Volume 5

"Haus der kleinen Forscher" Foundation (Ed.)

Y. Anders, I. Hardy, S. Pauen, J. Ramseger,
B. Sodian, M. Steffensky, R. Tytler

Early Science Education – Goals and Process-Related Quality Criteria for Science Teaching

Scientific Studies on the Work of the
"Haus der kleinen Forscher" Foundation

KLEINE FORSCHER
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Early Science Education – Goals and Process-Related Quality Criteria for Science Teaching

Yvonne Anders, Ilonca Hardy, Sabina Pauen, Jörg Ramseger, Beate Sodian, and Mirjam Steffensky

With a foreword by Russell Tytler

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Preface

We are delighted to present the English-language edition of the fifth volume in the "Haus der kleinen Forscher" Foundation's scientific series, which was originally published in German in 2013.[1] The translation was made possible by a donation from the Siemens Stiftung, which is committed to inquiry-based learning in the domains of science and technology in Germany and throughout the world.

This year, for the first time, we are jointly hosting an international symposium with a focus on early education. Entitled "International Dialogue on STEM – Developing a Vision for Early Education," it will take place in Berlin on 2 and 3 November 2017. We are therefore particularly pleased that the present volume has been published in time for the symposium, and that it will reach an international audience.

The focus of this volume is on the goals of, and quality criteria for, early STEM education and on their measurement in children between the ages of three and ten. These are topics that are extremely important for both our foundations. Every STEM initiative must align its work with quality standards. We therefore consider it to be our responsibility, and the responsibility of all other STEM education initiatives, to constantly question what we do. As learning organisations, we should conduct regular self-evaluation and undergo external evaluation: Is the path we have taken an effective one? How can we further develop the "quality of STEM education" in our own offerings? Good STEM initiatives build on empirical knowledge from different fields, they seek and use critical exchanges with experts, and they subject themselves and their offerings to regular evaluation.

The three expert reports in this volume provide important theoretical orientation for the work of the "Haus der kleinen Forscher" Foundation. The goals at the level of the children, the early childhood professionals, and the pedagogical staff at after-school centres and primary schools are a central basis for designing the Foundation's substantive formats and measuring the outcomes of science education within the framework of accompanying research on the Foundation's work. The process-related quality criteria help with the pedagogical implementation of, and reflection on, targeted goals of STEM education. We hope and believe that the expert knowledge compiled in this volume will also be of interest, and perhaps even of help, to other STEM initiatives.

Once again, our sincere thanks go to the authors of the expert reports in this volume for their support in producing the English-language version.

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1 *The "Haus der kleinen Forscher" Foundation's scientific series comprises eight volumes in German. Volume 5 is the first English translation of the series. Stiftung Haus der kleinen Forscher (2013). Wissenschaftliche Untersuchungen zur Arbeit der Stiftung „Haus der kleinen Forscher", Vol. 5. Schaffhausen: SCHUBI Lernmedien AG.*

We would also like to thank you, the readers, for your interest in our work. We hope that this volume will encourage dialogue between science and practice – especially at an international level.

Dr Natalie von Siemens

Managing Director and
Spokesperson of the
Siemens Stiftung

Michael Fritz

Executive Board of the
“Haus der kleinen Forscher” Foundation

Foreword

Russell Tytler

These expert reports, focusing on the principles that should underpin practice and evaluation of the "Haus der kleinen Forscher" Foundation, represent an authoritative and comprehensive survey of contemporary thinking in science education for children. As such it is a very interesting and thought provoking document that raises many of the issues of principle and the practicalities involved in designing a quality education for young children. For anyone implementing its vision, it will also be a challenging one given a long history of struggle to have science education adequately represented and competently delivered in the early years and through primary school.

I applaud the way this very well-known and experienced group of education researchers have charted a course through the multiple and often contested purposes of early and primary years science education, producing an account that lays out the different competencies that can and should be focused on. One of the challenges that I see having been negotiated in this study was how to take the core philosophy of the "Haus der kleinen Forscher" Foundation, which is built around notions of inquiry and exploration and the development in the child of a passion for learning about the natural world, to develop a set of recommendations around ways to validly evaluate such a program in terms of children's outcomes, and also educators' characteristics. As such, the document represents a significant attempt to define a culture of learning, based on the best research we have, across the ages 3–10.

This is no easy task, given that inquiry and exploratory approaches to science tend to focus on the development of higher order conceptual outcomes, and attitudinal outcomes, both of which are difficult to measure. These are not the 'low hanging fruit' of straightforward conceptual knowledge that is most common in science assessments. In Expert Reports A and B, dealing respectively with pre-school and primary school age children, the authors bring their considerable experience in cognitive science research into children's thinking, allied with reference to the literature around conceptual change and growth, to build a comprehensive framework for such an evaluation. Expert Report C, written by a well-known progressive educator with commitments to exploratory pedagogies, supplements this with an account of pedagogical principles that emphasise the child-centred, social and language-oriented nature of a quality science education. These accounts are different, but fundamentally compatible, as I will argue below.

In Expert Reports A and B, which follow a similar format, the emphasis is on the development of the whole child, through an exploration of the variety of competencies that should be associated with a science education. The programme needs to reflect an interplay of cognitive competencies, conceptual learning, metacognitive abilities, values, beliefs, and motivational orientations. These reports argue for and articulate a comprehensive set of such competencies, and consider for each the questions: How can this be validly measured? Are there instruments that exist or could be modified to measure these at this age level? And finally: Where should the emphasis lie? In charting this territory, the reports cover a broad literature on the following goals of competence: Motivation, interest and self-efficacy; scientific thinking and processes; scientific knowledge; and basic cognitive, social, fine motor, language and mathematical competencies.

Not surprisingly given the expertise of the authors, Expert Report A, and Export Report B after it, is exceptionally informative in its characterisation of scientific thinking and processes. This includes a well-articulated range of goals including multi-sensory engagement with science experiences, interest in detail, assessment of experiences, expectations and assumptions as early forms of hypotheses, experimenting through systematic manipulation, evaluating and justifying, and forming abstractions. Direct measurement of these is difficult, and video analysis and questionnaires of parents and educators are recommended for evaluation. In Expert Report B, dealing with the primary school years, these competencies are extended to include more formal considerations of coordination of explanations and evidence, and draw on a wider range of research findings to pin down the development of knowledge of the nature of science and methodology, appropriate for children with the developing ability to represent these distinctions.

These accounts steer a carefully thought-through pathway between the engagement of children in the practices of science and scientific thinking, their values and attitudes towards scientific exploration, and the development of knowledge appropriate to the level. Of course, this requires a need to formulate approaches to teaching and learning, and in this case a path must be steered through the twin demands of encouraging children to explore their ideas, and the need to support the development of ideas that are productive in leading to scientific ways of perceiving the world, and scientific ways of thinking and working. A nice distinction is made between foundational free-play experiences which allow the exploration of phenomena, and structured experiences in which children are led to compare, and to reflect. The pedagogy is one of guided inquiry. A number of tables are offered in these expert reports which exemplify the appropriate language, experiences and basic concepts for the topics of changes in water, and floating and sinking. These suggestions are strongly informed by a constructivist, conceptual change perspective on learning.

All of these constructions depend of course on the knowledge and competencies of the teacher, and the expert reports each have an equivalent section on the goals at the level of early childhood professionals. These sections are again a sophisticated review of the teacher knowledge needed to appropriately plan activities and support children's competency development. Teacher competencies include motivational and self-efficacy goals, scientific thinking, scientific knowledge and pedagogical content knowledge, and aspects of professional attitude including beliefs about learning, the nature of science, and the importance of science education. These considerations are directly and honestly dealt with, acknowledging challenges with the level of preparation of educators currently, and the diverse background of pedagogical staff in after-school centres or extracurricular programs. Measures are suggested for evaluating these professional competencies for educators.

Expert Report C articulates a strong inquiry perspective that critiques the normative tendencies of major versions of scientific literacy, and privileges exploration of questions devised by children, placing less emphasis on the structured guidance of Expert Reports A and B. The report lays out ten quality criteria for teaching and learning science that are supported by contemporary literature on children's reasoning and learning, and didactics. Taken as a set these criteria offer a comprehensive vision of child-centered science education that do not contradict the previous expert reports but offer a different, more child-focused emphasis. In part this is due to the introduction of two theoretical strands that were relatively silent in the previous expert reports – those of the role of language and representation in learning, and of collaborative reasoning and learning processes. It is precisely here that I believe there is a literature that can usefully inform the resolution of the tension between honoring children's individual learning exploration and the need to guide them towards more formal science ideas.

Expert Reports A and B situate learning about science concepts, and scientific thinking, within a framework of personal constructivism, such that interactions are imagined between the individual child, their experiences, and the guidance of the educator. Yet there is a well-established recent literature drawing on the ideas of Vygotsky (1981) that presents learning as a socially constructed and situated phenomenon. Social constructivist perspectives were developed precisely as an attempt to resolve the contradiction between personal and public knowledge (Driver et al., 1994). Sociocultural perspectives further emphasize the mediating role of language, such that learning is viewed as a process of induction into the discursive practices of the discipline – the development of disciplinary literacy (Moje, 2007). My own research focuses on the development of multi-modal representational tools underpinning both discovery processes in science, and reasoning and learning in the science classroom (Tytler & Prain, 2014). None of these perspectives contradict the basic thrust of the vision presented by these three expert reports, but rather offer an enriching perspective into the ways teachers can model and shape language in the classroom, and challenge and support children to represent and negotiate their ideas multi-modally (Tytler, Prain, Hubber & Waldrip, 2013). Language, from this perspective, refers to more than the development of a vocabulary, and encompasses the linguistic structures through which ideas are talked about and explanations are framed (Prain & Hand, 2016), as well as the visual and symbolic representations through which the world can be perceived anew.

Introduction

"Haus der kleinen Forscher" Foundation

Introduction

With a nationwide initiative, the non-profit "Haus der kleinen Forscher" ("Little Scientists' House") Foundation promotes the educational opportunities of children of pre-primary and primary school age in the domains of science, mathematics, technology, and computer science. The Federation's continuing professional development programme supports primary teachers and early childhood professionals from all over Germany in fostering children's spirit of inquiry and in collaboratively investigating natural phenomena and mathematical, computer science, and technological questions with them. The education initiative thus makes an important contribution to the qualification of primary teachers and early childhood professionals and to the development of institutional quality, on the one hand, and to developing children's personalities and interests and fostering the next generation of professionals in the STEM domains, on the other.[2] As of 30 June 2017, over 23,300 early childhood education and care centres, 1,300 after-school centres, and 4,000 primary schools throughout Germany had the possibility of actively participating in the initiative.[3] There are currently 225 local networks, which have, for the most part, been built up in collaboration with municipalities, non-state providers of early childhood education and care, trade associations, and educational institutions (e.g., adult education centres). Network partners also include science centres, museums, companies, foundations, and associations.

The main focus of the education initiative is the further qualification of the primary teachers and early childhood professionals who are responsible at their institutions for the education of the children in the domains of science, technology, computer science, and mathematics. Instead of merely arranging sporadic visits by external experts, or purely providing pedagogical resources, the initiative aims to provide primary teachers and early childhood professionals with continuing professional development and to support them on a long-term basis. The Foundation's professional development offerings are made available to teachers and early childhood professionals via a multiplier model.

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2 STEM = science, technology, engineering, and mathematics

3 Detailed information can be found on the Foundation's website at www.haus-der-kleinen-forscher.de.

Vision and Mission of the “Haus der kleinen Forscher” Foundation

Vision of the “Haus der kleinen Forscher” Foundation: Questioning – Inquiring – Shaping the Future

Our vision is that all children in Germany will experience educational venues where they can pursue their own questions and explore the world around them in an inquiry-based way.

These “Little Scientists’ Houses” will strengthen children for the future and empower them to think for themselves and to act responsibly.

Technologisation, digitalisation, and the consequences of climate change and social inequality increasingly influence our everyday lives. We shall contribute to enabling people to find their bearings in our rapidly changing world and to remain open to new things.

Everyday engagement with nature and technology fosters children’s enjoyment of learning and thinking. We see early education as a key to being able to successfully meet the challenges of a complex world.

Mission of the “Haus der kleinen Forscher” Foundation

The mission of the “Haus der kleinen Forscher” Foundation is to ...

- promote a questioning and inquiring attitude in children;
- give children the opportunity to discover at a young age their own talents and potential in the domains of science, technology, computer science, and mathematics; and
- lay the foundations for reflective engagement with technological and social changes in the sense of sustainable development.

Together with their reference persons, the children experience fun and enjoyment in exploring and understanding the world around them. Children actively shape their education processes, thereby experiencing themselves as competent and self-efficacious. In the course of inquiry-based learning, children can develop problem-solving skills, find their own answers, and gain a feeling of self-confidence (“Yes, I can!”). The importance of these experiences and abilities for personality development and the child’s future professional biography extends far beyond childhood.

With a practice-oriented and high-quality approach to professionalisation, the Foundation supports primary teachers and early childhood professionals in facilitating the exploration, inquiry, and learning activities of children up to the age of ten. Through diverse continuing professional development offerings, teachers and early childhood professionals experience for themselves the fascination of engaging in independent inquiry. They expand their knowledge and pedagogical competencies, and implement them in their everyday work with the children.

The initiative supports educational institutions in sustainably developing themselves as “venues of inquiry-based learning” and – as “Little Scientists’ Houses” – in creating favourable learning environments for children.

In order to be able to make continuing professional development opportunities available to teachers and early childhood professionals from all interested primary schools, after-school centres, and early childhood education and care centres throughout the country, the “Haus der kleinen Forscher” Foundation trains multipliers (known as “trainers”), who deliver the courses in their respective networks. For their part, the over 600 trainers undergo continuing professional development in the Foundation’s substantive focal topics, they receive pedagogical resources for their adult education task, and they are given personal feedback within the framework of the Foundation’s training observation programme.

The Foundation’s substantive offerings cover the following domains:[4]

- **Continuing professional development:** Face-to-face workshops for primary teachers and early childhood professionals, and for trainers, and supportive e-learning and blended learning formats for teachers and early childhood professionals and for multipliers.
- **Internet presence:** The website www.haus-der-kleinen-forscher.de provides information for all interested parties.
- **Pedagogical resources**: For implementation purposes, the initiative makes high-quality pedagogical resources available free of charge to the educational institutions. They include, for example, thematic brochures, exploration and inquiry cards, didactic resources, and video examples.

4 *When expanding the offerings for children of primary school age, the Foundation also developed formats that address children directly (e.g., print materials, little scientists’ camps, a children’s website).*

- **The magazine *Forscht mit!*:** This periodical gives teachers and early childhood professionals practical tips for inquiry activities at their institutions, information about the work of the Foundation, and best practice examples from other educational institutions and networks.
- **"Tag der kleinen Forscher" (Little Scientists' Day)**: On this nationwide "join-in" day, children all over Germany are given the opportunity to explore a current research topic. To this end, the Foundation makes pedagogical resources available to the institutions and invites supporters from politics, industry, science, and civil society to join in.
- **Encouragement of collaboration:** Interested parents, mentors, and other education partners support collaborative exploration and inquiry at the educational institutions.
- **Certification:** Committed educational institutions are certified as a "Little Scientists' House" on the basis of predetermined evaluation criteria. All applicant institutions receive detailed feedback with suggestions for the further development of collaborative exploration and inquiry with the children (as at 30 June 2017: over 4,800 certified institutions).

Within the framework of the education initiative, different continuing professional development (CPD) topics are offered every year both for the primary teachers and early childhood professionals and for the trainers. Up to the end of 2016, new trainers, or pedagogues participating in the CPD programme for the first time, initially attended the workshops "Investigating Water" (Workshop 1) and "Investigating Air" (Workshop 2), in which the Foundation's pedagogical approach to collaborative inquiry with children is addressed in detail. Since 2017, the point of entry into the CPD programme is flexible. If the facilitators of learning consider that their pedagogical competence is in need of development, or if they wish to obtain an overview of the Foundation's pedagogical concept, they are given the option of either starting, as before, with the aforementioned face-to-face workshops or taking part in the seminar or the online course devoted to "Pedagogical Principles" *(Grundlagen zur Pädagogik)*. However, as a first point of entry, the early childhood professionals and primary teachers and the trainers can also choose between the other modules on science, technology, computer science, or mathematics topics. Content is offered in a variety of different formats: local face-to-face workshops, self-learning formats, for example, online courses or pedagogical resources in print form, and educational events. Moreover, the "Little Scientists' House" Certificate supports the development of the quality of pedagogical work at the institutions and makes their commitment to good early STEM education outwardly visible. Thus, the Foundation's efforts are geared increasingly towards the needs of its target groups based on their prior knowledge and experience, their interests, and their time-related flexibility.

Substantively, the Foundation's CPD portfolio was rounded off at the beginning of the school year 2017/18 by incorporating the domain of computer science education with the workshop "Exploring Computer Science – With and Without a Computer". In addition, the Foundation is currently expanding its workshop, content, and pedagogical resources offerings to include Education for Sustainable Development (ESD), which, for the first time, will be addressed not only to early childhood professionals and primary teachers but also to managers of early childhood education and care centres. Testing of the concept in practice got underway in 2017 in 29 model networks. From 2108 onwards, the new ESD offering will be made available to all early childhood education and care centres, after-school centres, and primary schools. Moreover, the technology education topic "From Here to There – Locomotion and Transport" will be offered as of autumn 2018.

All activities of the education initiative are scientifically accompanied and evaluated on an ongoing basis. The "Haus der kleinen Forscher" Foundation maintains an open dialogue with science and pedagogic practice; it sees itself as a learning organisation. In addition to regular monitoring for quality-assurance and quality-development purposes, the Foundation's work is evaluated in a professionally sound way within the framework of long-term external accompanying research conducted by renowned scientists and in research projects. The results of the scientific accompaniment are published by the Foundation and are freely accessible on its website.[5]

From 2011 to 2014, the accompanying research of the Foundation was advised and supported by the Research Steering Committee (FLK).[6] In addition, the Foundation established a Working Group on Accompanying Research in early 2010, which was composed of scientists, members of the Board of Trustees of the Foundation, Foundation staff members, and practitioners (primary teachers and early childhood professionals, trainers, and network coordinators). In the spring of 2015, the Research Steering Committee was replaced by the Scientific Advisory Board, which advises the Foundation on the scientific accompaniment and the

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5 *All results of, and publications relating to, the accompanying research are available as PDFs at www.haus-der-kleinen-forscher.de under the heading "Research and Monitoring". In addition, all results of the external accompanying research are published in the present scientific series. An overview of the volumes in this series published to date can be found at www.haus-der-kleinen-forscher.de (only the present volume is available also in English).*

6 *A list of the individual members of the Research Steering Committee (Forschungslenkungskreis) can be found at www.haus-der-kleinen-forscher.de.*

scientific grounding of its substantive offerings. Moreover, the Scientific Advisory Board issues recommendations to the Executive Board and the Foundation Board. It is composed of independent scientists from different professions, and its members are recognised experts from relevant disciplines:

- Prof. Dr Fabienne Becker-Stoll, State Institute of Early Childhood Research (IFP), Munich
- Prof. Dr Marcus Hasselhorn, German Institute for International Educational Research (DIPF), Frankfurt
- Prof. Dr Bernhard Kalicki, German Youth Institute (DJI), Munich and University of Applied Sciences for Social Work, Education and Care, Dresden
- Prof. Dr Alexander Kauertz, University of Koblenz-Landau
- Prof. Dr Armin Lude, Ludwigsburg University of Education
- Prof. Dr Johannes Magenheim, University of Paderborn
- Prof. Dr Kornelia Möller, University of Münster
- Prof. Dr Jörg Ramseger, Freie Universität Berlin
- Prof. Dr Dr Ortwin Renn, University of Stuttgart and acatech – the German Academy of Science and Engineering
- Prof. Dr Hans-Günther Roßbach (Chair), University of Bamberg and the Leibniz Institute for Educational Trajectories (LIfBi)
- Prof. Dr C. Katharina Spieß/Pia S. Schober, Ph.D., German Institute for Economic Research (DIW), Berlin and Freie Universität Berlin
- Prof. Dr Wolfgang Tietze, PädQUIS gGmbH, *An-Institut* at ASH Berlin
- Prof. Dr Christian Wiesmüller, University of Karlsruhe and German Association for Engineering Education (DGTB)
- Prof. Dr Bernd Wollring, University of Kassel

An extensive range of measures are in place to assure and develop quality at the "Haus der kleinen Forscher" Foundation (see Figure 1). The Foundation's own quality management continuously monitors the various Foundation offerings, such as the continuing professional development courses for trainers and for teachers and early childhood professionals. Regular surveys designed to capture the expectations and needs of the various groups of actors involved in the education initiative (network partners, trainers, teachers and early childhood professionals) are an important element of the monitoring system. The key results of the surveys are published in the Monitoring Reports (see, for example, Stiftung Haus der Kleinen Forscher, 2017).

Within the framework of the substantive (further) development of the Foundation's portfolio, new offerings are also always tested in practice. In collaboration with a group of teachers and early childhood professionals from primary schools, after-school centres, and early childhood education and care centres, every module is pilot tested before the professional development concepts and pedagogical resources are distributed within the regional networks. The participating teachers and early childhood professionals test the feasibility of initial practice ideas and provide feedback on the Foundation's support offerings. The professional development concepts are then revised and further developed on the basis of this feedback.

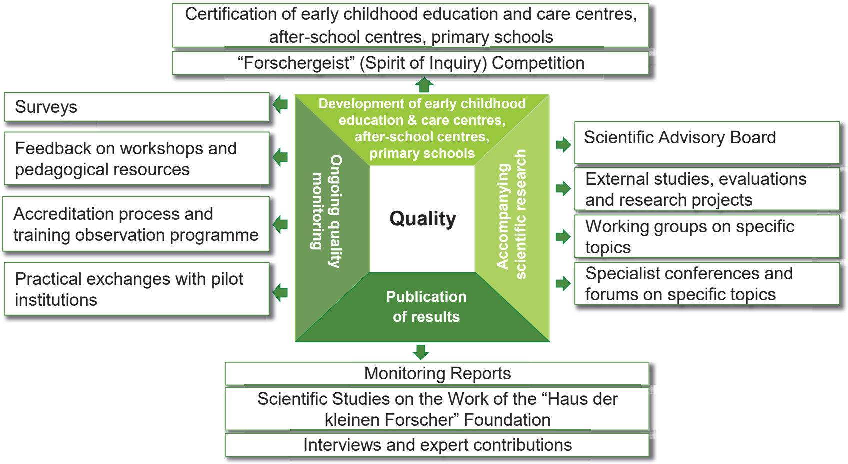

Figure 1. *Overview of the measures to assure and develop the quality of the Foundation offerings*

Another important quality development instrument is the certification of institutions as a "Little Scientists' House" (Stiftung Haus der kleinen Forscher, 2013). The Foundation decides on the award of certification in a standardised procedure that was developed in the style of the German Kindergarten Seal of Quality (Deutsches Kindergarten Gütesiegel) in collaboration with a team of scientists.[7] The reliability and validity of the certification procedure for early childhood education and care centres has been confirmed in an external scientific study (Anders & Ballaschk, 2014).

7 *Prof. Dr Yvonne Anders, Dr Christa Preissing, Prof. Dr Ursula Rabe-Kleberg, Prof. Dr Jörg Ramseger, Prof. Dr Wolfgang Tietze*

The expert reports on goals of science education that are published in the present volume are based on preparatory work carried out by the Working Group on Accompanying Research. The goals developed by this working group were presented at the inaugural meeting of the Research Steering Committee on 13 January 2011, and were welcomed as substantively appropriate and relevant for early science education. The consultations of the Research Steering Committee stressed that the measurement of the effectiveness of the multiplier model called not only for the measurement of competencies in children but also, and in particular, for the investigation of the concrete interaction processes in the early childhood education and care centres. However, it was noted that the availability of valid and practicable procedures designed specifically for the measurement and third-party observation of science competencies in the domain of early education was still extremely limited – both nationally and internationally – and that further research efforts were called for in this regard. To prepare for an empirical assessment of the goals of the Foundation, the committee recommended that the structure and designation of these goals should be further theoretically underpinned and prioritised, that they should be developed further in the direction of competence models for children and facilitators of learning, and that possible measurement instruments should be reviewed and proposed.

To implement this recommendation, the Foundation established a group of scientific experts entitled "Goals of Science Education Between the Ages of Three and Six and Their Assessment," who prepared the first of the expert reports in the present volume. This report by Yvonne Anders, Ilonca Hardy, Sabina Pauen, and Mirjam Steffensky features a detailed theoretical description of the goals at the level of the children and of the early childhood professionals and information on their empirical measurement (an overview can be found in Appendix I and II of this volume). A preliminary version of this expert report was presented and discussed at the second meeting of the Research Steering Committee on 6 October 2011. The goals identified by the authors, and their theoretical justification were endorsed by the members of the Research Steering Committee. Moreover, prioritisation was recommended with regard to the substantive relevance of the goals, the anticipation of specific outcomes, and the effort involved in their assessment (availability of suitable measurement instruments). These prioritisation recommendations are presented in the conclusions of the expert report, which was discussed and approved at the third meeting of the Research Steering Committee on 22 March 2012.

Building on the expert report for pre-primary level, the Foundation set up a working group to formulate goals of science education at primary school age. Yvonne Anders, Ilonca Hardy, Beate Sodian, and Mirjam Steffensky prepared the second expert report in this volume, "Goals of Science Education at Primary

School Age and Their Assessment". The emergence of this expert report was also accompanied by the Research Steering Committee, which endorsed the report at its fourth meeting on 5 November 2012.

The third expert report in this volume deals with the pedagogical implementation of goals, and formulates ten quality criteria for science teaching. While Anders, Hardy, Pauen, Sodian, and Steffensky primarily describe *person-related* goals and competencies at the level of the children and the teachers and early childhood professionals, Jörg Ramseger focuses on *process-related* classroom interaction – that is, on the process quality of science education in the teaching-learning situation. This expert report was discussed at the fifth meeting of the Research Steering Committee on 10 April 2013, and was welcomed by the committee members.

Summary of Key Findings of the Expert Reports

"Haus der kleinen Forscher" Foundation

Summary of Key Findings of the Expert Reports

The fifth volume of the publication series "Scientific Studies on the Work of the 'Haus der kleinen Forscher' Foundation" comprises detailed theoretical elaborations of goals and quality criteria for early science education that are of relevance for the work of the Foundation. Three expert reports are presented that constitute the theoretical foundations for the (further) development of the various substantive offerings of the Foundation (e.g., continuing professional development formats, pedagogical resources).

The first two expert reports discuss goals of early science education at pre-primary and primary school age. They describe the theoretical framework and operationalisable target criteria for the measurement of the outcomes of science education in children and in pedagogical staff at early childhood education and care centres, after-school centres and primary schools. The third expert report focuses on the process of pedagogical implementation and describes ten quality criteria for science teaching.

In the expert report *Goals of Science Education Between the Ages of Three and Six and Their Assessment,* Yvonne Anders, Ilonca Hardy, Sabina Pauen, and Mirjam Steffensky specify pedagogical content goals of early science education. The content-specific goals are derived partly from the substantive preparatory work of the "Haus der kleinen Forscher" Foundation and partly from the current state of theoretical and empirical research. The authors prioritise goals at the level of the children and the early childhood professionals, and they discuss existing instruments for measuring these dimensions or the necessity of developing suitable new measures.

