; Puhlmann & Tiemann, 2009; Björkman, Labetzki, & Tiemann, 2012).

In order to ensure that the lessons were analysed in an objective and reliable way, the inter-rater reliabilities were calculated by two coders. The German and Swedish videos were analysed with the programme Videograph® (time-sampling method based on 10-second intervals) by one bilingual coder (Rimmele, 2008).

Table 1: Coding variables, categories und reliabilities of the coding manual - general organisation of the teaching process and Scientific Inquiry (Puhlmann & Tiemann, 2009); category "no" is not listed

	Variables	Categories	Reliability (κ)
surface structure	phase of teaching	• initial phase • repetition phase • development phase or new-content phase • consolidation phase • application phase • other activities	.73
	teaching method	• teacher talk • class discussion • independent seatwork • student presentation	.81
	social form	• frontal teaching • individual work • partner work • group work	.85
deep structure	*Scientific Inquiry*	• formulation of research question • formulation of hypothesis • planning an investigation • performing an investigation • analysis of survey data • other classroom activities	.91

The reliabilities were calculated in a previous study (Puhlmann & Tiemann, 2009) in which the bilingual coder was involved as well to verify the inter-rater reliabilities. 10 % of the videos were double-coded, which is sufficient for the calculation of inter-rater reliabilities (Blömecke, Eichler, & Müller, 2004). Table 1 shows that the instruments represent reliable video analysing tools, because of their satisfactory values (very good reliabilities: $.75<\kappa<1.0$; satisfactory reliabilities: $.60<\kappa<.75$) (Wirtz & Caspar, 2002).

To identify significant differences within the German and Swedish lessons and between each category, the relative frequencies first have been tested for normal distribution. The T-test was used (Bortz & Döring, 2005), if normal distribution was given, if not, the Wilcoxon-test was used (Bortz, 2005).

Results

The results of this video study give first impressions of how chemistry lessons are organised in Germany and Sweden. The videos were evaluated with the above-mentioned coding manual (Table 1). In the following part, first the typical organisation of German and Swedish chemistry lessons in general (Table 2) will be described and second its organisation of the process of *Scientific Inquiry*.

A typical German chemistry lesson can be characterised by a short *initial* (1,8 %) and *repetition phase* (3,2 %) and a longer *consolidation phase* (6,0 %). The *development phase* (83,4 %) represents the longest part of the lessons, in which new content is taught. It is mostly dominated by *independent seatwork* (41,4 %) and *class discussion* (32,2 %). Frontal teaching social forms (*class discussion* (32,2 %) and *teacher talk* (18,6)) occur most of the time. In general, *class discussion* (35,8 %) represents a very dominant teaching method with the German chemistry lessons.

In contrast to Germany, the Swedish chemistry lessons are characterised by a short *initial phase* (0,5 %) but a longer period of *repetition* (9,2 %) and *other activities* (11,2 %) such as organisational instructions. The *development phase* (73,3 %) is mostly dominated by the *independent seatwork* (74,1 %) (initiated in *group work* (74,1 %)) and *teacher talk* (22,2 %).

However, the calculations with the means of classical test theory did not reveal significant differences.

Finding descriptive differences within the general organisational teaching processes in Germany and Sweden, divergences within the deep structure on the level of *Scientific Inquiry* can be assumed as well. The results in Figure 1 & 2 show the average duration of the phases

Table 2: Differences within general organisation of the teaching process (sorted by relative frequency [%]; listed are the three most frequent categories).

	Variables	Germany	Sweden
general organisation of whole chemistry lessons	teaching phases	1. development phase (83,4) 2. consolidation phase (6,0) 3. other activities (5,7)	1. development phase (73,3) 2. other activities (11,2) 3. repetition phase (9,2)
	teaching methods	1. class discussion (35,8) 2. independent seatwork (33,4) 3. teacher talk (18,37)	1. independent seatwork (42,6) 2. teacher talk (27,75) 3. class discussion (19,9)
general organisation within development phase	teaching methods	1. independent seatwork (41,4) 2. class discussion (32,2) 3. teacher talk (18,6)	1. independent seatwork (74,1) 2. teacher talk (22,2) 3. class discussion (3,8)
	social form	1. frontal teaching (51,8) 2. group work (43,8) 3. individual work (3,2)	1. group work (74,1) 2. frontal teaching (25,9) 3. ---

of *Scientific Inquiry* in German and Swedish chemistry lessons.