At the level of the children and their development, the authors recommend the following goals:

- Motivation, interest, and self-efficacy in engaging with natural phenomena
- Scientific thinking and process when engaging with natural phenomena
- Knowledge of science

At the level of the early childhood professionals, priority is given to the following goals:

- Motivation, interest, and self-efficacy in engaging with natural phenomena
- Scientific thinking and process when engaging with natural phenomena, and methodological competence and understanding the nature of science
- Knowledge of science
- Pedagogical content knowledge
- Aspects of professional role perception and self-concept (especially collaborative ability)
- Epistemological attitudes to, and beliefs about, science education

The expert report *Goals of Science Education at Primary School Age and Their Assessment* by Yvonne Anders, Ilonca Hardy, Beate Sodian, and Mirjam Steffensky follows on from the expert report on the goals at pre-primary level, and focuses on the children and the pedagogical staff at after-school centres and in extracurricular afternoon programmes at primary schools. In line with the Foundation's commitment to achieving cumulative learning pathways across education levels, the goals described in the second expert report are the same as those that are the focus of the expert report on pre-primary level. However, because the children are older and the institutions (after-school centres, primary schools) are different, the configuration of the goals differs somewhat from that in the first expert report.

Expanding the goals for children between the ages of three and six, the aim for children of primary school age is also to achieve a general understanding of the nature of science at the meta level, similar to that aspired to in the case of the pedagogical staff at after-school centres and in extracurricular afternoon programmes at primary schools. For these pedagogues, the goals in the domain of pedagogical content knowledge are supplemented with knowledge of school-based learning (incl. knowledge of curricula, educational objectives, and target competencies) and with the ability to design and implement effective learning environments within the framework of these structures.

The goals of science education that are recommended for children and pedagogues at pre-primary and primary level are graphically summarised in the figures in Appendix I and II.

The expert report *Process-Related Quality Criteria for Science Teaching* by Jörg Ramseger is addressed directly to teachers and educators at pre-primary and primary level with the aim of supporting them in planning lessons and in self-evaluating science learning opportunities. To this end, the expert report describes ten criteria for pedagogical implementation that determine success with regard to the superordinate educational goals of science teaching: (1) Make nature "question-able", (2) Incorporate prior knowledge, (3) Develop experiments together with the children, (4) Practise working in a precise way, (5) Foster scientific discourse, (6) Use models and representations, (7) Take the social and historical embeddedness into account, (8) Point out that science is open to change, (9) Ensure learning gains, and (10) Facilitate perceived self-efficacy.

Jörg Ramseger considers criteria (1), (2), (4), (5), (6), and (9) to be particularly relevant for early science education at pre-primary and primary school age. Moreover, he stresses the central importance of the tenth quality criterion, which relates to the development of the children's perceived self-efficacy through inquiry activities.

A Goals of Science Education Between the Ages of Three and Six and Their Assessment

Yvonne Anders, Ilonca Hardy, Sabina Pauen, and Mirjam Steffensky

1. Theoretical Assumptions

Yvonne Anders

The importance of science education is growing in our technology-oriented society. For this reason, the non-profit “Haus der kleinen Forscher” Foundation is actively engaged in promoting science education via a nationwide education initiative in the domains of science, technology, computer science, and mathematics for children of pre-primary and primary school age. With its professional development programme and pedagogical materials, the Foundation supports early childhood professionals, and pedagogical staff at after-school centres and in extracurricular afternoon programmes at primary schools, in providing learning opportunities for children and in facilitating their science education processes.

With the help of accompanying scientific research, the Foundation’s activities are evaluated in terms of their effectiveness and the achievement of their goals. In the present report, we specify the learning areas and goals of the “Haus der kleinen Forscher” education initiative, so that they can be operationalised within the framework of the aforementioned accompanying research. Moreover, we discuss the prioritisation of certain goals and provide information on existing instruments for measuring these goals, or on the necessity of developing suitable new measures.

This report marks a key step in the development of a comprehensive accompanying research programme for the “Haus der kleinen Forscher” initiative. Substantively, the descriptions of the Foundation’s goals focus on science education in early childhood education and care settings, which constituted the core of its work until 2011. In that year, the education initiative was expanded to include children between the ages of six and ten years and pedagogical staff at after-school centres and in extra-curricular afternoon programmes at primary schools. The goals described here can, in principle, be applied also to primary students and teachers. This is due to the fact they have been derived in part from current research on primary and secondary education. However, they have not yet been specifically adapted to the initial and target competencies of students and teachers at primary level.[8]

As regards the various recipients of, or actors involved in, the “Haus der kleinen Forscher” initiative, we begin by defining the goals at the level of the children and the early childhood professionals in the domain of science education. Addi-

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8 The second report in this volume, which is authored by Anders, Hardy, Sodian, and Steffensky, addresses the “Goals of Science Education at Primary School Age and Their Assessment”.

tional domains (e.g., technical or mathematical education), and other professionals involved (e.g., trainers) will be addressed at later stages in the report.

The learning goals are derived partly from the pedagogical materials of the “Haus der kleinen Forscher” Foundation and the content of its professional development programme, but mainly from current theoretical and empirical research findings. To facilitate the subsequent operationalisation of these goals in scientific studies, we prioritise, specify, and briefly describe them. We have chosen an inter-disciplinary approach, adopting, inter alia, the perspectives of (developmental) psychology, (pre-primary) pedagogy, empirical education research, the didactics of science, the professional sciences, and teaching-learning research. The specification of the goals is guided by theoretical assumptions regarding the acquisition of competencies in (early) childhood and by the structure, emergence, acquisition and impact of professional competencies of early childhood professionals. These theoretical assumptions constitute the framework within which the learning goals are developed and anchored. It is important to note, however, that research on professional competencies of early childhood professionals is still in its infancy, and that the theoretical assumptions described here still lack empirical foundation. For that reason, they should be seen as a heuristic model rather than as a formal model. In what follows, we begin by outlining the concept of competence that underlies the deliberations presented here. Next, we describe the assumptions about the acquisition of competencies in childhood. We conclude with a presentation of our assumptions regarding the professional competencies of early childhood professionals.

1.1 The Concept of Competence

In the case of the learning areas at the level of the children and the early childhood professionals, the authors of this expert report use a concept of competence that was described and differentiated by Weinert (1999, 2001). Following Weinert, competencies can best be described on the basis of the demands and tasks that a person must master in the respective domains. Competencies are understood here as multi-dimensional sets of abilities that can be differentiated into various facets. Competencies in the broader sense – that is, in the sense of action competence – describe the interplay of cognitive competencies, metacognitive abilities, values, beliefs, and motivational orientations. This understanding of competencies forms the basis of our further explorations.[9]

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9 The definition of competence that we have chosen reflects a general understanding of competence that is shared by many scientists in the interdisciplinary field of education research. The advantage of this

1.2 Assumptions About the Acquisition of Science Competencies in Early Childhood

With reference to the current state of research in developmental psychology, the authors of this report assume that, like other educationally relevant abilities and skills, the acquisition of science competencies starts long before formal schooling begins – namely at birth (see Weinert, Doil, & Frevert, 2008: 89). Although this assumption may appear trivial, it is an important justification for the "Haus der kleinen Forscher" initiative. Moreover, it is a fundamental prerequisite to measuring the development of science competencies in children between the ages of three and six.

The authors of this report see children as active learners and as shapers of the acquisition of science competencies, which is a cumulative process within which active acquisition, passive learning, and maturation processes occur. The environment plays a crucial role in the development of science competencies. Via stimuli, resources, and active influence on the part of facilitators, it constitutes the learning opportunities for the acquisition of science competencies. Children use and shape these learning opportunities both actively and passively. Against this background, the goodness of fit between a child's temperament and its environment must be considered extremely important (Siegler, DeLoache, & Eisenberg, 2005; see also Weinert, Doil, & Frevert, 2008).

The acquisition of competencies in different content domains (e.g., motor skills, language, general cognitive abilities, and science) poses various challenges to the child. With reference to research in developmental psychology (e.g., Karmiloff-Smith, 1992; Weinert, 2000), the authors of this report assume that the acquisition of competencies is a domain- and content-specific process. In other words, while a child's language development may be age-appropriate, it may display deficits in acquiring science competencies. Moreover, the child may have difficulties within a specific domain (e.g., scientific thinking), difficulties developing general cognitive functions (e.g., problem solving), or difficulties in building up concrete knowledge of nature (Sodian, 2002; see also Weinert; Doil, & Frevert, 2008).

When specific tasks are being solved, competency domains at different levels (e.g., language skills, problem-solving skills, knowledge of nature) always act together. Moreover, competencies in one domain may be a prerequisite for the

definition is that it can be applied both to professional competencies and to children's competencies. It does not conflict with the understanding of professional competencies adopted, for example, in the qualification frameworks EQR and DQR or the qualification framework for early childhood education (see Robert Bosch Stiftung, 2011). Rather, competencies are the basis for acquiring professional qualifications.

acquisition of competencies in another domain. For example, if language skills are poor, this will very likely have an effect on building up knowledge of nature. Furthermore, the authors of this report assume that cognitive abilities develop in conjunction with emotional and social skills (Jerusalem & Klein-Hessling, 2002; Raver, 2002; Zins, Bloodworth, Weissberg, & Walberg, 2004) and that action competence always reflects the interplay between cognitive, metacognitive, and motivational skills (see above). When investigating the acquisition of science competencies, it therefore makes sense to adopt a broader perspective on the child. These fundamental assumptions have influenced in different ways the classification of the proposed goals at the level of the children.

There is broad national and international consensus that science learning at the various levels of education should be oriented towards the educational concept of scientific literacy (for pre-primary level, see, e.g., Fthenakis, 2009; French, 2004; Gelman & Brenneman, 2004; for primary level, see, e.g., GDSU, 2002; QCA, 2000; for secondary level, see, e.g., KMK, 2004; Bybee, McCrae, & Laurie, 2009). Science competence in the sense of scientific literacy encompasses knowledge components (knowledge of scientific concepts and theories and knowledge about science and scientific ways of thinking and working, i.e., the nature of science) and the ability to apply this knowledge in real-life contexts. It also includes non-cognitive components, for example attitudes towards, interest in, and enjoyment of science (Bybee et al., 2009).

It follows from this that **emotional and motivational aspects and perceived self-efficacy** are key goals. They are defined in domain-specific and content-specific terms and described in Section 2.1 below.

Moreover, within **science competencies,** the authors of this report distinguish between function-related and knowledge-related competencies – that is, *how* children acquire knowledge of natural phenomena, and *what* they know about phenomena and concepts.

The headings of the relevant sections are

(a) *Scientific Thinking and Process when Engaging with Natural Phenomena* (Section 2.2) and
(b) *Knowledge of Science* (Section 2.3).

Furthermore, the knowledge of science dimension is described by way of example on the basis of individual content. This has implications for its subsequent operationalisation and for the development of measurement instruments.

In addition to the aforementioned science competencies, the authors of this report also describe **basic competencies** (Section 2.4), that is, general competencies such as *cognitive, language, mathematical, fine motor, and social competencies.* These competencies are assumed to moderate the development of scientific competencies. Although not all of these domains can be classified as priority dimensions for measurement purposes, it would seem reasonable to take general cognitive competencies into account in future assessments.

The proposed classification does not claim to be exhaustive. Rather, the authors of this report assume, for example, that metacognitive competencies, such as strategies for the control of learning processes and the development of a theory of mind (Sodian & Frith, 2008), also play a major role in the acquisition of scientific competencies. Although these metacognitive competencies will be addressed briefly in the corresponding sections on scientific knowledge, thinking, and understanding, it would be beyond the scope of this report to describe and define them in detail. Hence, there is a lacuna in this regard. Moreover, the competencies to which we have given priority in this report as goals of science education are those for which measurement concepts already exist or can be developed within a reasonable timeframe.

The competencies and aspects of children's experience outlined are described in detail in the second chapter of this report (Sections 2.1 to 2.4), and are graphically illustrated in Appendix I.

1.3 Assumptions About Professional Competencies of Early Childhood Professionals

In addition to the definition and specification of the goals of science education at the level of the children, this report also defines and specifies goals at the level of the early childhood professionals. To derive these goals, we take as our starting point the target competencies of the children, and we ask what professional competencies early childhood professionals must have in order to successfully facilitate the children's learning processes. Through its professional development programme, the "Haus der kleinen Forscher" initiative seeks to stimulate and further develop the professional competencies of early childhood professionals. When defining and specifying goals at the level of the early childhood professionals, we also draw on current theory and research, which guides the systematic structuring of our classification. The underlying assumptions are presented in what follows.

One important assumption is that, besides the family, early childhood education and care centres are a key learning environment in which children spend a considerable amount of time. The authors of this report assume that experiences in early childhood education settings can decisively influence children's cognitive and social development. A number of major international longitudinal studies have dealt with the potential impact of preschool attendance on children's development. These studies have yielded growing empirical evidence of potential positive effects of preschool attendance (ECCE Study Group, 1999; NICHD ECCRN, 2002a, 2005; Roßbach, 2005; Sammons et al., 2004). However, they have also pointed out that the extent and persistence of these positive effects appears to be largely dependent on the quality of stimulation and, in particular, on the quality of the educational processes. Recent national-level studies in Germany have also yielded empirical evidence of the importance of good process quality for a positive impact on children's competence development (Anders, Große et al., 2012; Anders, Roßbach et al., 2012; Roßbach, Sechtig, & Freund, 2010).

Professionals at early childhood education and care centres design and implement learning opportunities and educational processes for the children. They therefore play a key role in creating high-quality stimulation in these settings. Thus, the question of the professional competencies of early childhood professionals is closely linked to the question of the prerequisites for high-quality stimulation.

To describe the interplay of professional competencies and professional action, Fröhlich-Gildhoff, Nentwig-Gesemann, and Pietsch (2011) proposed a competence model aimed at combining structural and process models (see Figure 2). Everyday situations and demands in early childhood education are characterised as highly complex, ambiguous, and non-standardisable. Early childhood professionals' professional competencies are characterised by the fact that they enable them to act independently, creatively, and reflectively in these complex situations and to master new challenges (Fröhlich-Gildhoff et al., 2011).

In their model for describing and analysing the action competence of early childhood professionals, Fröhlich-Gildhoff, Nentwig-Gesemann, and Pietsch distinguish foundations for action, willingness to act, and the realisation of action. According to this model, the thinking and action of early childhood professionals is shaped by action-guiding orientations, values, and beliefs. These aspects constitute the professional attitude, a basic structure that influences all professional thinking and action. The foundations of the ability to act result from the interaction of explicit scientific and theoretical knowledge, tacit experiential knowledge, skills (e.g., methodological or didactical), motivation, and the perception and analysis of the particular pedagogic situation. The aforementioned aspects influence action planning and the willingness to act. And finally, action takes place in a specific situation that can be evaluated and reflected upon, and that can thus, in turn, influence the prerequisites for further action.

The authors of this report assume that the foundations of early childhood professionals' ability to act – that is, the structural prerequisites for their professional action competence – can, in principle, be learnt and modified (e.g., with the help of the "Haus der kleinen Forscher" Foundation's continuing professional development programme).

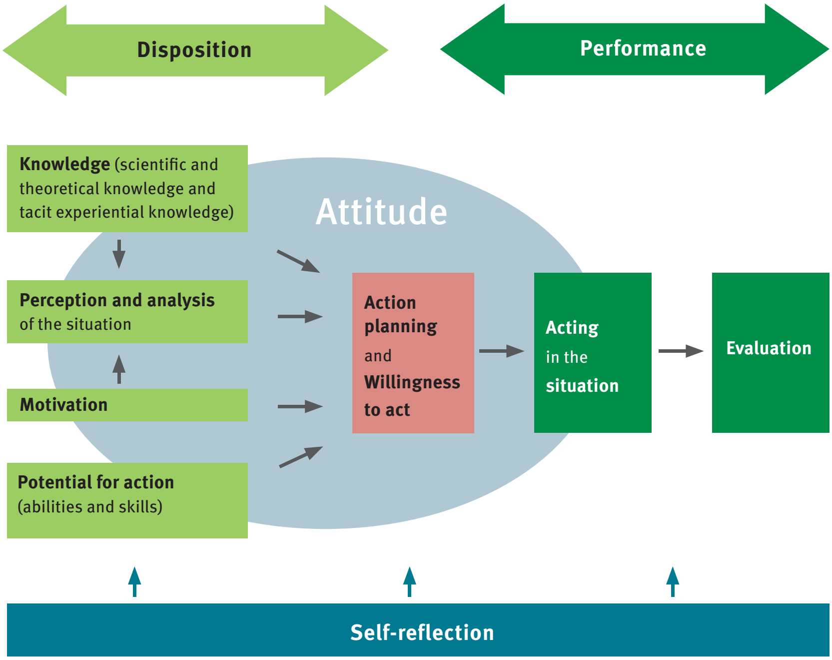

Figure 2. *Model of the competence of early childhood professionals (Fröhlich-Gildhoff, Nentwig-Gesemann, & Pietsch, 2011)*

In line with international theoretical and research approaches, the authors of this report distinguish various facets of professional action competence. When doing so, they further differentiate in the context of the "Haus der kleinen Forscher" initiative the prerequisites for action outlined by Fröhlich-Gildhoff et al. (2011), namely (a) motivation, (b) knowledge, and (c) attitude.

Motivational and emotional aspects are considered to be central facets of professional action competence (Baumert & Kunter, 2006). They include motives for choosing the profession, emotions while exercising the professional activity, and emotional attitudes towards the content of the occupation. Making no claim to be exhaustive, the authors of this report focus in Section 2.1 on three facets: (a) *emotional attitude to, and interest in, science;* (b) *enthusiasm for designing and organising learning processes in the science domain;* and (c) *perceived self-efficacy with regard to the facilitation of science learning processes, as a subcomponent of the motivational and emotional aspects.*

Moreover, the authors also assign special importance to the **professional knowledge of early childhood professionals**. Although the corresponding theoretical approaches are anchored in the theory of professional action competence of primary and secondary teachers, they have been applied also to early childhood professionals (Aubrey, 1997; Siraj-Blatchford et al., 2003). Shulman (1986, 1987) distinguished different categories of teacher knowledge: content knowledge, curriculum knowledge, pedagogical content knowledge, general pedagogical knowledge, knowledge of learners and their characteristics, knowledge of educational contexts, and knowledge of the historical foundations of education. In education research, the focus on the fundamental categories of content knowledge (CK), pedagogical content knowledge (PCK), and general pedagogical knowledge (PK) has prevailed in recent years. However, individual aspects of the other knowledge domains have been incorporated into these facets.

Content knowledge (CK) refers to in-depth conceptual background knowledge and in-depth knowledge of content in the respective domains (e.g., science, mathematics).

Pedagogical content knowledge (PCK) refers to knowledge about how domain-specific content can be made accessible to learners. It includes, for example, knowledge of children's typical subject-specific cognitions (e.g., knowledge of their conceptions and typical misconceptions), knowledge of the potential that everyday situations and learning material hold for learning processes, and knowledge of effective instructional strategies for facilitating learning processes in the respective domains.

General pedagogical knowledge (PK) refers to facets of knowledge that transcend subject matter and that are necessary for designing and implementing learning opportunities and pedagogic interaction. They include knowledge of forms of learning, group-leadership strategies, developmental psychology, and relationship development and management.

The weighting of the individual facets of knowledge is a topic of debate, especially with regard to early childhood professionals. To date, there are hardly any empirically grounded findings on the structure and significance of professional knowledge. However, based on theoretical and conceptual deliberations, we consider the domain-specific knowledge facets (CK and PCK) to be a prerequisite for the provision of activating learning opportunities in the context of the "Haus der kleinen Forscher" initiative.

In Sections 3.3.1 and 3.3.2, we specify our deliberations on **content knowledge** and **pedagogical content knowledge** in the domain of science. Our classification at the level of early childhood professionals is oriented towards the target competencies at the level of the children, which are transferred to demands in a pedagogical content knowledge context.

General pedagogical knowledge (PK) will not be addressed further here because, from our perspective, the current state of research still lacks the transparency that would be needed to review and specify PK within the framework of this report. Moreover, competency facets of general pre-primary didactics are currently being addressed by expert groups, for example at the Robert Bosch Stiftung and the Weiterbildungsinitiative Frühpädagogische Fachkräfte (WiFF), a professional development programme for early childhood professionals (see Deutsches Jugendinstitut e. V., 2011; Robert Bosch Stiftung, 2011). Furthermore, because qualified early childhood professionals are expected to have core general pedagogical competencies, these competencies are not focused on as a goal of the "Haus der kleinen Forscher" initiative.

Professional attitude, in the sense of a basic structure that guides action, is closely linked to the motivational and emotional aspects, and also to the individual knowledge components. It is considered to play a very important role in the development of professional action competence (Fröhlich-Gildhoff et al., 2011). In early childhood education, the professional attitude is a very broad construct that includes not only pedagogical orientations, values, and beliefs but also aspects of professional self-concept and role perception. From this conception follows our assumption that the professional attitude has an indirect effect on child development, which is mediated by process quality (Kluczniok, Anders, & Ebert, 2011). In Section 3.4 of this report, the authors focus on individual aspects of the professional attitude that arise from the goals of the "Haus der kleinen Forscher" Foundation and their mirroring in the goals at the level of the children. *Pedagogical orientations and beliefs about fostering science education at pre-primary level* and individual domain-general aspects of *professional self-concept and role perception* (e.g., an inquiry-based attitude and reflective ability) are discussed. At this juncture, these aspects are reduced to those that have priority and are potentially measurable.

The competency domains of early childhood professionals outlined above are described in detail in the third chapter of this report (Sections 3.1 to 3.4) and are graphically illustrated in Appendix II.

The competency domains for early childhood professionals overlap partially with the quality criteria that the "Haus der kleinen Forscher" Foundation has developed within the framework of its certification procedure. To be certified as a "Haus der kleinen Forscher" (Little Scientists' House), applicants must document that collaborative inquiry with the children is an integral part of everyday life at their pedagogical institution and that their early childhood professionals regularly participate in relevant continuing professional development workshops. The approach chosen by the Foundation for this procedure is closely aligned with that of the German Kindergarten Seal of Quality (*Deutsches Kindergarten Gütesiegel;*

Tietze & Förster, 2005), which distinguishes between structural quality features of the institution and orientation quality, process quality, and external openness aspects.[10] However, in the Foundation's certification process, greater emphasis is placed on the system of the institution, whereas the present report considers only the prerequisites on the part of the early childhood professionals.

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10 *Detailed information about the certification procedure and the evaluation criteria can be found on the Foundation website at http://www.haus-der-kleinen-forscher.de/en/practice-supporting-the-childrens-learning-process/certification-supporting-quality-and-commitment/.*

2. Goals at the Level of the Children

2.1 Motivation, Interest, and Self-Efficacy in Engaging With Natural Phenomena

Yvonne Anders

2.1.1 Motivation and Enjoyment of Learning When Engaging With Natural Phenomena

Besides the cognitive prerequisites, emotional and motivational aspects, in particular, also play an important role in learning and knowledge acquisition. It is assumed that children learn more effectively when their learning is intrinsically motivated and accompanied by positive emotions (see Deci & Ryan, 1993). The "Haus der kleinen Forscher" Foundation offerings aim to awaken interest in science, to introduce children to science, and to show them the enjoyable and interesting aspects of engaging with natural phenomena. This leads directly to an enjoyment of learning science. Whereas the aforementioned motivational aspects refer more to situation-specific emotions in the course of action, enjoyment of learning relates to the enjoyment of acquiring knowledge.

An open, positive attitude to science, intrinsic motivation to engage with natural phenomena and science questions, and a great enjoyment of learning science can be considered to be key goals of the "Haus der kleinen Forscher" Foundation. Ideally, this motivation and enjoyment of learning should carry over into primary school.

Measurement

Depending on the methodological approach and the children's age, motivational aspects can be measured using both observational and rating procedures (external assessment and self-assessment [basal]). A number of procedures already exist. PISCES (Puppet Interview Scales of Competence in and Enjoyment of Science), for example, is an instrument for self-assessing the individual's science-related self-concept and enjoyment of science (Mantzicopoulos, Patrick, & Samarapungavan, 2008). A questionnaire developed within the framework of the SNaKE project measures interest in science in the sense of openness and curiosity. With regard to enjoyment of learning, detailed research on existing instruments has not yet been forthcoming. In the project *Kindergarten der Zukunft in Bayern – KiDZ* (Kindergarten of the Future in Bavaria – KiDZ; Roßbach et al., 2010), rating-based scales were used to measure enjoyment of learning in the domains of mathematics and language. These scales proved sensitive to programme effects and may be

transferable to the domain of science as implemented by the "Haus der kleinen Forscher" Foundation. In summary, it can be noted that instruments that are specifically adapted to "Haus der kleinen Forscher" Foundation content have yet to be developed.

2.1.2 Interest in Science

The term *interest* is defined in the sense of an active effort to expand competence (Muckenfuß, 1995). Understood this way, interest is a component of the self-concept and is characterised by action, cognitive engagement with the object field, and selective assessment. It can be assumed that interest in, and enjoyment of engaging with, specific content are closely related. Besides enjoyment of the activity, children should also develop a deeper, long-term interest in the subject. This is believed to enhance intrinsic motivation to learn. Whether younger children develop interests in the sense of a specific person-object relationship (educational theory of interest, Krapp, 2002) is a matter of dispute. It is assumed that interest is configured differently in children than in adults, but that it functions according to similar principles (see Prenzel, Lankes, & Minsel, 2000).

Measurement

Typical instruments for measuring primary school students' interest using self-assessment rating scales, as applied, for example, in the TIMSS study (Wendt, Bos, Selter, Köller, Schwippert, & Kasper, 2015) are less suitable for children between the ages of three and six. This is because, at that age, children often find everything interesting. Therefore, it is difficult to obtain normally distributed data. Besides the instruments mentioned in Section 2.1 above (a clear delineation between interest and enthusiasm is difficult at that age), structured interviews are most commonly used (see, e.g., Upmeier zu Belzen, Vogt, Wieder, & Christen 2002; Wieder, 2009). To measure interest within the framework of accompanying research on the "Haus der kleinen Forscher" initiative, existing instruments would have to be specifically adapted.

2.1.3 Perceived Self-Efficacy

The term *perceived self-efficacy* refers to people's beliefs in their capabilities to master demands (see Bandura, 1997). It should be emphasised that perceived self-efficacy is always context-specific. The learning opportunities afforded by the "Haus der kleinen Forscher" Foundation are aimed at enabling children to perceive a high level of self-efficacy ("Yes, I can!") when conducting inquiry activities and engaging with natural phenomena, and with regard to their capability to acquire science competencies and learn science.

Measurement

A self-assessment instrument developed by Schwarzer and Jerusalem (1995) can be used to measure general perceived self-efficacy following Bandura (1997). The instrument has been applied in numerous studies. It comprises ten items for measuring general optimistic self-beliefs (e.g., "I can always manage to solve difficult problems if I try hard enough."). Domain-specific variants have also been published, for example the school-related perceived self-efficacy scale (Jerusalem & Mittag, 1999; Jerusalem & Satow, 1999). The perceived science-related self-efficacy of secondary school students was investigated, for example, in the third international comparison of student attainment, PISA 2006 (Prenzel et al., 2007). Martinelli, Bartholomeu, Caliatto, and Sassi (2009) developed an instrument for measuring the school-related perceived self-efficacy of children at primary school age. The various measures are a suitable starting point from which to develop an instrument for measuring the science-related perceived self-efficacy of children at pre-primary age that is specifically tailored to the offerings of the "Haus der kleinen Forscher" Foundation.

2.2 Scientific Thinking and Process When Engaging With Natural Phenomena

Sabina Pauen

In the public sphere, children are increasingly referred to as "little scientists" (Gopnik, Kuhl, & Meltzoff, 2001; Elschenbroich, 2005). This reflects the fact that children are inquisitive creatures who act quite purposefully to gain new knowledge (Wilkening & Sodian, 2005). At the same time, however, it should be borne in mind that children's cognitive abilities undergo significant developmental changes between the ages of three and six (see, e.g., Goswami, 2008). It is therefore necessary to determine what progress in scientific thinking about natural phenomena is typical of this age group, and how it can be recognised. Against this background, relevant goals can be formulated.

When doing so, we define **scientific thinking and process when engaging with natural phenomena** as a *cognitive process of the active expansion of knowledge about natural units and processes* (acquisition of knowledge about natural materials, things, and processes, e.g., elements or laws of nature). In this connection, eight core aspects can be distinguished, which we propose as goal dimensions at the level of the children. When selecting these aspects, the authors of this report followed typical steps in the process of scientific inquiry:

1. *Consciously experiencing and observing*
2. *Describing and recording experiences*
3. *Comparing and discussing experiences*
4. *Forming expectations and expressing assumptions*
5. *Trying things out and experimenting*
6. *Evaluating and justifying experiences*
7. *Integrating experiences and forming abstractions*
8. *Engaging in further deliberations*

As *knowledge and understanding of natural phenomena* is the subject of the elaborations of Steffensky and Hardy (Section 2.3 below), it will not be not addressed here. Nor will *metaknowledge about scientific testing techniques,* which is normally observed in children only from school age onwards.

In what follows, we elaborate on the aforementioned eight goal dimensions. Specifically, we explain what we mean by each individual heading, what competencies children between the ages of three and six typically possess, and how progress in the development of these competencies can be recognised.

2.2.1 Consciously Experiencing and Observing

The starting point of every experience is the *perception* of specific circumstances. As explained above, the authors of this report focus on the perception of situations or processes in nature. All sensory modalities may be relevant here. *Observation* is a targeted and particularly attentive form of perceiving objects or processes. Strictly speaking, observation is limited to seeing. Although the term *observation* is often used in a much broader sense in the literature on preschool pedagogy, it will be supplemented in the present context with the overarching concept of conscious experience.

Children experience nature with all their senses. By adding the qualifier *conscious,* we emphasise that the child actively engages with the perceived situation.

Observation is considered to be a particularly typical form of conscious experience.

Facilitating conscious experiences when engaging with natural phenomena is undoubtedly the cornerstone of, and starting point for, the early development of scientific thinking. The measurement of this goal on the basis of objectifiable parameters is possible in all age groups. The following types of differentiation can be made:

a) type of sensory experience (seeing, hearing, touching, tasting, smelling)

b) degree of concentration on a natural phenomenon

c) degree of active participation in the "investigation" of the phenomenon

d) focusing of the attention (holistically or analytically) on the phenomenon

e) interest in repetition

Re (a) type of sensory experience (seeing, hearing, touching, tasting, smelling)

Infant research has shown that oral exploration of objects is found more in younger infants, and that from the age of around nine months it declines in favour of visual and manual exploratory behaviours (see, e.g., Chen, Reid, & Striano, 2006).

Independent of their age, children differ in the way they use their senses. Whereas some children want to be as close to the action as possible and to perceive a phenomenon with as many senses as possible at the same time, others prefer to keep their distance, are generally more cautious, and initially use mainly their remote senses to explore an object or a phenomenon. Moreover, when it comes to perception, every child has very individual preferences. While some children mainly look, others also want to touch, taste, and smell. And finally, the type of sensory experience possible depends also on the object of perception: anyone who wants to learn something about rainbows relies on sight; anyone who wants to learn something about musical instruments needs, above all, hearing.

From a pedagogical perspective, despite (or precisely because of) such differences, the best way of providing as many children as possible with access to conscious experience is to appeal to different senses. At the same time, it can be argued that the fact that a child is increasingly receptive to different types of sensory experiences is proof of its willingness to actively engage with nature.

To date, no instruments are available for measuring the extent to which science experiences are multisensory. Generally, this aspect can best be measured within the framework of concrete behavioural observations. When doing so, it must be ensured that (1) in principle, the situation enables the use of different senses and (2) the child can freely choose to approach the natural phenomenon in question in different ways.

Re (b) degree of concentration on, or attention to, a natural phenomenon

When it comes to measuring the consciousness of science experiences, the receptiveness of the senses is not, however, the only relevant factor. Also of relevance is the child's concentration on, or attentional engagement with, the phenomenon. This can be determined on the basis of various behavioural parameters: concentration manifests itself in facial expressions and can be detected physiologically on the basis of changes in heart rate (Elsner, Jeschonek, & Pauen, 2006; Richards & Cronise, 2000). A low level of distractibility is also considered to be an indicator for concentration (e.g., Richards, 1998). Above all, however, concentration is reflected in the duration of the active engagement with a phenomenon.

Hence, an economical and psychologically meaningful way of measuring progress in scientific thinking would be to measure the duration of attentional engagement with a natural phenomenon or the degree of concentration when engaging with nature. These parameters can also best be realised within the framework of standardised behavioural observation.

Re (c) degree of active participation in the "investigation" of the phenomenon

Phases of active participation in activities increase the cross-linking of different sensory impressions, whereas phases of experience without active participation in activities support reflection. The ratio between active and passive participation in activities is likely to vary with age. While infants are more likely to play the role of observer, as they still lack motor skills, children between the ages of three and four years are usually particularly active. Because of their limited executive control (Garon, Bryson, & Smith, 2008), children in this age range have difficulties holding back and playing "only" an observer role. Children between the ages of four and six years are more likely to succeed in doing so. Because of their more developed self-regulatory skills, they are generally able to hold back a little more (especially when asked to do so). Here, phases of activity alternate with phases where the child adopts the observer perspective.

One possible measure of progress in scientific thinking and process that could be derived from the above description would be the degree of balance between phases of active and passive participation in play-based experimentation with natural phenomena. However, it should be noted that the ability to self-regulate depends not only on the way in which scientific thinking is fostered in early childhood education settings but also on the temperament of the child, on the way its parents and early childhood professionals deal with its impulses, and on maturation processes. Nonetheless, familiarising children with both roles – the role of perceiver and the role of active intervener – can be defined as an important educational goal when engaging with natural phenomena. Accordingly, within the framework of standardised behavioural observation, one could calculate the ratio between the cumulative duration of active and passive participation. The significance of this ratio for the acquisition of knowledge and understanding would first have to be investigated.

Re (d) (holistic or analytic) focusing of the attention on the phenomenon

Also of interest during the observation is whether the children focus their attention on global aspects of an object or situation, or on very specific details. These modes are referred to in the literature as holistic and analytic perception, respectively (Kemler, 1983). Although it cannot, in general, be said that one form of experience is better than the other, analytic observation or perception indicates that the child is engaging consciously and intensely with a specific aspect of the phenomenon (Schwarzer, 2000). This interest in details normally develops only once the child is familiar to a certain extent with an object or a phenomenon. Before that, “holistic wonder” predominates. From this perspective, one could define as a goal or early science education that, when engaging with natural phenomena, children should go through a process that begins with holistic wonder and ends with the targeted exploration of individual aspects. However, it is necessary to ensure that the focusing of attention does not lead to tunnel vision, where other important aspects are ignored.

Here, too, there is a lack of procedures for measuring this aspect within the framework of the process of scientific knowledge building itself. However, it would be conceivable to measure the number of different aspects of a situation to which a child explicitly refers in words or actions during the standardised observation of behaviour.

Re (e) interest in repetition

When a child frequently repeats a certain procedure of its own accord, or when it wants to see it again and again, this is a clear indication of its intensive cognitive engagement with that procedure. Thus, with the exception of repetitive stereotyped behaviours, the number of repetitions of an experience can be seen as a positive indicator of scientific thinking (in the sense of interest in perceiving a phenomenon or cognitive engagement with a phenomenon). The number of repetitions of the same (or a very similar) procedure during a standardised observation situation in which the child is given opportunities to actively explore a phenomenon can easily be numerically evaluated, provided one clearly defines what constitutes a repetition.

Measurement

To sum up, it can be stated that the following measures may indicate progress in relation to the **conscious experience** goal:

- openness to different sensory experiences when engaging with nature
- duration of the child's attention and depth of concentration when engaging with a given phenomenon
- balance between active and passive participation when trying things out and experimenting in the context of engagement with natural phenomena
- supplementing holistic wonder by focusing attention on significant aspects
- interest in repetition

There are no standardised instruments for measuring these aspects of the conscious experience of natural phenomena. Standardised observation of behaviour would seem to be a particularly suitable approach, although an experimental situation in which the phenomenon is first presented to the children and they are then allowed to explore it themselves is probably the best way of measuring in parallel all the aforementioned aspects. This situation would have to be recorded on video and analysed offline according to previously defined observation criteria.

2.2.2 Describing and Recording Experiences

Conscious experience is a key prerequisite for, but it does not equate to, the creation of new knowledge. Only when conscious experience is linked to existing cognitive schemas and prior knowledge can this process be deemed to be an initial form of *cognition* (e.g., "re-cognition"). This is what Jean Piaget called assimilation into existing cognitive structures.

Indicators of the linking of experiences may take different forms. In principle, every expression of what the child experiences can be an indication that the experience has been, or is being, linked to existing structures. One way of expressing an experience is to talk about it.

When a child talks about what it has experienced, or when it expresses an experience in another way (e.g., in the form of a drawing), this proves that the child is cognitively engaging with it. What is of interest, therefore, is whether conscious experience can be recognised at all, and, if yes, how it is described. Specifically, if the child correctly represents processes and, for example, describes them in the correct temporal and causal order, and if, when doing so, it explicitly names or represents different relevant aspects, this can be regarded as a positive indicator of knowledge building. In the case of verbally formulated experiences, the child's choice of words provides important information about its understanding of the subject matter. Thus, the child may use terms that (a) are already available in its vocabulary and accurately describe the object or process, (b) are transferred to the present situation from another context, (c) are neologisms, or (d) are newly introduced by the early childhood professional and taken up by the child (e.g., technical terms). Here, there is overlap both with Section 2.3, in which the child's knowledge and understanding are explicitly addressed, and with Section 2.4, which deals with general language skills as basic competencies that influence knowledge building.

When experiences are represented graphically, account must be taken of the fact that the graphomotor skills of three- to four-year-olds are still very limited (Pauen, 2011) and that the corresponding behaviours cannot be measured to any great extent until between the ages of five and six years.

Independent of the quality of the child's verbal or graphic description of its experience, it can be noted that every attempt to communicate with other people about natural phenomena is an indication of cognitive engagement with the subject matter. Of particular importance in the present context are the timing of the description and the context in which the child provides it:

a) The description is given in the situation in which the child is having the experience.
b) The description is given at a later point in time.
c) The description is given spontaneously.
d) The description is given in reaction to being spoken to.

A description given in the situation in which the child is having the experience is a *commentary* that indicates that the experience is consciously processed the moment it is experienced. If the description is provided at a later point in time, this confirms that the child has constructed a *memory* of it.

Also of interest is whether the description is provided *spontaneously* or as *a reaction to being spoken to*. Spontaneous descriptions, in particular, suggest sustainable cognitive engagement with what has been, or is being, experienced; this supports the linking of the experience to existing structures.

Hence, the following are indications of progress in scientific thinking:

- an increase in the number of spontaneous descriptions (in words, pictures, or another format)
- in the situation itself (e.g., during inquiry activities) and
- at a later point in time (e.g., reports during circle time or at home)

Measurement

In order to operationalise these aspects, it would appear necessary to systematically measure, or ask, whether, or in what way, the child engages with what it has experienced. When doing so, reports provided by the early childhood professional are just as relevant as those given by the parents. The Science Learning Assessment (SLA; Samarapungavan, Mantzicopoulos, Patrick, & French, 2009) is one example of a standardised and validated instrument for measuring children's knowledge about the natural world (here: butterflies). There are no comparable measures for other content domains. Nor are there any instruments with which children's ability to describe and record experiences could be measured in a domain-general way.

2.2.3 Comparing and Discussing Experiences

Comparisons are a special type of engagement with personal experiences. The following subtypes can be differentiated:

a) comparisons between states in the same situation (before-and-after comparisons)
b) comparisons between manipulated states (experimental comparisons)
c) comparisons with states or processes of an outwardly similar type (transfers)
d) comparisons with states or processes that are only structurally similar but that are from different domains (analogies)

Furthermore, one can distinguish:

a) quantitative comparisons
b) qualitative comparisons

What all the aforementioned types of comparisons have in common is that they presuppose an act of thought in which the child goes beyond the simple description of what it is experiencing or has experienced. In concrete terms, the child mentally represents at least two objects, states, or processes in parallel, and actively relates them to each other. Expectations and predictions can be derived only by systematically determining similarities and differences.

Before-and-after comparisons are of particular importance for understanding causal or functional relationships. Also of importance are experimental comparisons, which enable inferences to be drawn about potentially significant influencing factors.

The assessment of quantities frequently plays a role, especially in the case of these two types of comparisons. Children between the ages of three and six are capable, in principle, of assessing whether one entity is longer or shorter, bigger or smaller, or heavier or lighter than the other (provided the differences are clear enough). However, this capability depends also on language comprehension, so it is important to measure this aspect as a covariate.

Children between the ages of three and six years are also capable, in principle, of assessing whether quantitative changes in a dependent variable have occurred as a result of a specific manipulation (e.g., whether something has increased or decreased or has become warmer or colder). Here, however, short-term memory capacity also plays an important role.

By contrast, children in this age range have limited capabilities of using measurement instruments to assess quantitative changes. The use of such instruments presupposes not only knowledge of the purpose of different instruments (e.g., weighing scales, clock, thermometer) but also prior practice handling numbers, number lines, and ordinal scales. Competencies such as these are not usually imparted to children until primary school, and they are therefore rarely found among three- to six-year-olds (Pauen & Pahnke, 2008).

If more than two units or events of the same type are taken into account and included in a comparison, which may refer both to quantitative dimensions and to qualitative characteristics, children's ability to recognise *correlative structures and covariances* comes into play. These competencies are of decisive importance for category formation, generalisation, rule formation, and thus also for knowledge transfer. Rudimentary forms of these competencies can already be observed in infants – albeit only within the framework of tacit learning processes at first. The ability to explicitly identify and/or reflect on such correlations does not develop until late pre-primary and primary school age. However, it can be fostered from the age of three onwards.

Comparisons with experiences in other domains (e.g., with circumstances in other contexts about which the child already knows something) may help the child to access an understanding of natural phenomena about which it does not yet know anything. This is referred to in certain cases as *drawing analogies*. With reference to their ability to make qualitative comparisons between different circumstances, very contradictory observations can be made among children between the ages of three and six. On the one hand, they tend to playfully engage in free association when comparing circumstances, and they come up with things that adults would never think of. On the other hand, their ability to refer specifically and systematically to relational similarities, and to ignore surface similarities, is still very limited (Goswami, 2008).

There can be no doubt that an important goal of early childhood science education is to encourage children to make different comparisons. This raises the question of how it can be determined whether progress has been made in this regard. The answer depends on the type of comparison in question. If a child frequently repeats an activity, this is an indirect indication that it is interested in before-and-after comparisons. If a child spontaneously undertakes systematic variations while experimenting, this is a clear indication that it is particularly interested in experimental comparisons. Whether knowledge transfer takes place or analogies are drawn is not normally so easy to determine. Occasionally, the child makes verbal connections with other experiences that can be interpreted as analogies or transfers. If such activities are proven, they are an indication of in-depth mental processing of the content and good cross-linking of newly constructed knowledge structures.

Measurement

To date, there are no standardised instruments for measuring the ability to make, or to deepen, comparisons. If one wanted to develop such an instrument, it would certainly make sense to record within the framework of standardised observation of behaviour (a) how often a child repeats an action with slight goal variations, (b) how often it verbally refers to changes brought about by its own actions, or (c) how often it spontaneously makes (meaningful) comparisons with other situations.

2.2.4 Forming Expectations and Expressing Assumptions

On the basis of comparisons with previous experiences, the child forms *tacit expectations*. The formation of expectations can be observed even in newborn infants, and it is the prerequisite of all forms of contingency learning. It can be seen, for example, in “anticipatory looking”. If an infant sees an object disappearing on one side of an occluder, it will quickly shift its gaze to the other side of the occluder in anticipation of the reappearance of the object. If expectations are violated (e.g., when objects do not behave as initially anticipated), infants will react with surprise and increased attentiveness. This is also the case with older children: When children between the ages of three and six years show wonder, surprise, or irritation when observing a natural phenomenon or the outcome of an experiment, they document the fact that they expected something different. If, by contrast, they display pride, eager anticipation, or satisfaction, this indicates that their expectations have been confirmed. Emotional reactions are clear indicators of the importance that expectation formation has for children.

During the first years of life, children increasingly differentiate their expectations, and, as their linguistic ability grows, they also begin to formulate *explicit expectations* (Sodian, Körber, & Thörmer, 2004). Thus, their predictions reach a level of consciousness that facilitates both rule formation and communication about natural phenomena, and thus promotes cross-linking with prior knowledge.

If a child already has rule knowledge (Körber, Sodian, & Thörmer, 2005), or even prior knowledge in the form of a naive theory about a given natural phenomenon, the next development step is possible: explicit expectations become *hypotheses*. Between the ages of three and six years, the development of tacit and explicit expectations, in particular, plays a key role.

Whether the expectations that children form are consistent with "reality," in the sense of the laws of nature, is of less interest than whether they are aware of these expectations and can articulate them. For young children, thinking first and then acting is a great challenge. They are not yet used to taking the time to consider what might happen if they did a certain thing. And they have yet to learn how to communicate their deliberations. If an expectation is confirmed *after* it has been verbally formulated, the child will feel secure in its understanding of the situation. If an expectation is not fulfilled, this will motivate the child to ask "why?" and to investigate further.

Whereas in infants and young children the formation of expectations can be seen mainly from their emotional reactions to the outcome of events, somewhat older children are already able to verbally articulate their expectations when asked about them. Particularly advanced children even start to verbally articulate their expectations spontaneously, thereby demonstrating that they have developed a liking for thinking first and then acting.

Measurement

To date, the only instruments available are experimental procedures that investigate hypothesis formation in somewhat older children. However, within the framework of the standardised observation of behaviour, it would indeed be possible to measure spontaneous expectations, or expectations that are formulated upon request. The Ki-Ta-Nawi (early childhood education and care centre science diary) developed by Pauen (2009) is an example of such an instrument.

2.2.5 Trying Things out and Experimenting

A mastery of the art of experimenting is one of the tools of the trade of any good scientist. The term *experimenting* refers to the systematic manipulation of potentially relevant influencing factors while keeping other potential influencing factors constant (Körber, Sodian, & Thörmer, 2005).

Only by separately varying individual critical dimensions can their importance be explained more precisely. Recent studies in infant research suggest that children differentiate their physical knowledge by first identifying relevant influencing factors. However, as anyone who has frequent dealings with children between the ages of three and six years knows, systematic experimenting is the exception rather than the rule.

Experimenting is a highly complex act into which various other component skills must be integrated. In the present context, each of these component skills constitutes a separate goal. Here, the child actively plans an expectation-based action sequence, consciously processes its experiences, and makes comparisons. Although hardly any children between the ages of three and six will spontaneously engage in systematic experimentation, one does indeed encounter everyday situations in early childhood education settings in which children "try something out in a purposeful way" (i.e., test their expectations) and, when doing so, introduce variations. One typical behaviour would be testing which objects float or which objects are magnetic.

If one wants to define *experimenting* as a dimension of the goal of *scientific thinking* at pre-primary level, it would seem to make good sense to forgo purely expert definitions in favour of a somewhat broader definition of the term. Specifically, if one imagines a continuum with random "trying out" at one end and systematic manipulation of individual factors at the other, it would appear appropriate to locate children's experimenting behaviour between the two poles. When, in a specific situation, a child tries out different possibilities, all of which have the same aim (e.g., hearing how something sounds, testing whether things float, etc.), and this trying-out goes beyond simple repetition, this behaviour is covered by the term *experimenting*. The precondition would be that more than one variation is tried out.

Measurement

For measurement or operationalisation purposes, it would be conceivable to include in the assessment of the target behaviour, the frequency with which the corresponding component behaviours are observed, or to define different categories of experimenting behaviour that build on each other and thus indicate progress in the scientific thinking of the individual children. For example, progression might look like this:

a) The child engages with the material provided and purposefully tries to produce certain effects.
b) The child tries out more than one variant in order to produce a specific effect. It does not take into account the parameters that are varied at the same time.
c) The child makes sure that parameters remain constant and that only one factor is varied.
d) The child purposefully tries out more than two variants in order to produce a specific effect. When doing so, it always makes sure that other parameters remain constant.

Experimentation does not always have to be linked to action on the part of the child. It is also present when a child asks questions because it wants to know what would happen if a particular condition changed. This is the case, for example, when a child asks: "What would happen if I put salt into sparkling water?" and then adds "And if I used sugar?" Here, too, the decisive characteristic is that the child systematically asks about the significance of a specific variation. Moreover, a distinction could be made as to whether the child selects a controlled experiment from among different options (selection task) even if it is not yet capable of producing these conditions itself.

The measurement of the first-mentioned aspect at the action level can best be achieved within the framework of standardised observation of behaviour as provided for by Pauen's Ki-Ta-Nawi (2009) or by the Science Learning Assessment (SLA) developed by Samarapungavan, Mantzicopoulos, Patrick, and French (2009).

The additional (or parallel) measurement of verbal utterances presupposes dialogue with others. As an instrument for measuring both aspects does not yet exist, it would be necessary to develop one.

2.2.6 Evaluating and Justifying Experiences

Once the child has formed an expectation or expressed an assumption and found out by means of experiment whether its assumption is consistent with reality, the next step consists in acknowledging this experience. If the outcome is consistent with the child's expectation, evaluation is not usually a problem. The experience is interpreted as a confirmation of the child's own deliberations. The situation is different if the evaluation is not consistent with the child's expectations.

At pre-primary level, in particular, children often find it difficult to acknowledge an experience that is not consistent with their expectations. They prefer to repeat the same experiment again and again in order to see whether what they imagined would happen actually happens eventually. One often finds a tendency to simply deny or ignore evidence that contradicts their expectations.

Initial important progress in scientific thinking consists in acknowledging whether or not a given experience is consistent with one's own expectations (Sodian, Körber, & Thoermer, 2005).

The falsification of one's own expectations by counter-evidence is undoubtedly a great challenge because it calls for a number of demanding cognitive processes that correspond to the deduction of possible states for a given expectation. Moreover, children between the ages of three and six – and adults – tend to want to confirm their experiences rather than falsify them (Karmiloff-Smith & Inhelder, 1974). The insight that falsifications are important in order to gain knowledge of science has not yet developed between the ages of three and six.

Apart from simply stating whether or not a certain observation is consistent with one's expectations, it is also important to provide reasons why this is so. The justification of statements using empirical evidence is an essential characteristic of scientific reasoning (see Tytler & Peterson, 2005; Furtak, Hardy, Beinbrech, Shemwell, & Shavelson, 2010). If the children's own expectations or assumptions are confirmed, it is normally difficult to elicit from them anything other than the assertion that "it is what it is". However, this is not a proper justification. Experiences that disprove previous observations are therefore much more conducive to progress in scientific thinking. They can prompt children to reflect in depth about possible causes, because reference to the evidence does not appear to be useful. Jean Piaget saw in such situations of disequilibrium *(deséquilibration)* an important driving force for further cognitive development. Drawing on the works of Tytler and Peterson (2005), Furtak et al. (2000), and Jean Piaget, we distinguish in what follows:

a) *Circular reasoning:* It is so because it is so. (Not reasoning in the strict sense)
b) *Functionalist reasoning:* It is so because it is meant to be so (or because I want it to be so). (Recourse to the purpose or usefulness of a situation)
c) *Phenomenological reasoning:* It is so because X is so. (Also known as "focusing reasoning"; recourse to a specific aspect or a specific characteristic of the given situation)
d) *Relational reasoning:* It is so because it was also so in that case/because it was not so in that case. (Recourse to a specific other situation)
e) *Rule-based reasoning:* It is so whenever … (Also known as "formal reasoning"; recourse to general rules, different situations)

f) *Explanatory reasoning:* It is so because … (Recourse to explanatory constructs that are not directly observable)

Children between the ages of three and six can be deemed to have made progress in scientific thinking when their reasoning goes beyond (a) and (b) above. Whereas phenomenological and relational reasoning – and sometimes even rule-based reasoning – occur at pre-primary age, explanatory reasoning is the exception rather than the rule, as it is a particularly advanced form of the application of knowledge about the natural world.

Measurement

Whether a child is already searching for explanations for a phenomenon that it has observed, and, if yes, what type of reasoning it prefers, can best be determined operationally within the framework of a conversation about a surprising or unexpected outcome of a process. Standardised instruments that focus also on the measurement of scientific reasoning are few and far between, and those that are available are linked to specific domains (e.g., Samarapungavan, Mantzicopoulos, Patrick, & French, 2009; Furtak et al., 2010; Tytler & Peterson, 2005). However, they provide important ideas for the design of other instruments that relate to different content and that are suitable for children between the ages of three and six.

2.2.7 Integrating Experiences and Forming Abstractions

One reason why young children love to frequently repeat interesting effects is that they must first develop a feeling for the reliability of the connection between cause and effect. Hence, the ultimate purpose of the repetitions is to determine the statistical relationship between potential cause and effect.

If an observation is acknowledged, the next step consists in integrating it into existing knowledge structures. Only this integration leads to a lasting expansion of knowledge. The integration of new experiences into existing knowledge structures includes both the enrichment of existing knowledge (Spelke et al., 1992; 2009) and the restructuring of existing concepts (in the sense of conceptual change; Carey, 1985; 1993). As we are primarily interested here in children between the ages of three and six, processes of enrichment are the main focus of our attention. Children in this age range are often referred to in the literature as "universal novices" (Brown & DeLoache, 1978), although, as we know, they do not come into the world as a "tabula rasa" (Locke, 1872) but probably with innate "core knowledge" (Spelke, 2007).

In the case of *simple enrichment,* the new observation is added to the existing store of knowledge. It either confirms already established ideas or supplements them with a new aspect. In both cases there are no conflicts with already existing knowledge. The child registers the new information with interest but without any particular excitement or deep involvement. The situation is different if the new experience calls the existing knowledge structure into question. The child can deal with this situation in different ways, and can undertake the following:

a) correction in the sense of the *elimination* of an existing (false) conviction
b) *specification* of the context in which the existing knowledge is valid
c) *aggregation* of different knowledge elements (e.g., in the form of the abstraction of a general rule)

Each type of integration can be understood as an indication of scientific thinking, although specification and aggregation constitute particularly significant steps forward in thinking.

Measurement

This competency can be measured only by means of systematic questioning within the framework of standardised interviews with children aged around five or six. Although such an instrument does not yet exist, Piaget's clinical interview technique, which very often requires children to give reasons for an effect or a physical phenomenon, can serve as a model here.

2.2.8 Engaging in Further Deliberations

In the original definition of goals, mention was made of "inferences". Someone who draws inferences goes beyond simply integrating new experiences into existing knowledge systems. However, logical inferences are rarely found in children between the ages of three and six. Nonetheless, studies show that deductive and inductive reasoning is possible with contextual enrichment and support. Moreover, it is not unusual for children to link current experiences to previous experiences, thereby gaining new insights that they have not yet been able to verify or falsify by experience. In the present context, it seems reasonable to refer to such processes as *further deliberations,* because they are not usually genuine inferences in the sense of logical reasoning.

Further deliberations would also include the formulation of new questions that may give rise to further experiments. At this point, the cycle of scientific thinking comes full circle, and new expectations and assumptions come into play. If they are based directly on observations in the context of the child's own actions while engaging with the natural phenomenon, they are deemed to be *further deliberations*. Comparative or explanatory justifications, the integration of experiences, and the formation of abstractions can also be classified as further deliberations, provided the child spontaneously makes corresponding statements.

Further deliberations play a key role in the assessment of progress in scientific thinking about natural phenomena because they document the fact that the child actively engages with the new experiences and, on that basis, spontaneously formulates thoughts of its own.

Measurement

Operationally, it is possible to determine within the framework of conversations about an observed phenomenon how often such deliberations occur. However, such an instrument has not yet been developed.