Analysing the process of *Scientific Inquiry* (Table 1) it becomes apparent, that the phases of the *formulation of the research question and hypothesis* occur respectively seldom, whereas in Swedish classes the *formulation of hypothesis* lasts significantly longer (Figure 1).

Descriptively the phase of *performing* lasts the longest in both countries.

Beyond, the German chemistry teachers focus significantly longer on the *analysis of the survey data* (Figure 1 & 2), while in contrast, Swedish teachers mostly focus on the *performing phase*. This becomes obvious when the significant differences between each phase are examined. The Swedish teachers get their classes to *perform* investigations significantly longer compared to their *planning* and *analysis phases* (*performing > planning, analysing*), whereas in German chemistry lessons the *performing phase* is not significantly longer than the *analysis phase* (*performing ≈ analysing*), though the *planning phase* is significantly shorter than the *analysis phase* (*planning < analysing*). In summary, the German teachers put the focus on the *performing* and *analysis* of investigations, compared to the Swedish teachers, who focus solely on the *performance phase*.

Discussion

There are three important aspects, which need to be discussed. The first aspect deals with the general organisation of chemistry lessons in Germany and Sweden. On the level of the general organisational teaching phases, the lessons of both countries seem to be quite similar. Analysing the lessons on the level of the teaching method shows that in German chemistry lessons *class discussions* dominate, while in Sweden the *independent group work* and *teacher talk* is more common. Other studies showed similar results for German physics classes (Seidel & Prenzel, 2004). These results give first impressions of the different teaching patterns, which occur within each country.

A second important aspect concerns the phases of formulating *research questions* and *hypotheses*. It occurs that in the Swedish videos hypotheses are formulated significantly more often than in the German ones, but in general, the teachers in both countries initiate the phases of formulating *research questions* and *hypotheses* very rarely. It can be assumed that teachers generally have problems, integrating these phases into their lessons, also in countries with a lot of experiences in the field of *Scientific Inquiry*. It arises from the fact that the teachers often know that their students seem to have difficulties in formulating questions and hypotheses (Hammann, Phan, Ehmer, & Bayrhuber, 2006; Shute & Glaser, 1990; Tschirgi, 1980), also in older ages (Njoo & de Jong, 1993; Tschirgi, 1980), as well as the teachers have themselves no experience in formulating the research questions and the hypotheses (Ozel & Luft, 2011). Additionally the short duration of the formulation of the *research question* and the *hypothesis phases* show that the process of *Scientific Inquiry* with the intended five steps is only partly realised in chemistry lessons in both countries, despite its importance within *Scientific Thinking*.

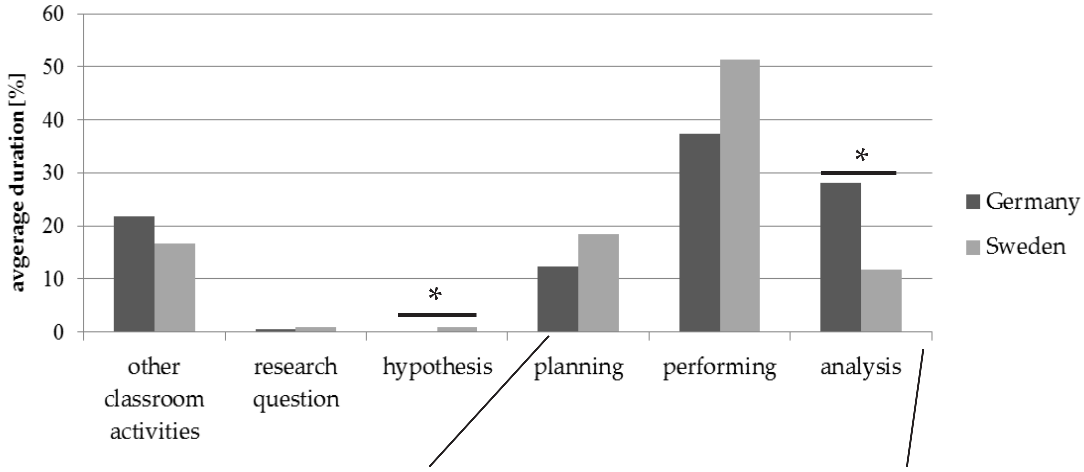

Figure 1: Steps of *Scientific Inquiry* (* = p < 0.05, ** = p < 0.01, *** = p < 0.001; n.s. = not significant)