2.3 Knowledge of Science

Mirjam Steffensky & Ilonca Hardy

This section focuses on the **knowledge of science** of children between the ages of three and six. First, the authors of this report briefly present a number of research findings on the knowledge of younger children. Next, the knowledge of science that should be the target of science learning at pre-primary level is described, and this description is concretised using domain-specific examples of common science topics at this level. When doing so, the authors are guided by what is considered to be desirable basic knowledge for all children, taking into account conditions such as the typical qualifications of early childhood professionals and existing practices at early childhood education and care centres. We assume that, under favourable individual learning conditions and with adaptive support, this basic knowledge can be supplemented with advanced concepts and appropriate practices, such as those that are the target of initial instruction at primary school.

We use the term ***knowledge*** in a very broad sense. In line with research on conceptual change (Vosniadou, 2008), it could also be referred to as *conceptions*. Thus, knowledge comprises not only knowledge shared by the scientific community but also subjective explanations, which may be partially inadequate from a scientific point of view. Moreover, the term is used here in the sense of *applicable knowledge*.

Research findings on younger children's knowledge of science

Many studies have shown that younger children are capable of developing initial knowledge about scientific phenomena (Carey, 2009; Gopnik & Schulz, 2007; Goswami, 2012) that lays the foundation for successively more complex ways of thinking. Children can observe and describe phenomena and recognise relationships or patterns (e.g., the ice cream melts because it is warm outside). Scientific explanations, which often use more complex models, such as underlying structures of a process, are difficult for younger children to understand because they lack prior knowledge and related conceptions. For example, understanding a dissolution process (sugar in water) would call for a conception of particles and of the interaction between the sugar and water particles. However, children in this age range are already capable of grasping numerous concepts. Between the ages of three and four, for example, children know that plants and animals can grow, but that cars and bicycles cannot (Gelman & Opfer, 2010). With suitable support, they are capable of developing initial material-related conceptions about why objects float or sink, or meaningful conceptions of air and magnetism (see, e.g., Leuchter, Saalbach, & Hardy, 2011). These conceptions, in turn, form the basis of subsequent differentiated concepts, such as density or air pressure. Comparable positive findings have also been reported in the domain of knowledge about science. For example, from around the age of five, children can partially distinguish between assumptions and data, which is a fundamental prerequisite to scientific reasoning in different domains (Koerber, Sodian, Thoermer, & Nett, 2005).

The development of knowledge takes place in a gradual process that is influenced by diverse factors such as cognitive abilities, prior knowledge, individual prerequisites, and learning opportunities. This process is characterised by the restructuring, differentiation, and integration of knowledge. Children successively construct knowledge of natural phenomena based on existing (naive) conceptions. In the initial knowledge stage, it is likely that knowledge is fragmented, and that incompatible conceptions are simultaneously held. Only over time, and especially through purposeful engagement in appropriate learning environments, are more integrated and coherent conceptions developed (diSessa, Gillespie, & Esterly, 2004).

Knowledge of science in the education plans of the German federal states

All of the current education plans of the German federal states *(Laender)* for pre-primary level refer to science as an educational focus. A comparative analysis of the educational standards (Fthenakis 2009: 14ff.) revealed that the following thematic aspects are mentioned:

- materials, properties, and aggregate states of substances or mixtures of substances (e.g., water, air)
- plant and animal growth and care
- methods and processes of scientific thinking and working, such as observing, describing, communicating, comparing, classifying, measuring, and experimenting

Moreover, all the education plans refer to a sense of ecological responsibility as a goal of the engagement with science content (Education for Sustainable Development, ESD). In addition, affective and motivational components, such as the development of interest and intrinsic motivation in relation to the engagement with science, are emphasised. However, there is a lack of clarity regarding the appropriate depth and breadth of knowledge of science aimed for at pre-primary level. For example, the education plans include broad categories, and in education initiatives for the promotion of early science learning there is great divergence of opinion about the expected learning goals (Giest & Steffensky, 2010).

Characteristics of early knowledge of science

In line with research findings and international curricula, and taking into account subsequent learning experiences at primary school, we describe the knowledge that children should acquire by the end of pre-primary education. Initially, it is not a matter of defining specific content domains but rather of characterising the type of knowledge (in the sense of basic knowledge) to be acquired.

Science learning at pre-primary level is not conceptualised as the acquisition of the academic content knowledge focused on at school. Rather, children should be offered foundational experiences in scientifically relevant situations of everyday life so that they can build up basic knowledge, for example by perceiving phenomena, describing their observations and conceptions in their own, age-appropriate technical and everyday terms, and making comparisons with similar experiences and phenomena. In this way, children can be supported in expanding their knowledge base, applying it in diverse contexts, and making connections between different phenomena.

Hence, one goal of learning at pre-primary level is to develop experience-based, connectable, everyday knowledge of basic concepts (Fthenakis, 2009; Gelman & Brenneman, 2004; French, 2004; Eshach, 2006; Möller & Steffensky, 2010). Children are not expected to perform radical conceptual change whereby they transform naive knowledge into advanced scientific conceptions. However, we expect that they should be supported in constructing a conceptual basis and preparing subsequent conceptual development by productively challenging their naive conceptions and bringing them to a level at which they are connectable and appropriate for explaining phenomena of everyday life.

2.3.1 Foundational and Structured Experiences

Children's everyday experiences in scientifically relevant situations are fundamental to the development of basic knowledge. Further information on the role of experiences in the context of scientific thinking can be found in Sections 2.2.1 to 2.2.3.

The authors of this report distinguish between **foundational experiences** and **structured experiences**:

Foundational experiences are experiences of initial engagement and contact with scientific situations, processes, or phenomena. These experiences, and the resulting basic knowledge, are often encountered incidentally and in play contexts, and even adults do not perceive them as part of science experiences (van Schijndel, Singer, van der Maas, Han, & Raijmakers, 2010). Of primary importance is the active engagement with, and the physical perception of, natural phenomena such as air, water, or weight/mass. Thus, it can be assumed that experiences related to the fundamental categorisation of objects (e.g., into animate, inanimate, or into properties of matter; see Wiser & Smith, 2008) serve as a prerequisite to children undertaking further differentiation of scientific concepts. The special role of mathematics for the differentiation of concepts is also discussed by several authors (Wiser & Smith, 2008; Lehrer et al., 2005).

Before children begin to develop initial conceptions of floating and sinking, for example, we presume that they need to have had foundational experiences with water. Even if they do not yet know the term *liquid,* they must perceive water as something that is not directly graspable, that is soft, pourable, etc. These properties of water are so obvious that children must first have diverse experiences with them before they notice further, less obvious properties. For example, while taking a bath, children may notice that some objects float and others sink, or they may perceive that some objects are being pressed upwards by the water. Another example of such foundational, free-play experiences is pouring water from one container into a different-sized container. When doing so, children will notice, for example, that when they pour all of the sand from a large beaker into a smaller beaker, the smaller beaker will overflow. This type of experience is presumably a prerequisite to understanding relative size and to performing the process of comparison, for example in science inquiry.

Structured experiences are experiences in which phenomena are not only actively experienced but also deliberately reflected upon. Thus, conditions are created in which children can recognise how natural phenomena occur. The transition between experiences such as these and knowledge in the sense described above is fluent. A key element of such structured experiences is the drawing of comparisons between situations in which the same phenomenon is observed (see Namy & Gentner, 2002). This enables the child to recognise structural commonalities and establish initial regular (i.e., rule-based) relationships between perceptually dissimilar situations. For example, butter melts in the pan and on toast; chocolate melts in the car; ice cubes melt in a drink; a frozen lake melts in the sun. Although these situations differ greatly in their surface features, children can observe a change from solid to liquid even if they are unfamiliar with the relevant term, *melting*.

2.3.2 Formulations and Terms

Children should be capable of using relevant everyday terms and formulations to describe natural phenomena, and thus of *describing and recording experiences* (Section 2.2.2 above), one of the dimensions of the scientific thinking and process goal. The target here is the use of everyday terms that can be applied also in science contexts, for example *solid, liquid, hot, cold, melting, floating, sinking, air,* and *magnets*. In many cases, however, everyday paraphrases may suffice to represent and describe situations and phenomena. For example, the term *drying* can be used instead of *vaporisation* or *evaporation* (see also Section 2.4.4, basic language competencies).

2.3.3 Basic Concepts

In preschool science, learning goals are conceived of as children constructing and differentiating basic concepts that need not necessarily correspond to scientific concepts. However, these conceptions should be “connectable” to a further progression of concepts. In many cases, building up and differentiating basic concepts involves abandoning naive conceptions, and therefore presupposes the conceptual restructuring or differentiation of existing concepts. Thus, there is a link between this goal and two of the dimensions of the scientific thinking and process goal, namely *comparing and discussing experiences* and *integrating experiences and forming abstractions*. For example, when introducing children to the phenomenon of floating and sinking, one addresses the materials aspect rather than Archimedes’ principle

In everyday situations, it is often not possible to distinguish clearly between children's understanding of concepts and their ability to verbally describe them. For example, in order to describe the process of melting, children must be familiar with the terms *melting* and/or *solid* and *liquid*. Moreover, they require a conception of *melting* in the sense of the melting process (a solid becomes a liquid). Verbalisation can thus be seen as an aid to building up and expressing the respective concepts. At the same time, there remains the question of children's understanding of concepts at different levels. A difference may be expected between explanations using concepts presented, for example, in multiple-choice questions and explanations that are independently produced during interviews, as it is easier for children to react to presented concepts than to independently produce explanations (Pollmeier, Hardy, Koerber, & Möller, 2011).

Especially at an advanced everyday and scientific level, concepts can be conceived of as correlational knowledge, that is, knowledge that enables the formulation of relationships between states in the sense of "if-then" or "the more/less, the less/more" relationships. For example: "If the sun shines, the washing will dry faster." or "The thicker the ice on the puddle is, the slower it will melt". When formulating these types of relationships, varying degrees of situatedness of knowledge are likely. Some children are capable of formulating such statements in a more generalised way, for example: "The warmer it is, the faster things will melt". Others refer to concrete situations. Thus, the degree of generalisation refers to the degree of consistency with which the laws of nature are expressed.

An important aspect of knowledge of science is the manner in which (empirical) reasons for the occurrence of scientific phenomena are formulated, that is, the process of scientific reasoning. In the domain of science, special attention is paid to the way people deal with empirical evidence, and to the role that this evidence plays in their explanations (see also Beinbrech, Kleickmann, Tröbst, & Möller, 2009; Furtak et al., 2010). Assumptions about different levels of scientific reasoning are outlined in Section 2.2.6 (scientific thinking and process). Statements about natural phenomena are often formulated as propositions. The aim of early engagement with scientific questions is to highlight the importance of justifying propositions through observations (from everyday life or from experiments). The justification of statements, especially by using empirical evidence, is an essential characteristic of scientific reasoning. As explained in Section 2.2.6, four levels of reasoning at which statements are justified can be distinguished: non-reasoning, phenomenological reasoning (only one characteristic/observation is cited), relational reasoning (several data points are aggregated), and formal reasoning (rule-based justification).

Application with examples in the context of "water"

In Table 1, the above-mentioned knowledge components are concretised in an age-appropriate way using examples in the context of "water," namely aggregate states of water and the phenomenon of floating and sinking. The authors of this report describe an intermediate level of knowledge that children can typically achieve when provided with the respective experiences.

Experiences are differentiated into foundational free-play experiences and structured experiences in which children reflect on what they perceive. As far as possible, the *formulations and terms* presented are everyday terms and paraphrases actually used by children between the ages of three and six in the respective science contexts. The term *concepts* refers to connectable conceptions at varying levels. Correlational knowledge is located at a higher level of conceptual understanding than single-concept knowledge. Thus, it represents the beginning of generalisation in the sense of "if-then" or "the more/less, less/more" relationships.

Table 1. *Knowledge of the concepts of "melting and freezing" and "vaporisation/evaporation and condensation" (Steffensky, Lankes, Carstensen, & Nölke, 2012)*

	Melting and Freezing	**Vaporisation/Evaporation[11] and Condensation**
Experiences foundational	Playing with water, e.g., pouring it (from one container to another); touching it; trying to grasp it; splashing; playing with snow and ice, e.g. building things with snow, making shapes	Observing steam over boiling water; observing breath on a cold winter's day; drawing on a steamed-up mirror
structured	Letting ice cubes melt in the hand, the mouth, or in a drink; turning water to ice; playing on frozen puddles	Drying washing; drying water colours; drying hair with a hair dryer
Formulations and terms (The children use these terms and phrases [in German] to name and describe situations and phenomena. English translations may vary.)	*Properties of water and ice:* solid; hard; cold; liquid; soft; warm; can be poured (from one container to another) *Transitions between the states:* turns to liquid; turns to water; melts; defrosts; turns solid; turns to ice; freezes	*Properties of steam[12]:* invisible; like air; you can't grasp it/take hold of it *Transitions between the states* goes into the air; turns into air; turns into steam/mist; dries; boils; steams up/mists up; becomes water again

11 *No differentiation is made between the terms vaporisation and evaporation.*

12 *No differentiation is made between steam in the everyday sense of the word and steam in the scientific sense (i.e., water in a gaseous state).*

	Melting and Freezing	Vaporisation/Evaporation and Condensation
Basic concepts (The children can name and describe these concepts and use them to predict everyday situations. They establish relationships between characteristics of a situation and effects/observations. They usually frame these relationships as "if-then" relationships.)	Ice can turn to water and vice versa. Ice melts in the sun or on the radiator. Water freezes and turns to ice in the freezer/in winter. If it is warm, then ice will melt. The warmer it is, the faster ice will melt. Other things can melt, too, for example, chocolate, cheese, and wax. If it is cold, then water will turn to ice. The colder it is, the faster water will freeze.	Water can turn into steam and vice versa. Things dry in the sun. Liquid water becomes steam when it boils. A cold window pane/mirror fogs up and the water becomes visible again. If it is very warm/hot, water will go up into the air (water will boil). The warmer it is, the faster water will turn to air/the faster wet things will dry. The concept of condensation is much more difficult because it is not as easy to observe (something invisible becomes liquid water). Therefore, more generalised knowledge is not expected, and it is not described here.)

Table 2. *Knowledge of the concepts of material, buoyancy, and displacement in the context of "floating and sinking" (Hardy et al., 2006)*

	Material/Density	Buoyancy	Displacement
Experiences fundamental	Playing with water, e.g., pouring water from one container to another, touching it, trying to grasp it, splashing Playing with ships, using objects as rafts, throwing different objects into water and observing whether they float	Children's experiences with their own bodies at the swimming pool: lifting other children up, floating, trying to dive deep, etc.	Immersing objects in water and taking them out again; causing a glass of water to overflow
structured	Comparing which objects float and which objects sink; comparing everyday objects of the same shape, weight, size, and material; Testing whether objects that contain air always float	Trying to change the shape of objects that sink (e.g., plasticine) so that they float; trying out different loads for ships; trying out ships of different shapes	Comparing where the water rises higher (in the case of objects of the same shape, material, etc.)

	Material/Density	Buoyancy	Displacement
Formulations and terms (The children use these terms and phrases in German to name and describe situations and phenomena. English translations may vary.)	*Description of materials:* Designations of materials: wood, polystyrene, metal/iron, plastic, stone, etc. Heavy material, light material; lighter than/heavier than; feels heavy/light *Floating and sinking:* Surfaces/pops up; floats; comes up to the top; goes down; sinks; floats/does not sink completely	*Description of buoyancy:* Water pushes things (upwards). Water presses against things.	*Description of displacement:* Water needs space. Water rises.
Basic concepts (The children can name and describe these concepts. They establish relationships between characteristics of a situation and effects/observations. They usually frame these relationships as “if-then” relationships.)	Whether an object floats or sinks depends on the material it is made of. Whether an object floats or sinks does not depend on what it looks like: on its size, its weight, or on whether it has holes. Light materials float: wood, polystyrene, cork, wax, some plastics. Heavy materials sink: iron/ metal, stone, porcelain, clay, etc. If something is made of a material that is heavier (than water), then it will sink. If something is made of a material that is lighter (than water), then it will float.	The water presses (against me, against things in the water). Large, hollow objects often float. Hollow objects float better than objects that are not hollow. If something is immersed in water, then the water will press against it. The bigger something is, the greater the pressure of the water against it.	The water rises higher in the case of larger objects, than in the case of smaller objects.

Measurement

To date, there are only a few valid and standardised instruments for measuring the knowledge of science of children between the ages of three and six. A test to measure the science competencies of four-year-olds was developed within the framework of the German National Education Panel Study (NEPS). It covers the topics of health, environment, and technology (Hahn et al., 2013). The Science Learning Assessment (SLA; Samarapungavan, Mantzicopoulos, Patrick, & French, 2009) focuses more on specific subject content. It is a standardised and validated instrument that can be used to measure components of knowledge of science in one domain of animate nature (the life cycle of butterflies) and knowledge about scientific inquiry processes.

In the domain of inanimate nature, mention can be made here of a test developed within the framework of the SNaKE project with which terms and concepts in the domain of aggregate states and solutions can be measured (see Table 1, Carstensen, Lankes, & Steffensky, 2011; Steffensky, Lankes, Carstensen, & Nölke, 2012). Moreover, the test comprises several items with which selected aspects of the ways of thinking and working (observing/measuring and [systematically] comparing) can be measured that are related to the said content-specific aspects. However, because of the small number of items in this domain, the test is of an explorative nature.

To date, structured interviews with an open-ended question format have been the main method used to measure the conceptual knowledge of young children in the domain of floating and sinking (e.g., Leuchter, Saalbach, & Hardy, 2011, Kallery, 2015). Because of the small number of items and the small sample sizes, the psychometric properties of these instruments have not been systematically validated. However, even between the ages of three and six it would be conceivable to use insights from standardized tests from primary level in the domain of floating and sinking that measure children’s cognitions at different levels of understanding on the basis of multiple-select or multiple-choice questions (e.g., Kleickmann, Hardy, Möller, Pollmeier, & Tröbst, 2010). Along these lines, standardized instruments to measure children’s conceptual knowledge in the domains of magnetism, floating and sinking, evaporation and condensation, and material type have been developed within the framework of the project EASI Science (e.g., Ziegler & Hardy, 2015).

2.4 Basic Competencies

Yvonne Anders

In addition to the domain-specific science competencies, domain-general competencies are also a goal of the educational offerings of the “Haus der kleinen Forscher” Foundation. They comprise general cognitive competencies, language competencies, social competencies, fine motor competencies, and mathematical competencies. It is assumed that the Foundation’s educational offerings have an indirect rather than a targeted and specific impact on these competencies. By way of illustration, consider the following example: When experimenting, children learn collaboratively with others and have joint experiences. In this way, social competencies are addressed as well. We assume, however, that these competencies are also addressed by other group activities that are not connected with the offerings of the “Haus der kleinen Forscher” Foundation. For this reason, we do not currently classify basic competencies as a priority goal for measurement purposes.

Although basic competencies are not assigned priority in the context of the measurement of the outcomes of the “Haus der kleinen Forscher” initiative, it will be necessary to measure some aspects, at least in the sense of control variables. In what follows, we describe the basic competencies and assess their importance for outcome measurement. We also discuss possible ways of measuring them.

2.4.1 Cognitive Competencies

The term *general cognitive competencies* refers to various verbal and non-verbal abilities such as problem-solving strategies, memory capacity, speed of information processing, ability to concentrate, visuospatial perception, and metacognitive abilities (e.g., Zimbardo, 1995). It is undisputed that general cognitive competencies also influence the acquisition of domain-specific knowledge and strategies. Against this background, they are also important in the context of the offerings of the “Haus der kleinen Forscher” Foundation. On the one hand, it makes sense to measure children’s general cognitive abilities in order to control for their influence. On the other hand, we assume that engagement with natural phenomena and experimenting can also have a positive impact on general cognitive competencies (e.g., problem-solving strategies).

Measurement

There are already a number of instruments for measuring the general cognitive competencies of children aged three years and upwards (Roßbach & Weinert, 2008). For example, the level of development in the domains of spatial reasoning, inductive reasoning, analogous reasoning, orientation in the lifeworld, visuospatial awareness, and phonological storage capacity can be measured with the *Wiener Entwicklungstest* (Vienna Development Test, WET) developed by Kastner-Koller and Deimann (2002). One advantage of this general development test is that it also includes scales for measuring the level of development of motor skills and social skills. In addition to general development tests, there are also instruments that focus exclusively on cognitive competencies. They include, for example, the Kaufman Assessment Battery for Children (K-ABC), a German-language version of which is also available (Melchers & Preuss, 2009). The K-ABC is a good means of measuring both overall intelligence and non-verbal intelligence.

2.4.2 Social Competencies

Social competencies is an omnibus term for different facets that relate to adaptation to social norms and rules and to the assertion of the individual's own needs (see Kanning, 2001). Caldarella and Merrell (1997) distinguish the following dimensions: formation of positive peer relations, self-management, social cooperation, social assertion, and skills in the context of academic learning (e.g., the ability to listen to the teacher). Moreover, conspicuous or problematic social behaviour constitutes a separate dimension that is of particular relevance at pre-primary level, because there is a risk that early behavioural problems will get worse over the course of the child's development (Campbell et al., 1996). In the case of problematic social behaviours in children, internalising and externalising symptoms can be distinguished (see Achenbach & Rescorla, 2000). Internalising symptoms are mainly behaviours characterised by excessive social withdrawal and anxiety, while externalising symptoms comprise aggressive and delinquent behaviours. Delinquency is not, of course, an issue between the ages of three and six.

Although we do not classify social skills as a priority goal of the educational offerings of the "Haus der kleinen Forscher" Foundation for measurement purposes, they are nonetheless relevant in many respects. On the one hand, social skills are related to the development of cognitive performance (Jerusalem & Klein-Heßling, 2002). On the other hand, it can be assumed that children who exhibit more pronounced prosocial behaviour have better prerequisites for availing of the learning opportunities afforded by the "Haus der kleinen Forscher" Foundation. This explains the status of social competencies as a control variable in studies aimed at investigating outcomes at the level of the children. Moreover, it can be assumed that the learning opportunities and forms of learning (joint exploration of natural phenomena and collaborative inquiry) supported by the "Haus der kleinen Forscher" initiative also foster prosocial behaviour and cooperative competencies.

Another reason for taking social competencies into account in an outcome study stems from the fact that, in Germany, the fostering of precursor competencies at pre-primary level still meets with scepticism and reservations in many quarters. A frequently voiced assumption in this context is that the fostering of cognitive competencies is implemented at the expense of the fostering of social development. Against this background, it would seem to make good sense to include the domain of social competencies in the measurement. In this way, it can be proved that the "Haus der kleinen Forscher" initiative has no negative effects on children's social behaviour.

Measurement

Several tried-and-tested instruments already exist for measuring social competencies or conspicuous social behaviours (Weinert, Doil, & Frevert, 2008). Most of these instruments are rating procedures that make use of the assessments of parents, early childhood professionals, and other adults in the child's environment. There are also a number of observation-based procedures.

Mention can be made here of the Child Behaviour Checklist (CBCL), which is based on the Achenbach Scales (e.g., social withdrawal, attention deficits, aggressive behaviour; Achenbach, 1991; Arbeitsgruppe Deutsche Child Behaviour Checklist, 1998). The Strengths and Difficulties Questionnaire (SDQ) for children from the age of four years (Goodman, 1997) has also proved its worth. The SDQ measures the following aspects: emotional problems, conduct problems, hyperactivity, peer problems, and prosocial behaviours. There are a number of other instruments with similar conceptualisations; and some general development tests include scales for measuring the level of social development.

2.4.3 Fine Motor Competencies

Following Bös and Mechling (1983), the term *motor functions* refers to all control and functional processes underlying posture and movement. Gross motor functions comprise movements and posture of the torso, the legs, the arms, and the head. Fine motor functions refer to all finer movement and coordination processes (moving the fingers, grasping, manual dexterity).

With regard to the offerings of the "Haus der kleinen Forscher" Foundation, the authors of this report assume that the various activities that children engage in, for example when experimenting, also stimulate the development of motor functions, and especially fine motor functions. However, in contrast to other goal dimensions, it can be assumed that motor skills have less influence on overall cognitive development and subsequent scholastic development. For this reason, they are not classified as a priority dimension.

Measurement

There are already a number of validated instruments for measuring motor skills in children between the ages of four and six. However, the goodness of fit between these instruments and the Foundation's offerings would have to be tested. Two examples can be mentioned here: first, the *Motoriktest für 4–6jährige* (MOT 4–6; Zimmer & Volkammer, 1987), a test of sport motor development that is geared completely towards the movement needs of children between the ages of four and six and measures various aspects of children's motor functions, for example, fine motor dexterity, reaction capacity, and coordination capacity; second, the *Wiener Entwicklungstest* (Vienna Development Test, Kastner-Koller, & Deimann, 2002, see above) which includes scales for measuring fine motor and gross motor functions.

2.4.4 Language Competencies (Domain-General)

That language acquisition plays an important role in children's development is well documented (see, e.g., Weinert, Doil, & Frevert, 2008). The ability to understand, produce, and use language is very important, not only for cognitive development and cognitive performance but also for social development. Language is the prerequisite for participation in a speaking world.

Language abilities and skills are made up of a number of different, only partially separable, components. They include the rhythmic and prosodic component (stress, elongation, intonation); the phonological component (semantically differentiating sound categories); the morphological component (word formation); the syntactic component (word order); the lexical semantic component (meaning structure); and the pragmatic component (rules of language use; Grimm & Weinert, 2002).

The relevance of language competencies as a goal to be considered in the context of the "Haus der kleinen Forscher" Foundation is explained by their relevance for cognitive development as a whole. Thus, we consider it absolutely essential that language competencies be measured as a control variable within the framework of outcome measurement.

Moreover, we assume that engagement with the environment, as promoted by the "Haus der kleinen Forscher" initiative may also have a positive impact on children's language competencies. However, the potential impact of the "Haus der kleinen Forscher" initiative on general language competencies is considered to be secondary compared to its impact on science-specific terms (see Sections 2.1.2 and 2.2.2).

Measurement

Instruments that enable language abilities and skills to be measured in a reliable and valid way are now available also in the German-speaking area. However,

some of these instruments were developed as screening tools for the early identification of language acquisition problems, and they therefore differentiate mainly at the lower levels of performance. The following instrument types can be distinguished:

(a) general language tests that measure receptive and expressive aspects of different linguistic components
(b) language tests that test specific abilities and skills (e.g., expressive or receptive vocabulary)
(c) language-related subtests within the framework of tests of development or tests that measure general cognitive abilities (for a critical overview, see Fried, 2004)

Large longitudinal studies often use receptive vocabulary as a measure of the language abilities of children between the ages of three and six, for example by administering the corresponding subtest of the Kaufman Assessment Battery for Children (K-ABC), which is available also in German (Melchers & Preuss, 2009).

Receptive vocabulary is considered to be a measure of crystallized intelligence, and would thus be a very efficient control variable. It has a predictive function for both reading and language comprehension. This also explains its importance for the subsequent scholastic career. Accordingly, when measuring the outcomes of the Foundation's offerings it appears to make sense to also measure general receptive vocabulary in order to control for language competencies.

2.4.5 Mathematical Competencies

Like the acquisition of language competencies, the acquisition of early mathematical competencies is considered essential for cognitive and scholastic development (e.g., Duncan et al., 2007). Early mathematical abilities and skills include, for example, knowledge of numbers, counting, an understanding of quantities, comparing, classifying, doing arithmetic, and comprehension of mathematics-related language (see Roßbach & Weinert, 2008). The conceptual proximity of individual abilities and skills to science competencies is evident. This explains why it can be assumed that the learning opportunities afforded by the "Haus der kleinen Forscher" initiative also have a positive impact on mathematical competencies, and that mathematical competencies, in turn, have a positive impact on the acquisition of science competencies. That is why we are including them as a goal.

However, a research concept always needs a focus, and if we were to treat mathematical competencies and science competencies equally, this would soon overtax the model because competencies (knowledge, beliefs etc.) on the part of early childhood professionals would have to be correspondingly expanded and measured. At this point, therefore, mathematical competencies will be classified as secondary compared to science competencies.

In studies aimed at measuring dimensions of science competencies, mathematical competencies should be measured as a control and moderator variable. This is because of (a) possible overlaps with the development of science competencies and (b) the fact that a number of programmes for the promotion of mathematical competencies at pre-primary level are currently being implemented, and possible outcomes of these measures should be distinguished from the outcomes of the Foundation's work.

Measurement

Various instruments for measuring mathematical competencies are now also available in the German-speaking area. Purely mathematics-related tests include the Neuropsychological Test Battery for Number Processing and Calculation in Children (Aster, Weinhold, Zulauf, & Horn, 2006), the *Osnabrücker Test zur Zahlbegriffsentwicklung* (Osnabrück Test for the Development of Number Sense; van Luit, van de Rijt, & Hasemann, 2001), the NEPS Test (Neumann, Duchardt, Grüßing, Heinze, Knopp, & Ehmke, 2013) and the *Test zur vorschulischen Zahlen- und Mengenkompetenz* (Test of Preschool Quantity-Number Competencies; Krajewski, 2003). In international studies, researchers frequently make use of the subtests of the Kaufman Assessment Battery for Children (K-ABC), which is also available in German. The arithmetic subtest has proved especially sensitive to the effects of learning support (see Anders, Große et al., 2012; Anders, Roßbach et al., 2012; Roßbach et al., 2010).

3. Goals at the Level of Early Childhood Professionals

3.1 Motivation, Interest, and Self-Efficacy in Engaging With Natural Phenomena

Yvonne Anders

Motivational and emotional aspects of professional action play an equally important role in imparting science competencies as they do in acquiring science competencies, which is why they are also regarded as a goal at the level of the children (see Chapter 2). Although they are related to individual facets of the professional attitude, especially pedagogical orientations and beliefs (see Section 3.4), they are considered to be an independent facet of the professional action competence of early childhood professionals (e.g., Baumert & Kunter, 2006; Fröhlich-Gildhoff et al., 2010). Here, we address three aspects that we consider to be particularly important for the implementation of the “Haus der kleinen Forscher” initiative, and that therefore constitute goal dimensions at the level of the professionals.

3.1.1 Emotional Attitude to, and Interest in, Science

The *emotional attitude to science* is an affective attitude component and is closely related to pedagogical beliefs. Education professionals’ emotions towards a subject can be transmitted to children, irrespective of whether these emotions are positive (e.g., science is experienced as enjoyable) or negative (e.g., science induces fear and aversion). Moreover, research shows that negative emotions towards a school subject can lead professionals to avoid imparting science competencies (Erden & Sönmez, 2011).

Interest in a domain is closely related to emotional attitude. *Interest,* in the sense of a psychological disposition, refers to an active effort to expand competence (Muckenfuß, 1995). Understood in this sense, interest is a component of the self-concept and is characterised by action, cognitive engagement with the object field, and selective assessment. It can be assumed that interest in, and enjoyment of, engaging with specific content are closely related. Accordingly, professionals who implement the fostering of science in early childhood education settings should also develop a deep interest in, and enjoyment of, engaging with science. It can be assumed that this interest and enjoyment will also be reflected in enthusiasm when designing and implementing learning processes in the domain of science (see Section 3.3.2), and will thus have an impact on children’s competence development. Moreover, interest and enjoyment can be directly transmitted to children, thereby fostering their intrinsic learning motivation.

An open, positive emotional attitude to science, and a great interest in the domain can thus be regarded as a dimension of the goal at the level of the early childhood professionals who participate in the Foundation's professional development programme.

3.1.2 Enthusiasm for Designing and Implementing Science Learning Processes

In line with motivation research, *enthusiasm* in the work context is understood as the stable, positive experience of the professional activity. Thus, teacher enthusiasm reflects the degree of positive emotion experienced during the activity of teaching (Kunter, 2011, p. 44). It was shown that teachers' enthusiasm for the subject taught correlated positively with instructional quality. This explains why subject-related enthusiasm is also relevant for early childhood professionals when implementing their educational mandate. In relation to the design and implementation of science learning processes at early childhood education centres, *enthusiasm* thus reflects how positively early childhood professionals perceive the design and implementation of science learning at their institutions. It can therefore be assumed that an early childhood professional's enthusiasm is associated with his or her emotional attitudes to, and beliefs about, the importance of science learning between the ages of three and six. It is also assumed that this enthusiasm has an impact on the development of children's science competencies, their motivation, their willingness to learn, and interest in, science.

3.1.3 Perceived Self-Efficacy With Regard to the Facilitation of Children's Science Learning Processes

Perceived self-efficacy refers to a person's belief in his or her ability to master demands (see Bandura, 1997). Tschannen-Moran and Woolfolk-Hoy (2001, p. 117) define *teacher efficacy* as "a teacher's belief in her or his ability to organize and execute the course of action required to successfully accomplish a specific teaching task in a particular context." What is particularly noteworthy about this definition is that perceived self-efficacy is always linked to a specific context. In the context of the "Haus der kleinen Forscher" Foundation, the perceived self-efficacy of professionals with regard to facilitating children's science learning processes in early childhood education settings can be emphasised.

Measurement

Individual aspects of the above-mentioned facets can be measured with the Early Childhood Teachers' Attitudes toward Science Teaching Scale (Cho et al., 2003). This instrument, or similar instruments (e.g., Kuhn, Lankes, & Steffensky, 2012), would have to be adapted to the concrete content of an outcome study. Furthermore, instruments are also available for other content domains at primary and secondary level, and they could be used as a basis for developing a new or enhanced instrument (e.g., Kunter, 2011; Pauen, 2006).

3.2 Scientific Thinking and Process When Engaging With Natural Phenomena

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In addition to content knowledge and pedagogical content knowledge, early childhood professionals also require knowledge about science, which comprises (a) an understanding of the *nature of science* and (b) methodological knowledge *(methods of scientific thinking and working)* of procedures that are frequently used at pre-primary level and are mentioned in the education plans of the German *Laender* and in didactics resources (e.g., Hardy et al., 2010). These procedures include, for example, making observations, comparing, sorting, testing, measuring, and documenting. Early childhood professionals should not only be able to apply these methods of thinking within domain-specific activities, they should also demonstrate a general understanding of the scientific method. For example, they should understand that, regardless of the type of instrument used, measurement always involves a comparison with a standard unit with the aim of being able to make general objective and quantifiable statements. They also require an understanding of why measurement errors should be taken into account when interpreting results. Early childhood professionals can further be expected to be capable of designing and interpreting simple inquiry activities and of constructing and interpreting simple forms of data representation used in science, such as tables, bar charts, and coordinate systems.

In close alignment with the dimensions of the goal of scientific thinking and process at the level of the children (Section 2.2), we concretise the domains as follows:

The first two components, "consciously experiencing and observing" and "describing and recording experiences," are fundamental demands on the cognitive processing of sensory impressions that early childhood professionals can be expected to master at an appropriately high level. Hence, they should be capable of observing natural phenomena in a concentrated and focused manner, and of reporting their observations in an appropriate verbal way – that is, by using scientifically relevant terms.

The anchoring of observations in previous learning experiences by making *relevant comparisons or analogies* is closely related to the nature of the conceptual knowledge base (see Section 3.3.). It can therefore be assumed that new experiences in a particular domain about which the person has already built up conceptions will be described much more frequently by means of comparisons relating to relevant features and characteristics of the situation. Experiences in a domain with pre-existing scientific misconceptions are more likely to be described in a basic manner. Early childhood professionals are expected to be capable of describing new observations and experiences by making structural comparisons with other, similar situations. In the content domain of "water," for example, they should be able to predict that an unknown solid metal object will sink, to draw comparisons with the sinking/floating behaviour of other metal objects (solid bodies), and to distinguish the sinking/floating behaviour of solid metal objects from that of hollow metal objects.

The components "forming expectations," "trying things out and experimenting," "evaluating and justifying experiences," "integrating experiences and forming abstractions," and "engaging in further deliberations" refer to domains of methodological understanding or scientific work at the level of the early childhood professionals. In science education, for example, secondary students' experimenting skills are differentiated as follows: hypothesis formation, design of inquiry activities, measurement of results, and interpretation of results at different levels of understanding (Schreiber, Theyßen, & Schecker, 2009).

In close alignment with the goal dimensions at the level of the children, it can be expected that early childhood professionals' actions in science learning situations be guided by specific assumptions that can be tested by means of simple inquiry activity designs (while controlling for possible influencing variables). Early childhood professionals are not expected to display an understanding of the nature of science at the highest level. However, they should be able to distinguish between a hypothesis, a theory, and evidence.

Following Carey et al. (1989), different levels of the understanding of the nature of science can be distinguished. To be able to justify inquiry activity designs for the purpose of knowledge acquisition, early childhood professionals are expected to display relatively advanced conceptions of the relationship between theory, hypothesis, and evidence, and should be capable of using and interpreting experimental data. Interview studies have shown that even students at upper secondary level often still adopt an unreflective epistemological stance, namely, that knowledge of science is acquired in a simple and unproblematic way, for example by means of direct observation ("knowledge unproblematic," Carey & Smith, 1993). A stance such as this is characterised by the failure to make a clear distinction between theories and hypotheses, on the one hand, and empirical evidence, on the other, and by an inadequate understanding of the cyclic and cumulative nature of knowledge of science (Carey, Evans, Honda, Jay, & Unger, 1989).

In order to justify the role of experiments and inquiry activities in learning arrangements and to productively take them into account in learning processes, early childhood professionals require an advanced level of understanding of the nature of science (at least Level 2) in which science is seen as a search for explanations. The quality of reasoning (the "evaluating and justifying experiences" dimension) that early childhood professionals are expected to exhibit (see Section 2.2.6 at the level of the children) is also derived from their level of understanding of the nature of science. They are expected to use at least relational reasoning by drawing on the commonalities between observations as a basis for justifications, or to establish regular (i.e., rule-based) relationships. With regard to scientific reasoning, it should also be emphasised that the fundamental importance of empirical evidence (and thus, the role of the experiment) should be apparent to early childhood professionals. This means that the verification or verifiability of justifications is always questioned, and that such relational or rule-based justifications are used, and considered superior, because they are based on empirical data.

Measurement

Overall, instruments for measuring components of scientific thinking at the level of early childhood professionals differ from those at the level of the children. It can be assumed that some of these components are integrated into superordinate conceptual structures, and, in contrast to young children, contribute to a fundamental understanding of the role of science, which then guides action. Nonetheless, aspects of the scientific process, for example experimenting skills, can probably be measured separately.

To date, little research has been conducted on education professionals' knowledge about science (understanding of the nature of science and methodological knowledge). Instruments developed within the framework of the Science-P project (Möller, Sodian, Hardy, Koerber, & Schwippert) aim at measuring primary school teachers' understanding of the nature of science and their pedagogical content knowledge of methods of scientific thinking and working. When assessing the understanding of the nature of science, recourse can also be had to the internationally validated scale Student Understanding of Science and Scientific Inquiry (SUSSI; Liang, Chen, Chen, Kaya, Adams, Macklin, & Ebenezer, 2006). Pedagogical content knowledge of scientific thinking methods and the understanding of the nature of science is a little-researched domain. Hence, it is unclear whether it is a dimension in its own right. Overall, the extent to which the few available instruments are also suitable for early childhood professionals must be determined.

Initial findings on the assessment of evidence-based reasoning (e.g., Furtak et al., 2010 in the special issue of *Educational Assessment* devoted to "Evidence-Based Reasoning in School Science") focus mainly on coding systems for classroom situations. However, it is conceivable that these categories could also be applied to interviews with early childhood professionals.

3.3 Knowledge of Science and Pedagogical Content Knowledge

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Following Shulman (1987), there is relatively broad consensus that content knowledge, pedagogical content knowledge, and pedagogical knowledge can be regarded as the central domains of teachers' professional knowledge (Baumert et al., 2010; Borko, 2004; Darling-Hammond, 2010). Beliefs, for example about the structure of the domain to be taught or about teaching and learning, cannot always be delineated from professional knowledge. However, knowledge can be delineated from knowledge in action, that is, observable action in the actual teaching-learning situation. For example, a person may display considerable pedagogical content knowledge of instructional strategies, but may not apply it in the concrete situation because he or she does not make use of his or her diagnostic skills, or because of certain situational constraints.

Instruments for measuring professional knowledge obviously differ in terms of their proximity to the context of action. However, it is unclear whether paper-and-pencil tests should be considered less close to action than tests that use video vignettes, for example. Ultimately, performance in a learning setting can be measured only by observing concrete situations. There are corresponding rating instruments, for example for measuring the quantity and quality of specific pedagogic interactions (sustained shared thinking: Siraj, I., Kingston D., & Melhuish E., 2015; Siraj-Blatchford et al., 2003; Siraj-Blatchford & Manni, 2008; Hopf, 2011; König, 2006; see also instruments from classroom research, e.g., Rakoczy & Pauli, 2006, Kobarg & Seidel, 2003; Kunter, 2005).

3.3.1 Science Content Knowledge

Content knowledge can be regarded as a prerequisite for designing and implementing learning opportunities. It includes conceptual knowledge about the organisation and the structure of a subject. It is assumed that teachers' content knowledge needs to be more advanced than the knowledge that they teach. For example, they should be familiar with, and be able to draw on, the content of the subsequent level of education. Research has not yet established the content knowledge that professionals at pre-primary level require. In the international debate on this topic, it has been pointed out that early childhood professionals also need a substantial content-knowledge base in basic science topics (Garbett, 2003).

With respect to science content knowledge, it is assumed that the professionals will already have acquired both *foundational and structured experiences* with the domain in question (e.g., with water) and that they are capable of *appropriately describing the corresponding concepts verbally*. Hence, these elements will not be included in the following table. Rather, the aim of the table is to describe the conceptual understanding that early childhood professionals are expected to have. This understanding should be at a scientifically descriptive level.

Knowledge of basic concepts comprises knowledge of relationships between concepts, the assignment to basic concepts in the primary school curriculum, and the structure of the subject. Early childhood professionals should be capable of encouraging and facilitating the conceptual restructuring of naive conceptions at the level of the children and the transformation of these naive conceptions into simple conceptions that are suitable for everyday use.

To do so, early childhood professionals need conceptual knowledge that corresponds to the target conceptions for primary school age children, and, at least in part, to those of initial science instruction at the secondary level. In other words, professionals' conceptual knowledge should be constructed at a "pre-scientific" level of understanding. Pre-scientific knowledge is relational knowledge that includes knowledge of relationships that are not directly visible, and that describes the regularity of phenomena in an accurate and evidence-based way. It does not include more complex knowledge and explanations, such as differentiated particle models. In the domain of floating and sinking, for example, professionals should not only incorporate a conception of material (as a conception that is suitable for everyday use) into the design and implementation of learning environments, they should also be familiar with, and recognise, the relationship between relative density and buoyancy. This does not mean that they must display a knowledge of formulae. Rather, like primary school students, they must have a knowledge foundation upon which a knowledge of formulae can be built. At the same time, they should be aware of the role of empirical evidence and the use of inquiry activities and experiments to generate and verify knowledge. This awareness manifests itself in the relational *justification* of statements, that is, in the establishment of correlations between individual observations (see also Section 3.2, “Measurement”).

Table 3. *Early childhood professionals’ content knowledge of the domain of water*

Basic Concepts	*Density* Whether objects will float or sink does not depend on their size, on aspects of their shape (e.g., on whether they have holes), or on whether they contain air. Things that are lighter than the same amount of water will float; things that are heavier than the same amount of water will sink. (Things that have a lower density than water will float; things that have a higher density than water will sink.)	*Buoyancy* Water presses against all immersed objects; the greater the volume of the object, the more the water pushes it upwards/ the greater the buoyant force. Floating and sinking can be explained through a comparison of forces. If the buoyant force is greater than the weight force of the object, it will float. If the buoyant force is less than the weight force of the object, it will sink.	*Displacement* The amount of water displaced by an object depends on its volume.
Basic Concepts	*Melting/Freezing* Like other substances, water exists in three different states: solid, liquid, and gaseous. These states differ in terms of their properties. The shape of water in the solid state is stable, whereas in the liquid state it is flexible, that is, it adapts to the surrounding space. The term melting refers to the transition from the solid to the liquid state. Freezing is the reverse process. Melting and freezing are reversible processes that can be influenced by temperature, among other things. Every substance has a characteristic melting temperature.	*Vaporisation/Evaporation and Condensation* In a gaseous state, neither the shape nor the volume of water is stable. That means that gaseous matter completely fills the surrounding space. What is known colloquially as steam (e.g., above a pot of boiling water) is actually condensed water. Vaporisation/evaporation refers to the transition from the liquid to the gaseous state. The water does not disappear in the process. Rather, it is contained in the air as invisible water vapour, or steam (conservation of matter). Condensation is the reverse process Vaporisation/evaporation and condensation are reversible processes that can be influenced by temperature, among other things. Every substance has a characteristic boiling temperature.	

3.3.2 Pedagogical Content Knowledge

Pedagogical content knowledge describes the knowledge that teachers need in order to make content knowledge accessible to learners. *Knowledge of children's cognitions* and *knowledge of instructional strategies* are considered to be particularly relevant components of pedagogical content knowledge (Shulman, 1986; Grossman, 1990).

By instructional strategies, the authors of this report mean, in particular, strategies for structuring learning situations and didactically preparing material. Based on the goal dimensions at the level of the children, pedagogical content knowledge is thus needed to create opportunities for foundational and structured experiences that should, in turn, lead to the construction and differentiation of conceptual knowledge. For this, early childhood professionals need, first, a repertoire of relevant everyday situations or inquiry activity designs (e.g., Spreckelsen's "phenomena circles") that render the conceptual content perceptible in different ways, and, second, a knowledge of the cognitions (e.g., preconceptions) that children will probably apply to the learning situation.

In addition to knowledge of children's cognitions, early childhood professionals play a constructive and active role in the learning process. For example, they structure learning environments for children in order to enable them to compare things or to use counter-evidence, thereby stimulating their further conceptual development. The interactive design and implementation of this learning process using scaffolding techniques (on scaffolding, see, e.g., Einsiedler & Hardy, 2010; Punktambekar & Hübscher, 2005) or processes of sustained shared thinking (Siraj-Blatchford et al., 2003) constitute a further important facet of professional competence.

Whether this facet is an empirically validated sub-domain of the "knowledge of instructional strategies" component of pedagogical content knowledge, or a sub-domain of professional action competence that is measurable only in the concrete design and implementation of the learning situation, has not yet been clarified in the case of primary school teachers or early childhood professionals. It can be assumed that the implementation of learning opportunities is influenced also by beliefs about teaching and learning. For children's knowledge and motivation, constructivist-oriented beliefs are desirable, whereas a "hands-on but not minds-on" approach or a laissez-faire approach (strong emphasis on self-directed learning and rejection of support measures on the part of the teacher) is of little help (e.g., Kleickmann, 2008). With pedagogical content knowledge, there are overlaps with the goal in relation to motivational orientations and attitudes towards scientific thinking and working (see Sections 3.1 and 3.4).

Concretisation using the domain of water as an example

Table 4 below presents pedagogical content knowledge of the domain of water. This knowledge is differentiated into two categories: (a) knowledge of children's cognitions about the domain and (b) knowledge of instructional strategies. In addition, the table lists typical terms and paraphrases that children use, and with which early childhood professionals should be familiar. Table 4 makes no claim to be exhaustive. Rather, it mentions only a few exemplary terms and establishes correlations.

Measurement

To date, there are no instruments for measuring early childhood professionals' professional knowledge of and about science *directly* as opposed to measuring it via distal indicators such as the number of continuing professional development workshops attended. However, there are a few instruments with which primary teachers' professional knowledge of and about science can be measured, and these instruments could at least provide orientation for measuring early childhood professionals' knowledge.

Two instruments were developed within the framework of the PLUS study for measuring a) the content knowledge (Ohle, 2010) and b) the pedagogical content knowledge (Lange, 2010) of primary teachers on the topic of the water cycle. Empirically, the two knowledge components could be represented as two distinct factors. Moreover, it could be shown that both knowledge components influenced students' learning progress. An instrument for testing primary school teachers' content knowledge and pedagogical content knowledge of floating and sinking was developed within the framework of the video-based lesson analysis project ViU (Möller, Holodynski, & Steffensky). An instrument for measuring primary teachers' conceptions of science teaching and learning can be found in Kleickmann (2008). It comprises a number of different scales with which both constructivist-oriented beliefs and more transmissive beliefs can be measured.[13]

13 Depending on the research tradition, epistemological conceptions of early childhood professionals are perceived as a sub-aspect of professional knowledge or as a dimension in their own right. For this reason, we address relevant aspects when describing the content knowledge and pedagogical content knowledge of early childhood professionals, but we also treat them as a separate facet of competence.

Table 4. *Early childhood professionals' pedagogical content knowledge of the content domain of water*

Terms, Paraphrases	Cognitions	Instructional Strategies
solid, hard, cold, liquid, soft, warm, you can pour it, pour from one container to another, become liquid, become water, melt, defrost, become solid, become ice, freeze invisible, like air, you can't grasp it/take hold of it go up into the air, become air, become steam/mist, dry, boil, steam up/mist up, become water again	Most children find it easier to understand melting than the process of evaporation. As condensation processes are even more difficult to understand and to interpret, they should be explicitly addressed only in the case of advanced children, or children who are very interested in the topic. Typical conceptions at a naive level of understanding include: ■ Ice and water are unrelated; they are not one and the same substance. ■ Water disappears during vaporisation/evaporation and turns into nothing. ■ Water changes its location during vaporisation/evaporation but not its shape (state). "Water seeps into the ground." ■ Condensation is often explained by means of situation-specific interpretations, for example, by spraying water upwards to explain droplets of moisture on the lid of a pot during cooking.	**Situations of everyday life** in which children can experience/observe the process of melting/freezing and evaporation/condensation and that can be used as learning opportunities: ■ Ice, snowman, icicles, ice cubes, cheese on a pizza, butter in a pan, etc. ■ Drying, washing, blow-drying, puddles disappearing, boiling water, steamed up mirror, window, breath in the winter, etc. Simple **inquiry activities** about melting/freezing: ■ Comparing the properties of ice and water, for example with ice and water in freezer bags ■ Making ice cubes and letting them melt in different places, for example in cold and warm water, in a bright/dark place, in the hand, etc. *About evaporation/condensation:* ■ Observing the imprint of wet hands on blotting paper ■ Letting things dry in different places and comparing drying times ■ Boiling water and holding a cold lid over the rising steam **Sequencing** Before dealing with the process of melting, properties such as the possibility of touching/sensing and pouring solid and liquid substances should be addressed, using ice and water as examples. Because the melting process is easier to observe, it should usually be addressed before the process of evaporation. **Cognitive Structuring** Use of prompts, probes, and tasks, that facilitate the active cognitive processing of observations in different everyday situations and inquiry activities (see above). Examples include: ■ "W" questions, especially questions that ask for reasons why ■ Prompts to facilitate concretisation and verbalisation ■ Prompts to facilitate the transfer of observations to other situations ■ Focusing attention on essential characteristics of a situation ■ Modelling of procedures and ways of thinking

Terms, Paraphrases	Cognitions	Instructional Strategies
Designations of materials: wood, polystyrene, metal/iron, plastic, stone, etc. Heavy material; lighter than/heavier than; feels heavy/light Surfaces, floats, comes to the top, goes down, sinks, floats/does not go down completely Water pushes (upwards), presses against. Water needs space. Water rises.	Typical conceptions at a naive level of understanding of why an object floats or sinks include: ■ Weight concept ■ Shape concept ■ Hole concept ■ Air concept ■ Size concept ■ Drive concept	**Situations of everyday life** in which children can observe the sinking/floating behaviour of objects and have relevant experiences with buoyancy and displacement can be used as learning opportunities. They include: ■ Experiencing the sinking/floating behaviour of toys in the bath; throwing stones into water; ships ■ Experiencing buoyancy in the bath by pushing objects under water that then pop up ■ Experiencing buoyancy on one's own body in a swimming pool ■ Observing, when playing with water, that immersed objects cause the water to overflow ■ Determining during play the material that objects are made of: "Which of these things are made of wood, metal, stone ...?" Simple **inquiry activities** about the sinking/floating behaviour of solid bodies/the materials aspect ■ Testing the sinking/floating behaviour of different objects with which typical conceptions can be addressed or refuted, for example a wooden board with holes in it, a pin, a glass filled with air. About buoyancy: ■ Submerging objects of different sizes that float, for example, balls or polystyrene boards; submerging different hollow objects About displacement: ■ Immersing different-sized pots or balls in water and comparing the water level **Sequencing:** Children must first experience and observe that there are objects that float and objects that sink. In a second step, experiences with the buoyancy of water, and foundational experiences with different materials, can be used to direct the children's attention to possible causal explanations for the sinking/floating behaviour of objects: What explanations are useful or apply to all objects? (The notion that the flotation of an object depends on the material it is made of is connectable because the sinking/floating behaviour of an object depends on the density of the material.) **Cognitive Structuring** Use of prompts, probes, and tasks that facilitate the active cognitive processing of observations in different everyday situations and inquiry activities (see above) Examples include: ■ "W" questions, especially questions that ask for reasons why ■ Prompts to facilitate concretisation and verbalisation ■ Prompts to facilitate the transfer of observations to other situations ■ Focusing the children's attention on essential characteristics of a situation ■ Modelling procedures and ways of thinking

3.4 Aspects of the Professional Attitude

Yvonne Anders

It is assumed that the professional attitude constitutes the basic structure of all professional action. It comprises action-guiding orientations, values, and attitudes that shape the thinking and action of early childhood professionals. They include pedagogical orientations, values, and attitudes, on the one hand, and aspects of the professional self-concept and role perception as an educator, on the other (e.g., Robert Bosch Stiftung, 2011). Accordingly, personality traits also influence the professional attitude – which is assumed to be modifiable in principle – and it develops further through biographical self-reflection and reflection on pedagogical processes and actions. Via its action-guiding function, the professional attitude influences process quality in early childhood education settings and can thus influence the development and learning processes of the children. In addition to professional knowledge and motivational components, the aforementioned aspects of the professional attitude are considered to be key facets of the professional action competence of early childhood professionals.

The construct of professional attitude and its components are very broad-based and comprehensive, and they are sometimes quite unclearly defined in the literature. In what follows, we focus on those aspects that we consider to be relevant for fostering science competencies at pre-primary level and for implementing the "Haus der kleinen Forscher" initiative, and that can thus be regarded as goal dimensions. First, we identify and differentiate pedagogical orientations and attitudes towards fostering science competencies at pre-primary level, and then we address different aspects of the professional self-concept and role perception.

3.4.1 Pedagogical Orientations and Beliefs With Regard to Fostering Science Competencies

The *term pedagogical orientations and beliefs* refers to pedagogical conceptions, values, and attitudes, such as early childhood professionals' pedagogical goals and norms and their conceptions about child development and the tasks of early childhood education and care centres (see Tietze et al., 1998). To date, studies of pedagogical orientations and beliefs have focused for the most part on primary and secondary level. However, in these studies, a domain-specific investigation of pedagogical beliefs has proved useful and necessary for understanding the complex pattern of relations between beliefs, pedagogical processes, and child development (see Staub & Stern, 2002; Stipek, Givvin, Salmon, & MacGyvers, 2001). Hence, when it comes to supporting early education in the domain of science, education professionals' beliefs about science, and about the facilitation of the learning processes within which science competencies are acquired, are more crucial than their general and domain-general pedagogical beliefs. Besides the fact that studies to date have focused mainly on primary and secondary level, it should also be noted that comparatively few studies have dealt with attitudes to science or to imparting knowledge of science. Many more studies on this topic have been conducted for the domain of mathematics, for example. Nonetheless, some of the research approaches and theoretical concepts can, at least in part, be applied well to fostering science competencies at pre-primary level.