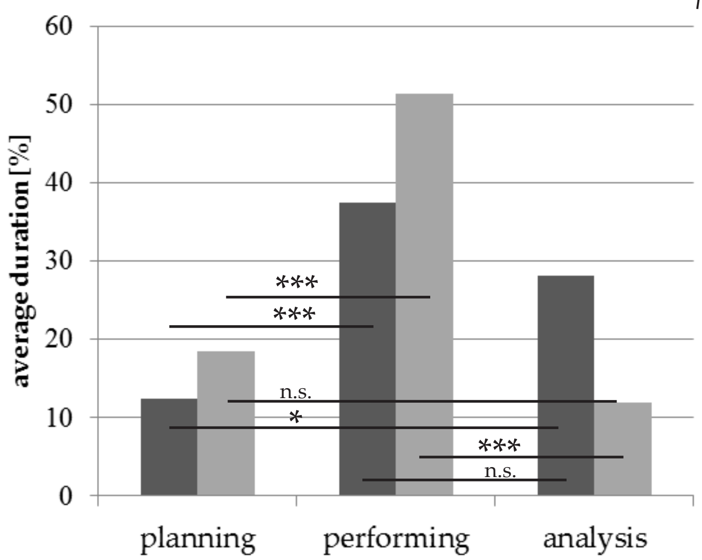

Figure 2: Significant differences of the *phases planning, performing* and *analysis* (* = p < 0.05, ** = p < 0.01, *** = p < 0.001; n.s. = not significant)

The third interesting aspect concerns the significant differences within the duration of the *planning, performing* and *analysis phases*. These results lead to the conclusion that the German video-recorded chemistry lessons are often more product-oriented, while Swedish chemistry lessons rather focus on the process of performing the investigation. Further investigations are required to understand the consequences of these differences more in detail (Björkman & Tiemann, 2011).

In summary, the findings show first results on how chemistry is taught in general and in terms of *Scientific Inquiry* in an international comparison between Germany and Sweden. In this regard it becomes apparent, that there are culture-specific teaching patterns in each country. Further studies of the deep structure will follow.

Acknowledgements

The authors want to thank the "Deutsche Telekom Stiftung" for its financial support. Furthermore, we thank Jurik Stiller and Rhys Dowler for their corrective support on earlier drafts of this paper as well as the two anonymous reviewers for their professional support in order to improve the quality of the article.

References

Anderson, R. D. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education, 13(1*), pp. 1-12.

Björkman, J., Labetzki, T., & Tiemann, R. (2012): Ein Instrument zur Videoanalyse von „Scientific Inquiry" – Chemieunterricht im internationalen Vergleich [An instrument for the video analysis of "Scientific Inquiry" – chemistry lessons in an international comparison]. In D. Höttecke (Ed.), *Konzepte fachdidaktischer Strukturierung für den Unterricht*. GDCP, Jahrestagung in Oldenburg 2011 (pp. 304-306). Münster: LIT.

Björkman, J., & Tiemann, R. (2011): Deutschland – Schweden: Der Erkenntnisgewinnungsprozess im Chemieunterricht im internationalen Vergleich [Germany – Sweden: Scientific Inquiry in chemistry lessons in international comparison]. In D. Höttecke (Ed.), *Naturwissenschaftliche Grundbildung als Beitrag zur Gestaltung partizipativer Demokratie*. GDCP, Jahrestagung in Potsdam 2010 (pp. 611 - 613). Münster: LIT.

Blömeke, S., Eichler, D., & Müller, C. (2004): Videoanalysen zum Einsatz von Informations- und Kommunikationstechnologien im Unterricht. Indikatoren und erste Ergebnisse für das Fach Mathematik [Video analysis concerning the use of information and communication technologies in education. Indicators and initial results for mathematics education]. In: Doll, J. & Prenzel, M. (Hrsg.): *Bildungsqualität von Schule. Lehrerprofessionalisierung, Unterrichtsentwicklung und Schülerförderung als Strategien der Qualitätsverbesserung* (pp. 212-233). Münster u.a.: Waxmann.

Bortz, J. (2005). *Statistik für Human- und Sozialwissenschaftler [Statistics for Human and Social Scientists]* (6. Aufl.). Berlin, Heidelberg, New York: Springer.