The following goal dimensions can be differentiated:

a) Conceptual beliefs about the nature of science

Traditional conceptual beliefs about the nature of science can be distinguished from constructivist beliefs. According to the traditional view, science is a closed system of knowledge that reflects truth. It follows from this that it is theoretically possible to acquire all scientific knowledge. Constructivist beliefs, by contrast, assume that knowledge of science comes about through engagement with the environment, and that science explains relationships and natural phenomena. Hence, scientific knowledge undergoes constant change and further development (e.g., Brickhouse, 1990). Professionals' conceptions of science influences their own engagement with the subject, and thus their pedagogical action. The static, traditional, view suggests that new content should be introduced transmissively in small steps. By contrast, the modern, constructivist, view allows for children to develop and reflect on scientific knowledge themselves, and it challenges them to engage in communicative exchanges.

b) Epistemological beliefs about the acquisition of science competencies

Beliefs about the acquisition of science competencies or the facilitation of the learning process are closely linked to conceptual beliefs. Epistemological beliefs are closely related to pedagogical content knowledge (Section 3.3.2), and in some theoretical approaches they are considered to be a knowledge component. The following types of beliefs can be distinguished (Kleickmann, 2008): (a) behaviourist/transmissive beliefs (children are recipients in the learning process; knowledge must be prescribed and received); (b) constructivist beliefs (knowledge is actively constructed by the learners themselves); and (c) practicistic beliefs (the provision of learning material has a learning-enhancing effect). These belief facets are linked to beliefs about adaptivity when designing and implementing learning processes. Thus, an early childhood professional may hold more developmental-psychology-oriented beliefs whereby learning processes should be aligned with the individual development of the child. This contrasts with beliefs whereby learning processes should be aligned with professional standards.

A developmental-psychology-oriented, constructivist belief whereby learning builds also on children's conceptions and their everyday worlds of experience, can be regarded as a goal dimension.

c) Beliefs about the importance of early childhood science education

Studies on the importance of different areas of pedagogical support in everyday life in early childhood education settings, and on early childhood professionals' attitudes thereto, have shown that the fostering of academic abilities is considered less important than the fostering of socio-emotional, artistic, or motor skills (Tietze et al., 2008). The fostering of academic abilities constitutes an educational domain that many early childhood professionals in Germany consider to belong at primary and secondary levels but not at pre-primary level. Moreover, within academic abilities, they often give priority to the fostering language skills over mathematical or science competencies.

One goal of the "Haus der kleinen Forscher" initiative is to give the fostering of science at pre-primary level due importance in the context of other areas of pedagogical support. In most cases, "due" importance will mean greater importance compared to the initial situation.

d) Beliefs about the science competencies that should be fostered in children between the ages of three and six

Fostering science at pre-primary level does not mean moving primary school content forward, but rather fostering science competencies in an age-appropriate and developmentally appropriate way. "Science competencies" is used here in the sense of the goals at the level of the child presented in Chapter 2 of this report. Early childhood professionals who work in early childhood education and care centres that participate in the "Haus der kleinen Forscher" initiative should therefore have internalised the target competencies in this way, and should make neither too low nor too high demands with regard to the acquisition of competencies by the children.

Measurement

Pedagogical orientations and attitudes of early childhood professionals have been addressed in various empirical research projects, also in the German-speaking area (e.g., Kluczniok, Anders, & Ebert, 2011; Kuhn et al., 2012; Mischo, Wahl, Hendler, & Strohmer, 2012; Thiel, 2010; Tietze et al., 1998). There are a number of questionnaire-based instruments for measuring pedagogical orientations and attitudes. Not all of these projects focus on science education, but there are international studies on sub-facets of the aforementioned attitudes and orientations (Cho et al., 2003; Erden & Sönmez, 2011; Faulkner-Schneider, 2005). In summary, it can be said that instruments exist but that they would have to be modified and further developed for application in the context of the "Haus der kleinen Forscher" initiative.

3.4.2 Aspects of Professional Role Perception and Self-Concept

Regarding professional attitude, we propose further goal dimensions over and above the attitudinal aspects described above. These dimensions relate to aspects of professional role perception and self-concept, and they also touch on personality traits. In an overview of qualification profiles in fields of work in early childhood education published by the Robert Bosch Stiftung (2011), for example, these goal dimensions were described as important professional competencies of early childhood professionals; they are also considered important in the context of the "Haus der kleinen Forscher" initiative.

a) Reflective ability

Early childhood professionals should critically and constructively reflect on and assess their role, pedagogical concepts, and pedagogical action. This reflection should be driven by the desire to improve their own pedagogical action.

b) Openness

Early childhood professionals should be open to themselves, to others, and to the world and should accept open work processes. They should be able to deal with uncertainty in professional action.

c) Inquiry-based attitude

Early childhood professionals should develop an inquiry-based habitus. In other words, on the basis of methodological competencies, they should be capable of systematically approaching even familiar situations with an inquiry-based, exploratory attitude and of grasping, describing, interpreting, and reflecting on situations in all their complexity (Nentwig-Gesemann, 2007).

d) Development of professionalism

Early childhood professionals should be capable of recognising their professional development needs and of sustainably organising and managing their continuing professional development. They should have a high degree of learning competence, and thus see the development of their professionalism as a lifelong process. Moreover, they should be willing to undergo professional development and to upgrade their professional knowledge and ability, and they should be convinced of the necessity to do so.

e) Collaborative ability

Early childhood professionals should be willing and able to communicate, interact, and collaborate with actors in their professional environment and with other relevant actors in implementing the offerings of the "Haus der kleinen Forscher" Foundation. Moreover, they should be capable of imparting specialised content to colleagues and target groups (e.g., parents, interns).

Measurement

Some aspects of the facets described above have already been measured in mainly qualitative studies (e.g., Behr & Welzel, 2009; Welzel & Zimmermann, 2007; Tröschel, 2006). These and similar instruments could possibly be used as a starting point for developing a new instrument. However, they would have to be adapted for application in the context of the "Haus der kleinen Forscher" initiative.

4. Conclusion and Recommendations

Yvonne Anders, Ilonca Hardy, Sabina Pauen, & Mirjam Steffensky

In the previous chapters, we have described substantive goals of early childhood science education and their theoretical underpinnings, and we have compiled a set of existing instruments for measuring these goals. The underlying concept of competence is very broad, so that a comprehensive study in which the entire spectrum of possible goals was investigated would hardly be feasible. Moreover, as we have shown, instruments for measuring the key constructs do not yet exist either at the level of the children or at the level of the early childhood professionals, and they would therefore have to be developed first. The development of reliable and valid instruments can be very time-consuming and costly. For these reasons, we undertake in the present chapter a prioritisation within the goals for all domains. When doing so, we undertake theoretical weighting, in the sense that we assign priority to those goal dimensions that have high theoretical importance, or that are expected to have comparatively substantial and clear outcomes. We also take into account aspects of measurability and measurement efficiency. And finally, we make specific recommendations for possible instruments or for the development of instruments. The presentation is organised in the same way as the previous chapters. It is followed by general recommendations for possible studies.

4.1 Prioritisation of the Goals at the Level of the Children and the Early Childhood Professionals

Goals at the level of the children (outcome variables)

a) Motivation, interest, and self-efficacy

We consider the **motivational and emotional aspects** presented to be substantively and theoretically highly relevant goal dimensions. However, the facets presented differ in their suitability for a scientific outcome study. On the one hand, the differential measurability of these facets must be taken into account; on the other hand, the extent to which practically relevant outcomes are to be expected in relation to the respective dimensions must be considered. The younger the children are, the more a natural enthusiasm for all things new must be assumed, so that it is hardly realistic to expect measurable outcomes of the Foundation offerings in this regard. Moreover, the younger the children are, the more difficult it is to separate the dimensions of enthusiasm, enjoyment, and interest. An efficient measurement of these aspects would be conceivable in children who are nearing completion of pre-primary education. Here, outcome measurement should focus on the temporally more stable *interest in science*.

Perceived self-efficacy appears to be a component that is not only theoretically highly relevant, but can also be expected to have programme-specific outcomes. Existing questionnaire procedures for primary school age children (e.g., Martinelli et al., 2009) could be used as a starting point for developing an interview procedure for children between the ages of three and six. With regard to children's interest in science, it should also be borne in mind that parents or early childhood professionals may be valuable sources of information about the extent to which children engage with natural phenomena, experiments, or specific games, for example. Thought could be given to developing questionnaires for parents or early childhood professionals that are specifically geared towards the content of the offerings of the "Haus der kleinen Forscher" Foundation.

b) Scientific thinking and process

We consider scientific thinking and process to be a theoretically and substantively highly relevant goal. Those abilities that are characteristic of the scientific process (e.g., formulating expectations, systematically varying relevant dimensions, and integrating new experiences into existing knowledge systems by making comparisons and seeking explanations) are likely to be of particular importance. *Forming expectations and expressing assumptions, trying things out and experimenting,* and *evaluating and justifying experiences* are regarded as priority dimensions.

As a general comment, it should be noted that the standardised measurement of progress in scientific thinking and process in children between the ages of three and six is not yet possible because the corresponding diagnostic instruments are lacking. Even though isolated attempts have been made (e.g., the Kita-Nawi, Pauen & Pahnke, 2009; the Science Learning Assessment (SLA), Samarapungavan, Mantzicopoulos, Patrick, & French, 2009) to develop such instruments, a comprehensive assessment of the effects on children of education programmes in the science domain (and thus also in the context of the "Haus der kleinen Forscher" initiative) cannot succeed until the parallel measurement and analysis of changes in children in many different behavioural parameters is possible. It would make sense to film children's behaviour in semi-standardised experimental situations and to use such video sequences as raw data to ensure the ecological validity of the measurements.

Hence, important tasks for the future consist in (a) describing suitable situations in which children's scientific thinking and process can manifest itself in diverse ways; (b) clearly defining framework conditions under which video sequences can be recorded; (c) providing a standardised coding scheme for the analysis of such video sequences that incorporates as many of the aspects mentioned in this report as possible and that enables the most objective measurement possible of the parameters of interest; (d) designing interview questions for early childhood professionals and/or parents that can yield supplementary insights into children's scientific thinking and process outside standardised situations; and (e) developing analysis schemes for behavioural products (e.g., drawings and other forms of documentation of children's engagement with natural phenomena).

If a standardised instrument for measuring such changes in children is available, valuable new insights into the development and fostering of scientific thinking and process can be gained with its help.

Based on the premise that scientific thinking and process manifests itself in the most diverse contexts, any topic can be chosen, provided the children in the age range under study are fundamentally interested in it.

c) Knowledge of science

In a summarising assessment of the facets of the knowledge of science described in this report, the characteristics of the scientific concepts appear to us to be the main indicator of the quality of scientific thinking on the part of the child. Scientific concepts were described as basic, connectable concepts in the important domains of early childhood science education. We concretised this using the domain of water as an example. Building up connectable concepts entails, in most cases, restructuring or differentiating naive conceptions, and it can be understood as justified correlational knowledge that enables relationships between states to be formulated.

As in the case of scientific thinking and process, there is a need for the development of standardised and valid instruments for measuring knowledge of science in children between the ages of three and six. If existing instruments are used (e.g., the NEPS test, the Science Learning Assessment, the SNaKE test, or the interviews on the subject of floating and sinking by Leuchter et al. 2010), the degree to which they are related to the activities of the "Haus der kleinen Forscher" Foundation must be clarified, and thus whether they are treatment-sensitive. The existing instruments may have to be developed further in order to tailor them more to the "Haus der kleinen Forscher" activities. Whether a range of topics are to be tested, or whether the aim is to gain detailed insights into selected domains, must also be addressed. The development of instruments for measuring children's knowledge is a major challenge. However, in view of the importance of the knowledge component, it would not be advisable to forgo doing so.

As the development of concepts is closely linked to means of linguistic expression and to possibilities of having (foundational and structured) experiences, the *knowledge of science* goal at the level of the children can be excellently represented by measuring scientific concepts. Moreover, focusing on scientific concepts enables connection to international research in the field of developmental psychology and the didactics of science on processes of conceptual change in scientific domains, and to existing instruments for measuring scientific knowledge on the topic of water at pre-primary level.

d) Basic competencies

The basic competencies described earlier should play the role of a control or moderator variable. For this role, it would appear to be expedient and adequate to have recourse to existing procedures. In order to secure the outcomes of the "Haus der kleinen Forscher" offerings, or to delineate them from the development of other competence domains, it would be important to measure *general cognitive competencies, social competencies,* and *language competencies*. General cognitive competencies could be measured by using individual sub-scales of the Kaufman Assessment Battery for Children (K-ABC; Melchers & Preuss, 2009), for example. The Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997) has proved its worth as an instrument for measuring social competencies. The SDQ scales "peer problems" and "prosocial behaviours" would appear to be particularly relevant in the context of the offerings of the "Haus der kleinen Forscher" Foundation. To measure language competencies, children's vocabulary could be measured at the same time. The Peabody Picture Vocabulary Test (PPVT; Dunn & Dunn, 2007), for example, has proved its worth in various studies.

Goals at the level of the early childhood professionals (outcome variables)

Overall, few studies have been conducted on the measurement of the above-mentioned competencies at the level of early childhood professionals. This is true, in particular, of the various knowledge components, which are considered to be of extreme theoretical importance.

a) Motivation, interest, and self-efficacy

With regard to the **emotional and motivational aspects** described above, it can be assumed in relation to science content that programme-specific effects may be quite difficult to measure, or may not correlate directly with professional action. Programme-specific outcomes and direct correlation are to be expected more in the case of facets that relate to professional action – specifically, the facet of *enthusiasm* for designing and implementing learning processes, and, especially, the facet of *perceived self-efficacy*. To measure these components, existing questionnaire instruments can be modified and further developed in order to adapt them to the specific offerings of the "Haus der kleinen Forscher" Foundation (Cho et al., 2003; Kuhn et al., 2012; Kunter, 2011).

b) Scientific thinking and process

With regard to the *scientific thinking and process* goal at the level of early childhood professionals, we distinguished between understanding the nature of science, on the one hand, and methodological knowledge (methods of scientific thinking and working), on the other. While *methodological knowledge* should be treated as a priority when measuring the competencies of early childhood professionals, *understanding the nature of science* should also be taken into account in the assessment, as there are clear overlaps with the goal dimensions at the level of the children in this domain. Both domains of scientific thinking and process constitute a basis for the appropriate provision, implementation, and interpretation of empirical learning situations for children by early childhood professionals, because only on the basis of fundamental methodological competencies and an adequate understanding of the nature of science can experiments and inquiry activity designs be used in a didactically expedient way. To date, there are no instruments specifically for early childhood professionals. However, it would be conceivable to adapt instruments from primary level, for example the instruments from the Science-P project (Möller, Sodian, Hardy, Koerber & Schwippert) or the Student Understanding of Science and Scientific Inquiry (SUSSI) scale (Liang, Chen, Chen, Kaya, Adams, Macklin & Ebenezer, 2006).

c) Knowledge of science

As in the case of the prioritisation of the target facets of knowledge of science at the level of the children, *scientific concepts* can also be regarded as the main indicator of knowledge of science on the part of early childhood professionals, and thus as the main indicator for this goal at the level of the professionals.

We note that early childhood professionals require at least conceptual knowledge at a relational level of understanding, which includes knowledge of relationships that are not directly visible, and which describes the regularity of phenomena by using evidence-based, accurate explanations and appropriate terms and formulations.

To date, there are no specific instruments for measuring early childhood professionals' knowledge of science. However, it would be conceivable to adapt instruments from primary level, for example, the test of knowledge about the water cycle developed by Ohle (2010), Moreover, it would be conceivable to use items from TIMSS, HARMOS, or perhaps even PISA, to measure content knowledge.

d) Pedagogical content knowledge

We have distinguished two facets of pedagogical content knowledge – knowledge of instructional strategies and knowledge of children's cognitions. Of special interest at pre-primary level is the quality of the facilitation of children's learning processes. Hence, we consider it appropriate to focus on the *knowledge of instructional strategies* facet, which refers to the didactic knowledge that is needed to produce foundational and structured experiences, and to the appropriate facilitation of learning processes that enables learners to participate in a constructive and active way. To measure the pedagogical content knowledge of early childhood professionals, instruments from primary level can be adapted, for example, Lange, (2010) or video-based instruments (Steffensky, Gold, Holdynski, & Möller, 2015).

e) Professional attitude

In the light of research findings on the **pedagogical beliefs and orientations of teachers** at primary and secondary level, it can be assumed that *epistemological beliefs* correlate strongly with professional action. Even though individual international studies on the fostering of mathematics at pre-primary level suggest that the variance of epistemological beliefs is less pronounced among early childhood professionals than among primary and secondary teachers, this *attitudinal component* should be treated as a priority in evaluation studies. This conclusion is also supported by the conceptual proximity to the components of professional knowledge described above. Moreover, it is expected that there should be changes in early childhood professionals' perceptions of the *importance of early childhood science education* in particular. For both of the aforementioned aspects, there are questionnaire instruments for primary teachers or instruments for early childhood professionals (e.g., BiKS and KiDZ, see Anders et al., 2012 and Roßbach, Sechtig, & Freund, 2010) that relate to other domains but can be appropriately modified and further developed.

Although we consider **aspects of professional role perception and self-concept** to be extremely important for professional action, the possible effects of the offerings of the "Haus der kleinen Forscher" Foundation on these competence facets are not expected to be very focused. Moreover, as there are hardly any instruments for measuring these components, we consider that, compared to the scientific yield, it would be too expensive to develop an instrument especially for the investigation of the Foundation's work.

4.2 Recommendations for Accompanying Research

Selection of goals that should be taken into account in the research design

From a scientific perspective, all the goals identified in this report are potentially relevant for studies on the Foundation's work. In addition to the recommendations described above, the prerequisite for the prioritisation of individual aspects within the framework of accompanying research is an evaluation from a pragmatic perspective. This evaluation should be carried out by the Foundation, as it makes sense to base it on the currently implemented Foundation offerings and the concrete content of the "Haus der kleinen Forscher" Foundation's professional development programme.

Further action and possible studies

The outcome model described in Chapter 1 above assumes that effects are transmitted to children in early education settings via the pedagogical action of early childhood professionals. Furthermore, the Foundation's work concept implies a multistage process whereby the Foundation's continuing professional development programme trains multipliers, who then train early childhood professionals locally, who in turn work with the children at the early childhood education and care centres. Hence, via the multipliers, the early childhood professionals are the main addressees of the Foundation's professional development offerings. Positive outcomes can occur in children only if early childhood professionals are given the prerequisites for successfully facilitating children's science learning processes. Thus, a multistage approach can be used, where first the level of the early childhood educator is investigated and then the level of the child.

The first step always entails conducting studies in which instruments for measuring the selected goals are developed and tested for reliability and validity. When planning these studies, it is necessary to also take into consideration the effort involved in developing instruments for measuring knowledge components and scientific thinking ability both at the level of the early childhood professional and the level of the child. If the intention is to focus on several competency dimensions (e.g., knowledge aspects and motivational and emotional factors and orientations), it is advisable to closely coordinate the various instrument-development studies because of the domain and topic specificity.

In the next step, a broader investigation of the outcomes can be conducted. Whether this investigation should initially focus exclusively on early childhood professionals, or whether it should take the form of an integrated investigation of outcomes at the levels of the early childhood professionals and the children, depends on the time schedule and the results of the instrument development studies.

Alignment of outcome studies with the certification of institutions

Finally, we recommend that the planning of outcome studies should be closely aligned with the criteria for the certification of institutions as a “Haus der kleinen Forscher” (Little Scientists’ House). This applies both to the substantive level (the respective relevant goals for the assessment of the successful implementation of pedagogical process quality, for example, should be consistent) and to the organisation level. It is conceivable, for example, that certified institutions would record and submit video sequences that could be used to develop and test new instruments for measuring goals at the level of the children. Moreover, parts of the instruments to be developed could be used both in an ongoing validation of the certification process and for accompanying research on the outcomes of the Foundation’s work.

B Goals of Science Education at Primary School Age and Their Assessment

Yvonne Anders, Ilonca Hardy, Beate Sodian, & Mirjam Steffensky

1. Theoretical Assumptions

Mirjam Steffensky

The non-profit "Haus der kleinen Forscher" ("Little Scientists' House") Foundation has, for some years now, been actively promoting science education for children between the ages of three and six with a nationwide education initiative. With its continuing professional development programme and pedagogical materials, the Foundation supports primary teachers and early childhood professionals in providing children with learning opportunities, and in facilitating their science education processes. In 2011, the initiative was expanded to cover children of primary school age. The main focus of the expansion was on extracurricular afternoon programmes at after-school centres and primary schools. In what follows, the term *after-school centre* refers to extracurricular programmes within the framework of all-day care. The underlying organisational forms vary greatly, not only at the level of the German federal states *(Laender)* but also at municipal level. They include, for example, (a) half-day schools with an after-school centre attached; (b) all-day schools, where participation in the afternoon programme is either voluntary, partially compulsory, or compulsory; and (c) independent afternoon education and care programmes. These structural differences will not be addressed here.

Within the framework of the present expert report, we describe the goals of the "Haus der kleinen Forscher" education initiative. These goals relate, on the one hand, to the level of the children and, on the other hand, to the level of the pedagogical staff at after-school centres and in extracurricular afternoon programmes at primary schools. The aim of this report is to specify the goals of the initiative for the participating children and the education professionals, on the one hand, and for accompanying scientific research, on the other. As the purpose of the accompanying research is to evaluate programme effectiveness and goal attainment, the final chapter of this report is devoted to prioritising goals for evaluation within the framework of these studies. The individual sections of the report include information on possibilities of empirically measuring the respective goals.

The present report follows on from the expert report "Goals of Science Education Between the Ages of Three and Six and Their Assessment" (Anders, Hardy, Pauen, & Steffensky, 2017, in this volume), which is referred to in what follows as the "pre-primary report". In line with the Foundation's mission, the aim is to achieve cumulative learning pathways across education levels. Therefore, the general goals described in the present report are the same as those that have already been focused on in the pre-primary report (i.e., knowledge of and about science, interest, motivation, etc.). However, they differ in detail because the children are older, the institutions are different (after-school centres or primary schools as opposed to early childhood education and care centres), and also because of the lessons (familiarising children with scientific and technical phenomena) delivered at this educational level. Nevertheless, the content of the present report sometimes overlaps with that of the pre-primary report. When this occurs, corresponding cross-references are provided. However, this report should be read as an independent text.

The goals of the "Haus der kleinen Forscher" initiative are derived partly from the preparatory work and the content offerings of the Foundation but mainly from the current state of theoretical and empirical research. In addition, reference is made to the curricular requirements of the *Laender* and the recommendations for *Sachunterricht* in science drawn up by the *Fachgesellschaft GDSU* (Society for the Didactics of *Sachunterricht;* GDSU 2013).[14] Although the Foundation's offerings are mainly extracurricular, the school parameters should be taken into account, as it is assumed that extracurricular programmes for the children refer, at least in part, to curricular learning.

Here, as in the pre-primary report, the review of the current state of theoretical and empirical research refers to approaches from the field of (developmental and instructional) psychology, educational sciences, and science education. It should be noted that there are almost no research studies on the specific competence of staff at after-school centres. The basis for the present report are research works on the competence of (primary) teachers. Going beyond the science domain, we also have recourse here to works in the domain of mathematics, as mathematics teachers have been more thoroughly researched. However, it is difficult to simply transfer the compiled international findings to staff at after-school centres or in extracurricular afternoon programmes at primary schools in Germany, as they are a very heterogeneous group. In after-school centres *(Horte)*, the staff are qualified educators, whereas extracurricular afternoon programmes in all-day schools are often delivered by persons without a pedagogical background (e.g., committed parents). The goals described here presuppose persons who have a pedagogical background, and they are aligned with competencies that should ideally be developed by education professionals.

Fortunately, the development of science competencies in children of primary school age has been well researched in recent developmental psychology, both with regard to knowledge of science (e.g., in the domain of physics; Wilkening, Huber, & Cacchione, 2006) and knowledge about science and scientific practices (Zimmerman, 2007). Whereas older developmental psychology, shaped as it was by Piaget's theory of the stages of cognitive development, assumed that children

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14 Sachunterricht, *"a subject taught at primary school familiarising pupils with scientific and technical phenomena and with social, economic and historical aspects of their own area" (KMK Glossary on Education, http://www.kmk.org/fileadmin/Dateien/doc/Dokumentation/Glossary_dt_engl.pdf).*

of pre-primary and primary school age had considerable cognitive limitations, research in the last three decades has provided evidence of very comprehensive and systematic early cognitive competencies in the science domain (see, e.g., Sodian, 2008; Wellman & Gelman, 1998). Among the scientifically interested public, among education professionals, and, to a certain extent, also among parents, the view is still widespread that younger primary school children are still at the pre-logical or pre-causal thinking stage, that older primary school children are at the concrete operations stage, and that children of primary school age are therefore overtaxed by the demands that science teaching makes on logical thinking and abstraction skills. Hence, the present report aims to contribute to conveying an appropriate image of the cognitive prerequisites of primary school age children for engaging with science education.

This report is guided by several theoretical assumptions that will be briefly outlined in what follows. They relate to (a) the underlying concept of competence at the level of the children and the education professionals, (b) the educational concept of scientific literacy, which constitutes the framework for the goal of scientific competence described here, and (c) theoretical models of the professional competence of teachers and its impact in teaching-learning situations.

1.1 Concept of Competence

The aims of science education and the professional development of teachers in the context of science education are influenced by the notion of (professional) competence described by Weinert (1999, 2001). Competence can be defined as a multi-dimensional set of abilities, skills, knowledge, attitudes, and motivational variables that form the basis for mastery of specific situations. The term “professional competence” is the application of the concept of competence to working life, and it is also used in the context of the teaching profession (Goodman et al. 2008; Baumert & Kunter, 2013). This understanding of competence forms the basis for our further deliberations (Goodman, Arbona, & Dominguez de Remiriz, 2008).

1.2 Scientific Literacy

In international scholarly debate, scientific competence is often described on the basis of the educational concept of scientific literacy. The education plans of the German *Laender* (federal states) for pre-primary and primary level (e.g., Fthenakis, 2009; French, 2004; Gelman & Brenneman, 2004 or, e.g., GDSU, 2013, QCA, 2000) and the educational standards for secondary schools (KMK, 2004; Bybee, McCrae, & Laurie, 2009) are aligned with this concept. *Scientific literacy* comprises applicable knowledge and non-cognitive components, such as interest in or attitudes towards science content (Norris & Phillips, 2003). Science knowledge is differentiated into *knowledge of science* and *knowledge about science*. The latter includes aspects such as the way in which knowledge of science has been derived, and the degree to which this knowledge is justified by evidence or theoretical explanation. Knowledge of science comprises an understanding of key scientific concepts, theories, and laws. The *knowledge about science* domain relates to knowledge about scientific methods (e.g., an understanding of ways of scientific thinking and working) and to what is known as "understanding the nature of science," which includes knowledge of the goals, limitations, and procedures of scientific inquiry, and knowledge of the role of science in our society.

Scientific literacy also includes non-cognitive domains, such as attitudes towards, interest in, and willingness to engage with, scientific topics and phenomena. Interest and a positive inner willingness to engage are important prerequisites for voluntary, intensive, and sustained engagement with a topic (Norris & Phillips, 2003).

The goals presented here are also aligned with the components of scientific competence in the sense of scientific literacy. Thus, in Sections 2.1, 2.2 and 2.3 we discuss the *knowledge about science,* the *knowledge of science,* and the *motivational and self-related constructs* of primary school age children. We describe knowledge about science as a learning goal for primary school children. In contrast to the pre-primary report, this includes "ways of scientific thinking and working" (practices) and "understanding the nature of science". The latter is included not only because it is a central aspect of knowledge about science, but also because it is assumed that an elaborated understanding of the nature of science facilitates the acquisition of knowledge of science (Zimmermann, 2007).

In addition to the aforementioned science competencies, we also describe *basic competencies* (Section 2.4), an omnibus term for general abilities, such as *cognitive, language, mathematical, and social competencies*, that are assumed to have a moderating effect on the development of science competencies.

A graphical overview of the recommended goals can be found in Appendix I.

1.3 Teachers' Professional Competence

Of importance for the achievement of such multi-criteria goals are not only the individual prerequisites of the learners but also the design and implementation of the learning opportunities (Fend, 1998, Helmke, 2003). The professional competence of teachers has a decisive influence on the design and implementation of learning opportunities. Baumert and Kunter (2013) proposed a framework model of teachers' professional competence that integrates several theoretical perspectives (Shulman, 1987; Bromme, 1997; see Figure 3 below). This model distinguishes four aspects of competence: professional knowledge, beliefs, motivation, and self-regulation. Professional knowledge is differentiated into the domains of content knowledge, pedagogical content knowledge, pedagogical/psychological knowledge, and orientation and counselling knowledge. As many of the studies (at the level of the teachers) that we draw on in this report refer to this model of teachers' professional competence, we use it as a framework model here.

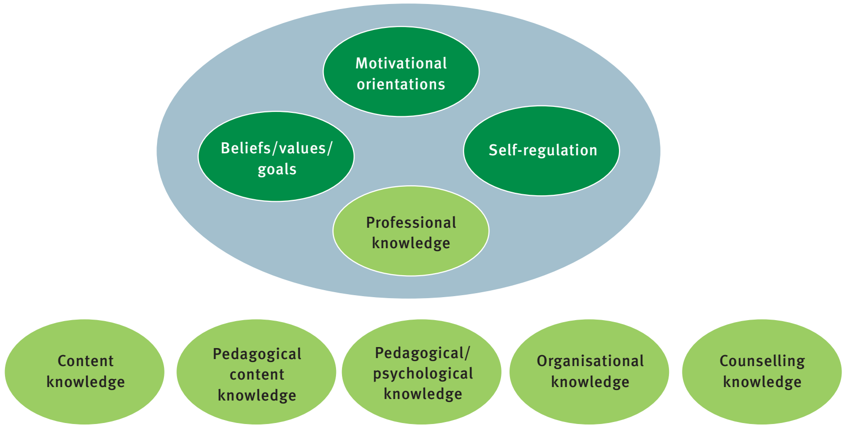

Figure 3. *Model of the professional competence of teachers following Baumert and Kunter (2013)*

In this report, we single out the content-specific components of professional competence that are the special focus of the "Haus der kleinen Forscher" initiative. Two domains of professional knowledge, *content knowledge* and *pedagogical content knowledge* (Section 3.3.3), are important goals of the Foundation's professional development programme because it is assumed that pedagogical content knowledge is a prerequisite for designing and implementing competence-enhancing learning opportunities (Baumert et al., 2010; Carlisle, Kelcey, Rowan, & Phelps, 2011; Hill, Rowan, & Loewenberg Ball, 2005; Sadler, Sonnert, Coyle, Cook-Smith, & Miller, 2013), and that content knowledge is, in turn, a prerequisite for developing pedagogical content knowledge (Krauss et al., 2008). With regard to content knowledge, we follow the educational concept of scientific literacy, and differentiate at the level of the pedagogical staff at after-school centres between *knowledge of science* (Section 3.3.1) and *knowledge about science* (Section 3.3.2).

In addition to the importance of knowledge components for the design and implementation of learning opportunities, classroom research has demonstrated the influential role played by beliefs (in the sense of attitudes, conceptions, and subjective theories, which may comprise epistemologically validated knowledge and explicit or tacit subjective conceptions). On the one hand, *epistemological beliefs* are perceived as key facets of the professional attitude that constitutes the basic structure of professional action (Section 3.2). On the other hand, epistemological beliefs and attitudes are closely related to components of professional knowledge (see Section 3.3). While epistemological beliefs, and beliefs about science teaching and learning, play a key role here, Section 3.2 also presents a selection of non-science-specific pedagogical beliefs and attitudes that are of relevance to the “Haus der kleinen Forscher” initiative.

In Section 3.4, we address three selected aspects of general *professional role perception and self-concept* that are of importance for the implementation of the “Haus der kleinen Forscher” approach – namely, reflective ability, collaborative ability, and the motivation to develop one’s own professionalism.

Motivation, enjoyment of engaging with science, and *interest* in science are fundamental prerequisites to long-term willingness to design and implement science learning opportunities. Also of importance are interest in designing and implementing science education processes and *perceived self-efficacy* with regard to the facilitation of science learning processes (see also Baumert & Kunter, 2013). These components are described in detail in Section 3.1.

The model of teachers’ professional competence that underlies the present report was developed in the context of classroom research. Although the terms and structure differ from those in the model of early childhood professionals’ action competence (Fröhlich-Gildhoff, Nentwig-Gesemann, & Pietsch, 2011) that we used in the report on the goals of science education at pre-primary level, the fundamental components are present in both models. Thus, both models assume that the competence of teachers and early childhood professionals to facilitate education and learning processes results from the interplay of knowledge components and personal prerequisites. Hence, the goals described here and in the report on science education at pre-primary level are connectable.

A graphical overview of the recommended goals for education professionals can be found in Appendix II.

2. Goals at the Level of the Children

2.1 Motivation, Interest, and Self-Efficacy in Engaging With Natural Phenomena

Yvonne Anders

2.1.1 Motivation and Enjoyment of Learning When Engaging With Natural Phenomena

In addition to the cognitive prerequisites, emotional and motivational aspects, in particular, play an important role in learning and knowledge acquisition. It is assumed that children learn more effectively when their learning is intrinsically motivated and accompanied by positive emotions (see Deci & Ryan, 1993). The "Haus der kleinen Forscher" Foundation's offerings aim to awaken an interest in science, to introduce children to science, and to show them the enjoyable and interesting aspects of engaging with natural phenomena. This leads directly to an enjoyment of learning science. While the aforementioned motivational aspects refer more to situation-specific emotions in the course of action, enjoyment of learning relates to the enjoyment of acquiring knowledge.

An open, positive attitude to science, intrinsic motivation to engage with natural phenomena and science questions, and a great enjoyment of learning science can be considered to be a key goal of the "Haus der kleinen Forscher" initiative. Ideally, this motivation and enjoyment of learning should carry over into secondary school.

Measurement

By primary school age, motivational aspects can, as a rule, be measured using rating procedures (external assessment and self-assessment), so that the use of time-consuming observation procedures does not appear to be absolutely essential for assessing this goal. A number of procedures already exist for primary school age children. For example, enjoyment of learning science content has been measured in the Trends in International Mathematics and Science Study (TIMMS; Bos et al., 2008; 2009) and in other studies. In her dissertation, Henman (2012) reported on her Children's Science Motivation Inventory (CAIMI), which she administered to children in grade 7. Guvercin, Tekkaya, and Ceren (2010) also used a questionnaire to investigate primary students' motivation in relation to science. In the *Kindergarten der Zukunft in Bayern – KiDZ* project (Kindergarten of the Future in Bavaria; Roßbach et al., 2010) rating-based scales were used to measure enjoyment of learning in the domains of mathematics and language. These scales proved sensitive to programme effects and may be transferable to the domain of science as implemented by the "Haus der kleinen Forscher" Foundation. Moreover, a number of other studies have examined student motivation in relation to mathematics (e.g., Givvin et al., 2001; Shores & Shannon, 2007). In summary, it can be noted that instruments exist, but that they would have to be developed further or adapted to the specific content of the "Haus der kleinen Forscher" programme for pedagogical staff at after-school centres.

2.1.2 Interest in Science

The term *interest* is defined as the active effort to expand competence (Muckenfuß, 1995). Understood in this way, interest is a component of the self-concept and is characterised by action, cognitive engagement with the object field, and selective assessment. It can be assumed that interest in and enjoyment of engaging with specific content are closely related. Besides enjoyment of the activity, children should develop a deeper, lasting interest in the subject. This is believed to foster their intrinsic motivation to learn. Whether younger children develop a specific person-object relationship (educational theory of interest, Krapp, 2002) is a matter of dispute; it is assumed that interest is configured differently in children than in adults, but that it functions according to similar principles (see Prenzel, Lankes, & Minsel, 2000).

Measurement

Typical instruments for measuring primary school children's interest in science (e.g., Bonsen et al., 2008) are based on self-assessment with rating scales. Cakmaci et al. (2012) reported on their attempt to measure Turkish primary students' interest in science using questions generated by the students themselves. Mayer (2012) measured interest in research activities with the Investigative sub-scale of the Inventory of Children's Activities (ICA-R; Tracey & Ward, 1998). Existing procedures would have to be specifically adapted for application within the framework of an evaluation of the "Haus der kleinen Forscher" programme.

2.1.3 Perceived Self-Efficacy When Conducting Inquiry Activities

The term *perceived self-efficacy* refers to people's beliefs in their capabilities to master demands (see Bandura, 1997). It should be emphasised that perceived self-efficacy is always context-specific. The learning opportunities afforded by the "Haus der kleinen Forscher" Foundation are aimed at enabling children to perceive a high level of self-efficacy ("Yes, I can!") both when conducting inquiry activities and engaging with natural phenomena and with regard to their capability to acquire science competencies and learn science.

Measurement

A self-assessment instrument developed by Schwarzer and Jerusalem (1995) can be used to measure general perceived self-efficacy following Bandura (1997). The instrument has been applied in numerous studies. It comprises ten items for measuring general optimistic self-beliefs (e.g., "I can always manage to solve difficult problems if I try hard enough."). Domain-specific variants have also been published, for example the school-related perceived self-efficacy scale (Jerusalem & Mittag, 1999; Jerusalem & Satow, 1999). The perceived science-related self-efficacy of secondary school students was investigated, for example, in the third international comparative survey of student achievement, PISA 2006 (Prenzel et al., 2007). Martinelli, Bartholomeu, Caliatto, and Sassi (2009) developed an instrument for measuring school-related perceived self-efficacy of children at primary school age. These various measures are a suitable starting point from which to develop an instrument for measuring science-related perceived self-efficacy in children of pre-primary and primary school age that is specifically tailored to the offerings of the "Haus der kleinen Forscher" Foundation.

2.2 Scientific Thinking and Understanding the Nature of Science

Beate Sodian

The goal of science education is to impart not only a domain-specific conceptual understanding of physics, biology, and chemistry (knowledge of science, see Section 2.3) but also domain-general knowledge of methods of scientific inquiry and ways of scientific thinking. In what follows, we use the superordinate term *knowledge about science* to refer to *scientific methodological competencies* and *understanding the nature of science*.

In developmental psychology and the didactics of science, understanding the nature of science and scientific methodological competencies are considered to be fundamental to the acquisition of an adequate understanding of science content (Kuhn, 2005; Lederman, 1992). In older developmental psychology (Inhelder & Piaget, 1958), scientific thinking was understood as formal logical thinking that meets ideal standards of scientific rationality, and thus involves an analytical approach that is suitable for solving any domain-specific problem. This view is long outdated, not least because it has been shown that even the reasoning of professional scientists does not meet these standards, but rather is often influenced by prior knowledge and theoretical biases (Dunbar, 1995). Moreover, more recent developmental psychology research has shown that even primary school age children (and sometimes even children of pre-primary age) do indeed have some of the analytical abilities that the older literature contended they did not have (Zimmerman, 2007). These research findings are relevant for science education at primary school age, and they will be addressed in more detail in this chapter.

In the more recent developmental psychology literature, scientific thinking is defined as “intentional knowledge seeking” (Kuhn & Franklin, 2006). Based on models of the process of scientific knowledge construction, the following steps can be distinguished (see Kuhn, 2002 and Figure 4): on the basis of theories, hypotheses are formed about the phenomenon of interest; experiments to test the hypotheses are planned and conducted; the data gained are interpreted; and inferences are drawn in relation the hypotheses with the aim of further developing and/or revising theories. This process is cyclical and cumulative. In other words, a cycle from hypothesis generation to data interpretation initiates processes of theory modification or revision that, in turn, form the basis of a new cycle of hypothesis generation and testing. In the case of the scientific thinking of professional scientists, the entire cycle of inquiry is accessible to reflection: theories are explicitly formulated; hypotheses are specified in such a way that findings that conform to expectations and findings that contradict expectations can be provided; the experimental design is chosen on the basis of the hypothesis to be tested, and it is elaborated in such a way that the hypothesis to be tested can be evaluated in comparison to alternative hypotheses; the data are interpreted in relation to the hypothesis to be tested, and, where necessary, a revision of the hypothesis and the further implications for the theory to be tested are explicitly derived from them. Over and above the concrete research process, scientists have an “abstractable”, verbalisable knowledge about the process of scientific knowledge construction (an understanding of the nature of science) that includes epistemological beliefs about the emergence and justifiability of knowledge of science (McComas, McClough, & Almaroza, 1998).

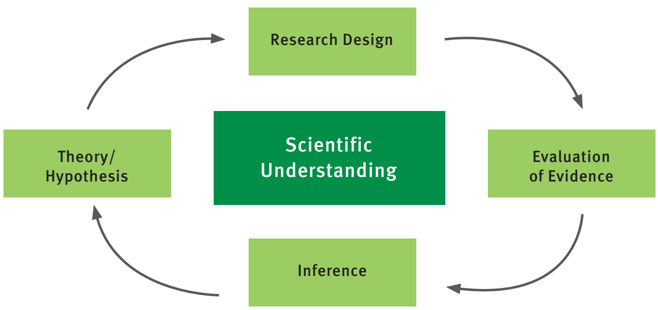

Figure 4. *Cycle of scientific knowledge construction (following Kuhn, 2002)*

If one transfers the simple model of the process of scientific knowledge construction to the exploration processes of laypersons, and especially of children, the problem arises that these processes are accessible to conscious reflection only to a very limited degree. Even adults find it difficult to make their own intuitive theories the object of *reflection* – in other words, to understand them *as theories* to which there might be alternatives and that can be (empirically) tested. Kuhn (1991) asked young adults about their theories about social problems, for example, about the causes of recidivism ("prisoners' return to crime"). After the subjects explained their theories, they were asked whether there might also be an alternative explanation for the phenomenon. They were then asked whether they had evidence to support their theories, or how they would go about getting evidence if they were to scientifically test them. Many adults, especially those without a college degree, answered this question by merely elaborating their own theories. In other words, they tried to make their theories more plausible and to present them as a description of reality ("how it happens"). They did not appear to have understood that there might be alternative theories, and that a theory could be empirically tested (see also Barchfeld, Sodian, & Bullock, 2011).

The *ability to differentiate between theory and evidence* is fundamental to scientific thinking and reasoning, and it should be the focus of efforts to foster early science education. However, if even adults have fundamental difficulties critically reflecting on their own theories and distinguishing between theory and evidence, how could it be possible to build up such an understanding of basic epistemological concepts at primary school age? More recent research findings have yielded indications of the understanding prerequisites of primary school children, and the effectiveness of instruction. These findings will be discussed in what follows with reference to the cycle of scientific knowledge construction (see Figure 4 above).

The presentation of the current state of research on knowledge about science at primary school age follows on from Pauen's deliberations in Section 2.2 of the pre-primary report (in Anders et al., 2017, pp. 43–59 in this volume) on "Scientific Thinking and Process when Engaging with Natural Phenomena" between the ages of nine months and six years. The first four processes differentiated by Pauen – "consciously experiencing and observing," "describing and recording experiences," "discussing and comparing experiences," and "forming expectations and expressing assumptions" – are geared mainly towards the *formation* of hypotheses and theories about scientific phenomena. The remaining four processes "trying things out and experimenting," "evaluating and justifying experiences," "integrating experiences and forming abstractions," and "engaging in further deliberations," relate mainly to the *testing* of theories and hypotheses and the evaluation of evidence. Pauen (in Anders et al., 2017, pp. 43–59 in this volume) investigated scientific thinking in the broader sense – that is, in the sense of processes of thinking and learning that characterise engagement with natural phenomena from early childhood onwards. By contrast, the present chapter deals with scientific thinking in the narrower sense, namely, in the sense of *intentional, conscious knowledge seeking* (Kuhn & Franklin, 2006). This substantive focus is informed by the current state of research; it is also expedient, not least in the interests of brevity of presentation.

2.2.1 Theory Formation

Theories are characterised by the phenomena that they model, by their terminology (a system of core terms that is used to describe and explain the phenomena), and by an explanatory model. The key function of theories is to provide *explanations* for natural phenomena. The search for explanations guides children's acquisition of knowledge from early childhood onwards, in the same way as it guides the process of professional scientific inquiry (Gopnik, Kuhl, & Meltzoff, 2001). By primary school age, children have already built up extensive intuitive explanations for many natural phenomena. Very often, however, these explanations deviate considerably from scientifically adequate conceptions. For example, younger primary school children often have mental models of the earth, the sun, and the movements of celestial bodies that correspond to the geocentric world view in antiquity. They represent the earth as a disc, and they believe that the sun rotates around the earth. As children lack a concept of gravity, they find it puzzling that it is possible that people "can live on the bottom of the earth" (Vosniadou & Brewer, 1992). These naive conceptions, which are the product of phenomenal perception, are not simply factual errors that can be easily corrected through information. Rather, the system of naive concepts must be restructured. This restructuring has been compared to the transformation of a scientific world view or to a paradigm shift in the history of science.

Vosniadou and Brewer (1992) investigated the process of restructuring intuitive cosmologies, for example by offering children polystyrene models of the earth (a disc, a sphere, a hollow sphere, etc.) and asking them to choose one. Some children chose a hollow sphere and cut holes in the top, so that the people who lived "on the ground" could see the celestial bodies through the holes. This example shows how children initially try to integrate the knowledge that they receive from adults ("the earth is a sphere") into their existing geocentric world view. Restructuring this world view is a complex and multi-stage process that requires the acquisition of a system of new and interlinked concepts. As elucidated in detail in Section 2.3 of this report, which is authored by Hardy and Steffensky, this is true of most sub-domains of physics, chemistry, and biology. Many experts in the didactics of science hold the view that the great difficulty and frequent lack of success in restructuring intuitive misconceptions lies not only in the complexity of the scientific concepts to be acquired but also in children's inability to reflect on their own intuitive theories. If theories are understood as mental constructs, then the process of restructuring can be supported by confronting children with evidence that is inconsistent with their theories.

One goal of the "Haus der kleinen Forscher" initiative should be to give children as young as primary school age guidance in *reflecting on their own intuitive theories*. The following section describes ways of achieving this goal and of measuring children's understanding of theories.

2.2.2 Understanding of Theories

The ability to understand that someone holds a theory about a phenomenon (which possibly deviates from one's own theory or from the scientifically adequate theory) is closely linked to social perspective-taking ability in so far as a deviating theory represents a complex form of a deviating perspective on a phenomenon.

Social perspective-taking ability is well researched in developmental psychology. From the age of around four years, children understand that another person may hold a false belief (e.g., about the place in which an object is hidden; for an overview, see Sodian & Thoermer, 2006). In contrast to understanding simple false beliefs, understanding theories presupposes that a (false) theory is understood as a system of coherent beliefs. In the social domain, it could be shown that younger primary school children have a (limited) understanding of the effect of biased social cognition. They understand, for example, that a negative action outcome (e.g., a paint box is knocked over and destroys a child's picture) can be interpreted either as malicious intent or as an accident, depending on whether the observer's biased view of the perpetrator is positive or negative (Pillow, 1991). An important characteristic of theories is that they guide the interpretation of phenomena. Therefore, in concrete, simple contexts, primary school age children appear to have a basic understanding that preconceived beliefs/prejudices influence the interpretation of events.

Using the context of medieval belief in witchcraft, Sodian, Carey, Grosslight, and Smith (1992) developed an interview to assess subjects' understanding of alternative theories. Subjects are told that 400 years ago, people believed that diseases could be caused by witchcraft (even children usually have at least a rudimentary familiarity with belief in witchcraft). In a first step, the researchers explore whether the subjects can imagine that 400 years ago, even scientists believed that witchcraft was a cause of diseases (cultural anchoring of theories). Then, they investigate the explanation of findings that contradict expectations: How would a medieval scientist react if a person who was the victim of witchcraft did not fall ill? How would he explain this unexpected finding? In the next step, the witchcraft theory and a modern medical theory (disease is caused by bacteria) are juxtaposed. When doing so, the researchers explore (a) whether the subjects understand that the symptoms of a disease and the effect of remedies are explained differently from the point of view of the medieval scientist and the modern physician; (b) whether they have any idea that the two scientists, if they were to meet today, could not communicate with each other in a simple and unproblematic way (incommensurability of terminologies); and (c) whether they have any idea that, if he were shown bacteria under a microscope, a medieval scientist would not necessarily be able to revise his beliefs (resistance of theory to change). The subjects' responses are assigned to different levels of understanding, depending on whether they understand belief in witchcraft to be a simple error (Level 1), an alternative explanation (Level 2), or a system of interconnected beliefs (Level 3).

In a longitudinal study on the development of scientific thinking between primary school age and early adulthood, Bullock, Sodian, and Koerber (2009) administered the Witchcraft Interview to persons aged 11, 17, and 22 years and found moderate changes from Level 1 in childhood, through Level 1.5 in adolescence, to Level 2 in adulthood (average levels of understanding, respectively). Even in adulthood, an explicit understanding of theories as coherent conceptual systems was rarely articulated. Most children perceived the belief in witchcraft simply as a false belief. They were often already capable of outlining explanations that conformed with theory. In other words, they were capable of taking the different theoretical perspectives and of deriving coherent inferences within these perspectives. However, they found it difficult to take a metatheoretical perspective on theories as systems of beliefs. Individual differences were already marked and significant in childhood. On tasks that required the use of experimentation strategies, subjects who had an advanced understanding of theories at age 11 achieved better results at age 17 than their peers who had a lower level of understanding of theories.

More recent studies have shown that a rudimentary understanding of theories can be achieved even in primary school students through epistemologically oriented instruction. Based on an intervention study conducted by Carey et al. (1989) with seventh-grade students, Sodian et al. (2002; see also Grygier, Günther, & Kircher, 2004; Grygier, 2008) developed an instructional unit for fourth grade in which understanding of alternative theoretical perspectives was addressed using examples from different domains. Pretest-posttest comparison revealed an average increase in understanding from Level 1 to Level 1.5 after a four-week instructional unit. A study conducted by Smith et al. (2000), in which a primary school class taught from a constructivist perspective was compared with a class taught from a more traditional perspective, also suggested that epistemologically oriented instruction has a positive impact, even at primary school age.

Hence, progress in relation to the goal of *reflective understanding of theories* can be achieved at primary school age through instruction. It is likely that such effects can also be achieved through activities such as those offered by the "Haus der kleinen Forscher" Foundation.

Measurement

Interviews can be used to measure the *reflective understanding of theories* dimension in older primary school children (Grygier, 2008; Kropf, 2010). Koerber et al. (2012) developed written test items in multiple-choice (MC) format that cover the core questions in the Witchcraft Interview. The test items with MC alternatives proved easier than the classical interview. A validation study (Kropf, 2010) revealed correlations between the two instruments, which is an indication of the validity of the test items. A comprehensive and economical "Inventory for Measuring Knowledge about Science at Primary School Age" was developed within the framework of the Science-P project (Möller, Hardy, Sodian, Koerber, & Schwippert; see Section 2.2.7). This inventory includes items for measuring the understanding of theories.

2.2.3 Hypothesis Formation and Testing, Experimental Design

From early childhood onwards, children form assumptions and expectations about natural phenomena (see Pauen's contribution in Anders et al., 2017, pp. 43–59 in this volume). Observations of young children between the ages of one and three years suggest that children may test such assumptions at an early age – for example, when, in the second year of life, they let a toy drop to the floor several times from different heights and observe the effects. There can be no doubt that, at an early age, children are also capable of using evidence to revise or confirm their assumptions, for example when they learn the meanings of new words. However, these processes usually take place without the child consciously reflecting on its own hypotheses and systematically planning experiments that would be suitable to test these hypotheses.

In older developmental psychology research, the ability to systematically form and test hypotheses using experimental designs was considered to be a characteristic of adolescence. Inhelder and Piaget (1958) assumed that formal logical thinking was the prerequisite for the ability to test hypotheses and understand experimental designs. Studies reported in the older research literature worked with complex, multivariate tasks that made high demands on the attentiveness and memory of the subjects and often required prior domain-specific knowledge. More recent research, by contrast, has systematically investigated the foundations of hypothesis testing in younger children (for an overview, see Zimmerman, 2007).

Hypothesis testing versus producing effects

In scientific thinking tasks, children often appear to be more interested in producing positive effects (e.g., baking a cake that rises) than in deciphering cause-effect relationships between variables (finding out what determines whether or not a cake rises). It was assumed that children lacked a conceptual understanding of hypothesis and evidence and that they therefore found it difficult to understand what testing an assumption or hypothesis meant (Kuhn et al., 1988).

Sodian, Zaitchik, and Carey (1991) were the first to systematically investigate first- and second-grade students' ability to differentiate between hypothesis testing and the generation of effects. Subjects were told a story about two brothers who had noticed that there was a mouse in their house, but who had not been able to see it because the mouse came out only at night. The boys wanted (a) to find out by means of experiment whether the mouse was big or small ("Find Out" condition: hypothesis testing) or (b) to feed the mouse ("Feed" condition: producing effects). In both experimental conditions, the children were supposed to choose between two boxes – one with a large opening, and one with a small opening – into which cheese could be placed, and to justify their choice. Over half of the first graders, and 86% of the second graders, were able to distinguish between the two tasks: In the "Find Out" condition, the children were able to differentiate between an inconclusive test (large opening) and a conclusive test (small opening) and to correctly justify their choice. In the "Feed" condition, by contrast, the children chose the box with the big opening in order to make sure that, regardless of whether the mouse was big or small, it would get the cheese.

Hence, even younger primary school children are capable in principle of differentiating between hypothesis testing and producing effects, and, when presented with alternatives, they choose a critical/conclusive test for a hypothesis. Of course, primary school children have a greater tendency than older subjects to seek to produce positive effects in the case of a correspondingly motivating task, and it is possible that, when doing so, they lose sight of their original goal, namely hypothesis testing. However, the findings described above show how even younger primary school children's comprehension of scientific thinking tasks can be supported and stimulated with the help of supportive contextual conditions.

Causal hypotheses and the control-of-variables strategy

Scientific hypotheses are frequently characterised by assumptions about cause-effect relationships between two or more variables (e.g., "Sweets cause tooth decay."). Testing such hypotheses requires a comparison between conditions with different values of the assumed causal variable (eating lots of/few sweets). When doing so, all other potentially relevant variables must be kept constant. Bullock and Ziegler (1999) gave primary school students the task of placing themselves in the role of an aircraft engineer who wanted to find out whether a certain characteristic of an aircraft (e.g., location of the "rudder": at the top or at the bottom) had an effect on fuel consumption. Two further variables (the shape of the nose and the wing type) were identified as potentially relevant. When asked how the engineer could test whether the location of the rudder would influence fuel consumption, the majority of the third and fourth graders suggested a contrastive test – in other words, the comparison of aircraft that differed with regard to the location of the rudder. This outcome shows that children from grade three onwards are capable of understanding that causal hypotheses can be tested by critically comparing conditions, and that they do not only produce positive effects.