Bortz, J., & Döring, N. (2005). *Forschungsmethoden und Evaluation für Human- und Sozialwissenschaftler [Research Methods and Evaluation for Human and Social Scientists]* (3., überarb. Auflage). Heidelberg: Spinger Medizin Verlag.

Chen, Z., & Klahr, D., (2008). Remote Transfer of Scientific Reasoning and Problem-Solving Strategies in Children. In R. V. Kail (Ed.), *Advances in Child Development and Behavior*, Vol. 36 (pp. 419-470). Amsterdam: Elsevier.

DeBoer, G. E. (2000). Scientific Literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching, 37(6)*, pp. 582-601.

Furtak, E. M. (2006). The problem with answers: An exploration of guided scientific inquiry teaching. *Science Education, 90 (3)*, pp. 453-467.

Gais, B., & Möller, K. (2006). Verstehen förderndes Lehrerhandeln im naturwissenschaftsbezogenen Sachunterricht - eine Videostudie. [Teacher Behavior Promoting Understanding in Science-Related Primary Lessons - A Video Study]. In D. Cech, H.-J. Fischer, W. Giese-Holl, M. Knörzer & M. Schrenk (Eds.), *Bildungswert des Sachunterrichts* (pp. 211-226). Bad Heilbrunn: Klinkhardt.

Gräber, W., & Nentwig, P. (2002). Scientific Literacy - Naturwissenschaftliche Grundbildung in der Diskussion [Scientific Literacy – Scientific Literacy in discussion]. In W. Gräber, P. Nentwig, T. Koballa, & T. Evans (Eds.), *Scientific Literacy* (pp. 7-20). Oplaben: Leske + Budrich.

Gyllenpalm, J., Wickman, P.-O., & Holmgren, S.-O. (2010) Secondary science teachers' selective traditions and examples of inquiry-oriented approaches. *Nordic Studies in Science Education, 6(1*), pp. 44-60.

Hammann, M., Phan, T., Ehmer, M., & Bayrhuber, H. (2006). *Fehlerfrei Experimentieren [Experimentation without mistakes]. MNU, 59(5)*, pp. 292-299.

Hofstein, A. (2004): The Laboratory in Chemistry Education: Thirty Years of Experience with the Developments, Implementation, and Research. *Chemistry Education Research and Practice, 5*(3), pp. 247-264.

Höttecke, D. (2001). Die Vorstellungen von Schülern und Schülerinnen von der „Natur der Naturwissenschaften" [The views of students regarding "Nature of Science"]. *Zeitschrift für die Didaktik der Naturwissenschaften, 7*, pp. 7-23.

Kungliga Skolöverstyrelsen [Royal National Board of Education] (1955). *Undervisningsplan för Rikets Folkskolor [Teaching Plan for Public Schools in the Kingdom of Sweden]*. Stockholm: Svenska Bokförlaget Norstedts.

Mayer, J. (2007). Erkenntnisgewinnung als wissenschaftliches Problemlösen [Scientific Inquiry as scientific problem solving]. In D. Krüger, & H. Vogt (Eds.), *Theorien in der biologiedidaktischen Forschung* (pp. 177-186). Berlin/Heidelberg: Springer.

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction – what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching, 47(4)*, pp. 474–496.

Möhler, J. (2008). *Schule der Zukunft? Vision und Realität der schwedsichen Skola 2000 [School of future? Vision* *und reality of the Swedish Skola 2000]*. Münster, New York, München, Berlin: Waxmann.

National Research Council (NRC) (2012). *A framework for K-12 science education: Practices, crosscutting concepts and core ideas*. Washington, DC: National Academic Press.

Njoo, M., & de Jong, T. (1993). Exploratory learning with a computer simulation for control theory: Learning processes and instructional support. *Journal of Research in Science Teaching, 30*, pp. 821-844.

Ozel, M., & Luft, J. (2011). Understanding Beginning Teachers' Conceptions of Inquiry Based Teaching. Presentation at conference of "European Science Education Research Association" (ESERA), Lyon, 5th September to 9th September.

Puhlmann, M., & Tiemann, R. (2009). Handlungsmuster und Problemlösen: Eine vergleichende Videostudie zwischen Nordrhein-Westfalen und Sachsen [Teaching patterns and problem solving: a comparative video study between North Rhine-Westphalia and Saxony]. In D. Höttecke (Ed.), *Entwicklung naturwissenschaftlichen Denkens zwischen Phänomen und Systematik*. Gesellschaft für Didaktik der Chemie und Physik, Jahrestagung in Dresden 2009 (pp. 434-436). Münster: LIT.

Reyer, T. (2004). *Oberflächenmerkmale und Tiefenstrukturen im Unterricht. Exemplarische Analysen im Physikunterricht der gymnasialen Sekundarstufe [Surface features and deep structures in teaching: exemplary analyses of physics lessons in upper secondary education]*. Berlin: Logos-Verlag.

Rimmele, R. (2008) Videograph-Multimedia-Player zur Kodierung von Videos [Videograph – Multimedia-Player for the coding of videos]. Kiel, IPN.

Sadler, T. D., & Zeidler, D. L. (2009). Scientific literacy, PISA, and socioscientific discourse: Assessment for progressive aims of science education. *Journal of Research in Science Teaching, 46*, pp. 909-921.

Seidel, T. (2003). *Lehr-Lernskripts im Unterricht. Freiräume und Einschränkungen für kognitive Lernprozesse - eine Videostudie im Physikunterricht [Teaching and learning scripts. Free spaces and restrictions for cognitive learning processes – a video study in physics education]*. Münster: Waxmann.

Seidel, T. (2005). Video analysis strategies of the IPN Video Study – a methodological overview. In T. Seidel, M. Prenzel, & M. Kobarg (Eds.), *How to run a video study*. Technical report of the IPN Video Study (pp. 70–78). Münster: Waxmann.

Seidel, T., & Prenzel, M. (2004). Muster unterrichtlicher Aktivitäten im Physikunterricht [Patterns of teaching activities in physics lessons]. In J. Doll & M. Prenzel (Eds.), *Bildungsqualität von Schule: Lehrprofessionalisierung, Unterrichtsentwicklung und Schülerförderung als Strategien der Qualitätsverbesserung* (pp. 177–194). Münster: Waxmann.

Seidel, T., Prenzel, M., Duit, R., & Lehrke, M. (Eds.) (2003). *Technischer Bericht zur Videostudie „Lehr-Lern-Prozesse im Physikunterricht" [Technical report of the video study "teaching and learning processes in physics education"]*. Kiel: IPN.

Shute, V. J., & Glaser, R. (1990). A large-scale evaluation of an intelligent discover world: Smithtown. *Interactive Learning Environments, 1*, pp. 51-77.

Simon, H.A., Langley, P., & Bradshaw, G.L. (1981). Scientific discovery as problem solving. *Synthese, 47*, pp. 1-27.

Skolverket [The Swedish National Agency for Education] (2008). *Vad händer i NO-undervisningen [What happens in science education]?* Stockholm: Skolverket.

Skolverket (2011). *Kursplan – Kemi*. Skolverket: Stockholm. Retrieved from http://www.skolverket.se/forskola-och-skola/grundskoleutbildning/laroplaner/grundskolan/kemi [11/10/2012].

Stigler, J.W., Gonzales, P., Kawanaka, T., Knoll, S., & Serrano, A. (1999). *The TIMSS-Videotape Classroom Study. Methods and findings from an explanatory research project on eighth-grade mathematics instruction in Germany, Japan, and the United States.* Washington, D.C.: U.S. Department of Education.

Strobl, G. (2008). Naturwissenschaftliche Bildung - fachorientiert oder Fächer übergreifend [Scientific Literacy – subject-oriented or interdisciplinary]? In K. P. Ohly, & G. Strobl (Eds.), *Naturwissenschaftliche Bildung* (pp. 31-45). Weinheim: Beltz Verlag.

Tesch, M., & Duit, R. (2004). Experimentieren im Physikunterricht - Ergebnisse einer Videostudie [To experiment in physics education – results of an video study]. *Zeitschrift für die Didaktik der Naturwissenschaften*, 10, pp. 51-69.

Tschirgi, J.E. (1980). Sensible reasoning: A hypothesis about hypotheses. *Child Development, 51*, pp. 1–10.

Wirtz, M., & Caspar, F. (2002). *Beurteilerübereinstimmung und Beurteilerreliabilität [Observer Agreement and Inter-Rater-Reliability]*. Göttingen: Hogrefe.