However, only from grade five onwards was a controlled test produced by around one third of the subjects. And only at age 17 did 80% of the subjects spontaneously produce a controlled experiment. When the children were presented with the eight possible combinations of variables in the form of picture cards in order to investigate whether they were able to distinguish a controlled experiment from a confounded experiment, 30% of the third graders, 60% of the fourth and fifth graders, and 80% of the sixth graders recognised a controlled experiment and were also able to correctly justify this choice. These findings indicate that even primary school students have a tacit understanding of the experimental method.

Moreover, training studies have shown that primary school students are capable of learning the control-of-variables strategy (CVS; Klahr & Nigam, 2004). However, it is important that they do not use it as a rigid rule ("Vary one variable, keep all others constant."), but rather that they understand why this strategy is employed to critically test hypotheses. In an intervention study, Sodian, Jonen, Thoermer, and Kircher (2006) demonstrated that, compared to a control class, fourth graders who had been taught with an epistemologically oriented curriculum spontaneously employed CVS significantly more often, even though it had not been explicitly taught as part of the curriculum. This finding indicates that, in older primary school children, an adequate understanding of the role of the controlled experiment in the process of scientific knowledge production can be achieved through instruction.

A further important finding of the longitudinal study conducted by Bullock and colleagues (Bullock & Ziegler, 1999; Bullock, Sodian & Koerber, 2009) is the stability of individual differences. Clear individual differences were observed at primary school, and they remained relatively stable into adolescence and young adulthood. These differences were not attributable to schooling. Rather, by fourth grade, the children who later went on to *Gymnasium*[15] had achieved a level of spontaneous use of CVS that was not achieved until age 17 by students who later went on to *Hauptschule*[16]. Hence, the findings do not permit the conclusion that *Gymnasium,* with its emphasis on formal analytical abilities, specially trains students in methodological competencies such as CVS. Rather, the individual differences that already exist at primary school are obviously not influenced by the type of schooling. The *targeted imparting of methods of scientific work* at primary school age would be urgently necessary in order to impart to weaker students, who do not spontaneously construct adequate strategies, the basic competencies that they need in order to benefit from science teaching.

In summary, it can be noted in relation to the goal dimension *knowledge of methods of testing hypotheses* that initial competencies are already present at primary school age and that the use of adequate strategies to test causal hypotheses can be achieved through targeted support.

Measurement

Hypothesis testing competencies should be measured independently of domain-specific knowledge of science. The experimental tasks developed to this end in the studies reviewed above are suitable for this purpose. However, measurement is very time-consuming. The *Inventory for Measuring Knowledge about Science at Primary School Age* (Möller, Hardy, Sodian, Koerber, & Schwippert) developed within the framework of the Science-P project, enables economical measurement (see Section 2.2.7; Koerber et al., 2011; 2012).

2.2.4 Evaluation of Evidence, Inference Processes

Children's ability to interpret data and to draw valid inferences from them in relation to the hypothesis tested has been less well studied than their experimentation strategies. In the older literature, grave deficits were demonstrated in primary school children. Kuhn et al. (1988) showed children and adolescents an example of a scientific investigation of the relationship between eating certain foods and getting colds. First, the subjects were asked about their own theoretical assump-

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15 Gymnasium *(plural:* Gymnasien*) is a type of secondary school aimed at the general higher education entrance qualification.*

16 Hauptschule *is a type of school at lower secondary level providing a basic general education.*

tions, for example, whether they believed that eating cake, vegetables, or granola bars was associated with getting colds. They were then shown the results of the investigation in the form of graphically represented patterns of covariation or non-covariation between eating a particular food and getting colds. The majority of the primary school students were not capable of taking in all the evidence presented and interpreting it in relation to their own hypothesis. Rather, they attended only to parts of the data pattern, and distorted the evidence in order to achieve consistency with their own hypothesis. Only in adolescence were most subjects capable of interpreting such data sets in a scientifically appropriate way.

The evaluation of evidence by children and adolescents should not, however, be measured against an ideal standard of scientific rationality, because biased interpretations of data that do not conform to expectations occur also among professional scientists. Moreover, comparisons between the evaluation of evidence by children and by professional scientists are hardly possible on the basis of such studies because they do not test genuine, causally justified theories about a phenomenon in relation to which the children already have adequate prior knowledge of causal relationships. Instead, they often test arbitrary ad hoc theories about relationships between variables. The findings of Kuhn et al. (1988) do not allow any inferences to be drawn about specific causes of deficits in children's evaluation of evidence because the tasks were very demanding in terms of attentiveness, memory, and language comprehension, which were not systematically controlled.

More recent studies have used very simple tasks to investigate children's fundamental understandings of the relationship between hypotheses and data. For example, Koerber, Sodian, Thoermer, and Nett (2005) demonstrated that children as young as four years were capable of interpreting simple covariation patterns with regard to their consistency or lack of consistency with a hypothesis. When only one variable was manipulated (e.g., the colour of a piece of chewing gum), and perfect, or almost perfect, covariation was presented (e.g., all, or almost all, the children who ate green chewing gum had caries), four-year-olds were able to correctly evaluate whether a character in a story who had a certain hypothesis would retain or revise it in the light of the evidence. However, when non-covariation between an assumed cause and an effect was shown (e.g., half the children who ate green chewing gum had healthy teeth and the other half had caries), preschool children were capable of correctly interpreting the evidence only if they were presented with the hypothesis that there was *no* relationship between the two variables. The competencies of the children in this age group did not depend on whether the evidence was presented in the form of realistic images or bar charts; a brief introduction to the convention of the bar chart sufficed to enable preschoolers to interpret the simple data patterns. These findings suggest that basic evidence-evaluation skills are present at primary school age, and that they can be used to impart the ability to interpret more complex data patterns.

The interpretation of more complex data patterns calls for intuitive stochastics. Although deficits on the part of adolescents and adults in interpreting complex 2x2 tables are well documented (Shaklee & Mims, 1981), basic competencies of primary students have scarcely been studied to date. A series of studies of contingency table analysis in primary school students showed facilitating effects of task presentation (symmetrical task conditions; Saffran, Barchfeld, Alibali, & Sodian, 2016), and explanatory competencies when task demands were reduced.

In low-content experimental tasks, primary school age children do, in principle, take note of evidence that contradicts a hypothesis, and they draw corresponding inferences. However, they are often incapable of doing so when, in actual science domains, the predictions that they have derived from pre-scientific preconceptions conflict with the evidence gained in the classroom (e.g., the prediction that “all heavy objects will sink in water,” which conflicts with the evidence that a heavy tree trunk floats).

One goal of science education is the competence to evaluate evidence in science domains. Evidence-based reasoning about scientific phenomena is a complex process that is still inadequately analysed. In a study by Hardy, Kloetzer, Möller, and Sodian (2010), the authors analysed evidence-based discourse in the primary classroom and found a low frequency and a low level of evidence-based reasoning. Often, only unsupported claims were made or single observations were cited as evidence. At the same time, however, there were indications of the positive effects of evidence-based teacher interventions (see also Section 2.3).

The goal is to develop children’s *ability to differentiate between a hypothesis and evidence and to evaluate evidence in relation to the hypothesis tested*. The aforementioned studies provide pointers for possible ways of facilitating this differentiation and reflection.

Measurement

Hardy et al. (2010) developed a system for coding the level of evidence-based classroom discourse, which can be used for video analyses of discourses about scientific phenomena. Individual competencies can be measured with the inventory developed within the framework of the Science-P project (Koerber et al., 2011; see Section 2.2.7).

2.2.5 Self-Directed Exploration Processes

Self-directed exploration processes in which a phenomenon is explored over a longer period of time are of particular importance for science education at primary level. In the field of developmental psychology, several microgenetic longitudinal studies have investigated how (older) primary school children learn in such situations, compared to adolescents and adults.

In order to eliminate effects of domain-specific prior knowledge, studies have created computerised microworlds, for example, the microworld of racing cars that differed on various dimensions (tyre width, spoiler, rear, etc.). Subjects were given the task of exploring the relationships between these variable dimensions and the speed of the racing cars, and of uncovering the causal relationships as fully as possible. They explored the microworld for between six and ten hours over a period of several weeks (Schauble, 1990; Kuhn et al., 1995). The children made learning progress. However, because of their deficient strategies, it was not as pronounced as that of adults. As a rule, they did not succeed in completely uncovering the causal structure of the domains. The findings suggest that self-directed exploration without support from teachers often yields only limited knowledge gains in primary school children. However, the microworlds that were realised in these studies are comparable only to a limited extent to real scientific phenomena.

It is recommended that *self-directed learning through exploration* be included as a goal of early science education.

Measurement

The measurement of such learning processes is time-consuming. It can be carried out with the methods used in the above-mentioned microgenetic studies. The inventory developed within the framework of the Science-P project is suitable for pretest-posttest comparison (see Section 2.2.7).

2.2.6 Understanding the Nature of Science

The ability of primary school children to develop alternative theories, form hypotheses, plan experiments, and interpret evidence in specific task contexts allows inferences to be drawn about their understanding of the nature of science. Moreover, adults have an abstract declarative, situation-independent understanding of the nature of science that includes concepts of theory and evidence, experiment, and data. To date, very few studies have been conducted on the declarative understanding of the nature of science in primary school age children. Building on an interview study of seventh-grade students' understanding of the nature of science conducted by Carey, Evans, Honda, Jay, and Unger (1989), Sodian and colleagues (Sodian, Thoermer, Kircher, Grygier, & Günter, 2002; Sodian, Jonen, Thoermer, & Kircher, 2006; Grygier, 2008) conducted studies of fourth graders' understanding of the nature of science using a correspondingly adapted version of the Nature of Science Interview developed by Carey et al. (1989). This interview contains questions about the goals of science (What is science all about? What are the goals of science?); the individual elements of the research process (What is a hypothesis/a theory? What is an experiment?); the relationship between theories/hypotheses and experiments; the causes of unexpected findings; and the understanding of the revision of hypotheses and theories. Just like the seventh-grade students in the study by Carey et al. (1989), the majority of the primary school students expressed an understanding of the nature of science as an activity for producing positive effects or collecting factual information, and they did not establish any relationships between theories/hypotheses, experiments, and evidence.

However, a brief period of instruction in the form of a curriculum unit explicitly devoted to the epistemology of science was shown to have positive effects even on fourth graders' understanding of the nature of science. It proved possible to raise the level of understanding and to impart a fundamental understanding of the nature of science as a search for explanations, and an understanding of knowledge of science as the outcome of the testing of hypotheses and theories. Moreover, in a subsequently taught science domain, a correlation was observed between understanding the nature of science, on the one hand, and learning progress, on the other. In a pretest-posttest comparison of a curriculum unit on the subject of floating and sinking, Grygier (2008) found that a class who had received instruction in the epistemology of science dismantled significantly more misconceptions and built up significantly more scientifically adequate conceptions than a control group. These findings underscore the importance of epistemologically oriented instruction, which can be successfully delivered in an age-appropriate way, even to primary school students (Grygier, Günther, & Kircher, 2004).

An explicit *understanding of the emergence of knowledge of science* and *an insight into the main elements of the research process* are an important goal of science education. The aforementioned studies provide evidence of the presence of fundamental understanding prerequisites at primary school age and of the beneficial effects of instruction.

Measurement

This goal can be measured using the Nature of Science Interview developed by Carey et al. (1989), in a form adapted for primary level (see Grygier, 2008), or the

Inventory for Measuring Knowledge about Science, which was developed within the framework of the Science-P project (see Section 2.2.7).

2.2.7 Measurement Instruments

The above overview of the developmental psychology literature on science (methodological competence and understanding of the nature of science) at primary school age demonstrated the context dependency and task dependency of competencies in hypothesis testing, evidence evaluation, and understanding the nature of science. Primary school students have been found to exhibit consistent deficits in open-response formats and multivariate task contexts. However, when closed-response formats were used (e.g., a choice between different experiments), and tasks made reduced information-processing demands, even young primary school students exhibited fundamental understanding prerequisites (e.g., an understanding of hypothesis testing as opposed to producing effects). On the basis of these findings, an *inventory for the economical and valid measurement of knowledge about science at primary school age,* was developed within the framework of the Science-P project (Koerber, Mayer, Osterhaus, Schwippert, & Sodian, 2015).

The underlying competence model postulates three levels of understanding: (1) naive conceptions, (2) intermediate conceptions, and (3) scientifically adequate conceptions. In the multiple-choice or multiple-select format, the response alternatives represent the three levels of understanding. For example, the choice of the "controlled experiment" response option is a scientifically adequate solution to the task of testing a hypothesis about a causal relationship between variables; the choice of the option "contrastive test without controlling variables" is a partly correct intermediate conception; and the choice of the option "reproduction of an effect without varying the conditions" is a naive (mis)conception. A comparison of one-dimensional and multidimensional Rasch models revealed, with satisfactory reliability, a one-dimensional structure of the competency *knowledge about science* (Mayer, 2012). A validation study showed, as expected, that, compared to one-on-one interviews, the use of predefined response alternatives elicited responses that reflected higher levels of understanding. Moreover, it could be largely ruled out that the children guessed the answers in the paper-and-pencil-based test procedure (Koerber et al., 2012). The instrument can be applied from the end of grade two onwards, and, as expected, developmental changes from the level of naive conceptions to the level of intermediate and scientifically adequate conceptions have been found to occur between grades two and four. Individual developmental pathways are currently being studied longitudinally. The instrument enables a differentiated measurement of knowledge about science and the clarification of correlations with primary school students' knowledge of science.

2.3 Knowledge of Science

Ilonca Hardy & Mirjam Steffensky

In line with cognitive development research findings in the field of science education and developmental psychology, knowledge of science is understood in what follows as conceptual knowledge that is elaborated and applicable, or that can be classified as individual conceptions of specific phenomena.

2.3.1 Structure of Knowledge of Science

At the beginning of primary school, children already display different, and differentially appropriate, conceptions of scientific phenomena. These result, in part, from their experiences in the natural world, from knowledge gained from learning opportunities at pre-primary level, from individual preferences, and from the language used in everyday life and in the media. With appropriate learning opportunities, children's existing conceptions undergo increasing differentiation and restructuring in the course of their time at primary school. Although many of the children's naive conceptions appear to make sense as an interpretative framework in everyday life, at the beginning of primary school, very few of these conceptions are already consistent with explanations and models shared by the scientific community. Therefore, the goal should be to support the cognitive restructuring of these conceptions during the primary years, especially through high-quality learning opportunities, so that children can develop conceptions that have explanatory power and are (more) consistent with scientific models (Vosniadou et al., 2008; Duit & Treagust, 2008; Cepni & Cil, 2010; Möller, Hardy & Lange, 2012; Shulman, 2009). The acquisition of advanced conceptual knowledge is not based on a collection of facts, but rather is understood as a slow and usually meandering process, in the course of which different forms of intermediate conceptions and fragmented knowledge may occur (Schneider, Vamvakoussi, & van Dooren, 2012; Duit & Treagust, 2008).

Some authors emphasise that children's knowledge is quite theory-like and coherent (Vosniadou & Brewer, 1992; Vosniadou, Vamvakoussi & Skopeliti, 2008), whereas others argue that learners' knowledge is often idiosyncratic and fragmented (diSessa, Gillespie, & Esterly, 2004; diSessa, 2008). There is mixed evidence as to whether learners' initial knowledge in a domain is coherent or fragmented.

According to the coherence approach, conceptual changes can be regarded as changes to coherent interpretative frameworks (theories), within which even children's initial domain-specific knowledge is organised according to logical principles and supported by core knowledge. In the form of framework theories, this initial knowledge also influences the construction of new knowledge structures. New information is interpreted within an existing theoretical framework, so that, when new information is presented, so-called synthetic (mental) models or intermediate conceptions may emerge that combine aspects of the original conception with aspects of the new explanation. In further learning processes, these intermediate conceptions can develop into scientifically adequate models (Vosniadou & Brewer, 1992; Vosniadou, Vamvakoussi, & Skopeliti, 2008). For example, investigations of children's mental models of the earth identified several different initial theories about the earth and revealed that younger children often form an initial mental model of a flat earth that is closely related to their everyday observations that the surface of the earth is flat and that objects fall to the ground. Hence, they use core knowledge and everyday experiences as an interpretative framework within which they explain phenomena (Vosniadou & Brewer, 1992).

For various domains (e.g., forces, the day/night cycle, and the earth), numerous, mainly cross-sectional, studies (e.g., Ionnides & Vosniadou, 2002) have supported claims that children's initial knowledge is coherent and integrated. However, even the proponents of the coherence approach acknowledge that there is a large group of children in every age range whose knowledge exhibits a low level of integration.

Proponents of the *fragmentation approach* (e.g., diSessa, 2008; Clark, 2006) focus on this inconsistency of conceptions by stressing the contextuality and unstructured nature of initial knowledge. They assume a continuum of conceptual development, whereby individual, context-specific units of knowledge are successively integrated into more comprehensive systems (diSessa, Gillespie, & Esterly, 2004).

Based on findings from this research field in relation to different age groups and content areas (e.g., diSessa, 2008), it is assumed that, depending on the child's stage of conceptual development, the process of conceptual restructuring may include not only the integration of conceptions but also their context-dependent differentiation and fragmentation. Thus, it is apparent from a large number of research findings that children's initial, or uninstructed, understandings, in particular, can by no means be regarded as theory-like and coherent. For example, a series of studies on primary school students' understandings of air pressure and evaporation and condensation found that the children simultaneously used multiple concepts to explain phenomena, and that these concepts included both naive and advanced ideas (e.g., Tytler, 2000; Tytler & Prain, 2010). The Science-P project, which deals with the development of scientific competence at primary level, also found that children's initial knowledge in the domains of evaporation and condensation and floating and sinking was, for the most part, inconsistent and distinctly domain-specific (Kleickmann, Hardy, Pollmeier, & Möller, 2011).

It can therefore be assumed that the integration of initially disparate knowledge structures is a central process of conceptual development. The results of a further longitudinal study of conceptions of floating and sinking indicate that conceptual change can include both phases of fragmentation and phases of integration, depending on the status of the initial conceptual knowledge in combination with the quality or focus of the subject-specific learning opportunity (Schneider & Hardy, 2012). This also means that it is to be expected that (a) when interpreting natural phenomena in learning environments, children use different, inconsistent explanations; (b) these explanations are context-dependent; and (c) without adequate support, children do not usually notice inconsistencies.

2.3.2 Conceptual Knowledge in Different Content Areas

In the area of physical science, the majority of primary level curricula include topics such as “matter and properties of matter” (e.g., air, evaporation/condensation) and “forces and motion” (e.g., pushing and pulling). In what follows, the topics “floating and sinking” and “water cycle/ states of matter” are described by way of example because they include fundamental concepts relating to the broad experiential background of water, and they may therefore build on connectable conceptions gained from learning opportunities at pre-primary level. For some time now, the consideration of connectable knowledge has been discussed in science education in the context of learning progressions (Alonzo, 2012). The aim of this discussion is to conclusively link learning opportunities at different educational levels, in order to ensure continuous conceptual development in important areas of science.

In research on conceptual development, a distinction is typically made between explanations of different ranges when describing children’s initial knowledge, and the knowledge that is the target of school-based learning opportunities. These types of conceptual knowledge differ in terms of their content, scientific correctness, and functional characteristics (Schneider & Hardy, 2012). Thus, it is possible to distinguish naive conceptions, everyday conceptions, and scientifically appropriate conceptions.

In the context of floating and sinking, for example, *naive conceptions* refer to one-dimensional explanations that focus on weight, size, shape, etc. They are therefore inconsistent with scientific explanations, and have no explanatory power beyond very few observations. Thus, many children expect that a large block of wood will sink in water because it is heavy, but that a small metal needle will float because it is so light.

Everyday conceptions, by contrast, can explain a wider range of observations in everyday contexts. However, they can be falsified by systematic observation and the results of inquiry activities. Here, children recognise relations between different observable variables, but they do not link them to explanatory physical concepts. For example, a child might use the concept of material to explain why a metal needle sinks in water, and it might also apply this explanation to other solid (not hollow) bodies of the same material. Nonetheless, the range of the explanation is limited, as it cannot explain why a hollow body, for example a ship made of iron, does not sink in water.

In order to provide a *scientifically appropriate* and economical explanation for all observations of floating and sinking, the concepts of the density of different materials and buoyancy force must be used, as they include the physical mechanisms that underlie the phenomenon to be explained. The use of scientific concepts always involves the expression of correlational knowledge, for example in "if-then" or "the…, the…" formulations, such as the following statement by a child: "The larger an object is, the more water it will displace." This correlational knowledge may still be very situated, (e.g., "If I place this sponge in the sun, it will dry."). However, as it becomes increasingly generalised, it becomes more and more consistent with scientific concepts (e.g., "If the temperature is increased, the liquid will evaporate faster").

It should be noted that, at primary school age, explanations that employ scientific concepts do not yet involve the use of knowledge of formulae. Children can, however, correctly refer to physical relationships between variables, which are needed to describe the respective phenomena. Moreover, with regard to the characterisation of conceptions as misconceptions, everyday conceptions, or scientific conceptions, it should be emphasised that the degree of integration of individual conceptual knowledge may vary, and that the process of knowledge integration and differentiation is idiosyncratic. Hence, children may combine different types of conceptual knowledge, or may use different explanations in similar contexts without noticing these inconsistencies (Schneider & Hardy, 2012).

Also related to knowledge of science is the way in which *justifications* for natural phenomena are formulated. In science, particular importance is placed on the use of empirical evidence and on defending explanations, arguing, and drawing conclusions from investigations (see also Beinbrech, Kleickmann, Tröbst, & Möller, 2009; Furtak et al., 2010). The justification of statements, especially by using empirical evidence, is a fundamental characteristic of scientific reasoning.

Here, justifications can be differentiated according to the level at which statements are supported: no justification; phenomenological justification (only one characteristic/observation is cited); relational justification (several data points are aggregated); or formal (i. e., rule-based) justification.

Thus, with regard to primary school children's knowledge of science, the aim is to achieve an advanced level of understanding compared to that at pre-primary age. The target level corresponds to that of *everyday conceptions* or *scientific conceptions* (in the sense of an understanding of the scientifically correct relationships between variables/processes in different domains) described above. In grades one and two, everyday understandings are more likely, whereas in grades three and four, scientific conceptions can increasingly be expected.

Moreover, children should develop an awareness of the fundamental *relevance of empirical evidence for scientific reasoning,* which finds expression in the justification of assertions at a relational or rule-based/formal level.

Measurement

There are several instruments to assess the knowledge of primary students in many content areas of science, for example the TIMSS test (Mullis & Martin, 2013). Moreover, there are assessments for specific content areas. In the Science-P project, for example, group-administered test instruments in multiple-choice or multiple-select format for measuring the conceptual knowledge of primary school children in the domains of "floating and sinking" and "evaporation and condensation" were developed and tested on a representative sample of over 1000 primary school children. The pilot test confirmed the feasibility of using paper-and-pencil test procedures to measure *conceptual knowledge* at primary school age. However, it revealed differences between the concepts presented, for example, in selection tasks, and the explanations that children produced themselves in interviews, with the reaction to presented concepts being deemed easier (Pollmeier, Hardy, Möller, & Koerber, 2011). Sample items and information about the construction of the test can be found, inter alia, in Kleickmann et al. (2010). A further subject-specific test of primary school students' achievements in the domain of states of matter, which comprises 24 closed-ended items and was administered to a sample of over 1000 primary school children, can be found in Ohle, Fischer, and Kauertz, 2011.

Examples of primary students' ideas about floating and sinking, and states of matter

Floating and sinking

- Typical naive conceptions: Things that are small float. Things that are big sink. Things that have air in them float (air pulls things upwards). Things that have holes in them sink. Things that have an engine float. Water pushes/pulls/sucks things downwards.
- Everyday conceptions: Hollow things float. Things made of light material (lighter than water) float. Things made of a heavy material (heavier than water) sink. Things made of wood/polystyrene/cork/wax float. Things made of stone/metal/ceramics sink. If you put something into water, the water will press against it.
- Scientific conceptions: Things that are heavier than the same amount of water sink. Things that are lighter than the same amount of water float. Things that are pushed upwards strongly enough by the water float. Things that are heavier than the buoyancy force sink. The larger the object is, the stronger the pressure of the water against it and the better it will float.

Also related to children's conceptions is their ability to verbally express their observations and explanations, that is, to name and describe phenomena and facts. Examples of this are designations of materials (wood, polystyrene, metal/iron, plastic, stone), feels heavy/feels light, surfaces, floats, comes to the top, goes down, sinks, water pushes, water needs space, water rises.

An understanding of matter and the concept of weight can be seen as a precursor to understanding floating and sinking (Carey, 1991). However, a differentiation between volume and mass in the concept of density, with an accompanying "theory of matter," can be expected at the beginning of secondary level, at the earliest (e.g., Smith, 2007; Wiser & Smith, 2008). Nonetheless, by the end of primary level, and after appropriate instruction, children are capable of using average density to explain floating and sinking (Hardy, Jonen, Möller & Stern, 2006; Möller, Jonen, Hardy, & Stern, 2002). The concept of displacement can be regarded as a further prerequisite to understanding floating and sinking. Here, the common misconception that the amount of water displaced depends on the weight of the object must be abandoned in favour of the volume of the object.

States of matter

- *Typical naive conceptions:* Water simply disappears. Water is (completely) absorbed by the ground or other surfaces and disappears. Ice can turn to water, but a liquid cannot turn into a solid. Melting and dissolving are identical processes.
- *Everyday conceptions:* Water goes upwards; it transfers to the ceiling, the sun, or the clouds. Ice can turn to water and vice versa. Water can turn into steam and vice versa. Water is changed into air.
- *Scientific conceptions:* Water is in the air as invisible water. Factors that influence changes of matter: The warmer it is, the faster water will go into the air, and the faster ice will melt. When it is cold, vapour becomes water, or water changes to ice. The colder it is, the faster water will freeze.
- *Linguistic formulations:* solid, hard, cold, liquid, soft, warm, you can pour it, pour from one container to another, become liquid, become water, melt, defrost, become solid, become ice, freeze, invisible, like air, you can't grasp it/take hold of it, go up into the air, become air, become steam/fog, dry, boil, steam up, become water again.

2.3.3 The Role of Structured Learning Experiences in Effective Learning

Assuming that primary students approach a topic with a range of experiences and specific, often naive, ideas, an effective learning environment (see Section 3.3.3) should give the children an opportunity to productively question their conceptions, to build up new explanations for phenomena that they have observed, and to integrate them to form coherent views (Linn, 2006; Schneider & Stern, 2009). Classroom research has shown that the usual learning environments at primary and secondary level are often not successful in enabling students to build up new concepts in the long term. As a result, misconceptions persist into late secondary level and adulthood (Wandersee et al., 1994; Treagust & Duit, 1998).

Especially in primary school learning environments, therefore, it is important to combine student orientation and discovery learning oriented towards empirical evidence and experiments, on the one hand, with structuring elements, on the other. Overall, classroom research has shown that structured learning environments with adaptive support for learners can, in particular, foster the development of knowledge in science (Klahr & Nigam, 2004; Hardy, Jonen, Möller, & Stern, 2006). It must therefore be emphasised that not all primary school learning opportunities support a change in initial knowledge of science towards scientifically more adequate conceptions. Although a cross-sectional study conducted by Kleickmann et al. (2011) revealed that the probability that a child would exhibit more integrated and advanced knowledge increased with the amount of instruction it had already received in the two topics covered by the test, the knowledge growth could not be explained completely by the amount of instruction received.

2.4 Basic Competencies

Yvonne Anders & Beate Sodian

Science competencies are complex and specialised competencies that presuppose basic cognitive competencies and social competencies, such as adequate receptive language skills, reading comprehension skills, mathematical skills, working memory, planning skills, cognitive flexibility, perspective-taking skills, cognitive behavioural control, and persistence. These basic skills can influence the way, and the extent to which, primary school age children benefit from the educational offerings of the "Haus der kleinen Forscher" Foundation. As the few existing studies on scientific thinking at primary school age have revealed large individual differences, it must be examined whether different educational offerings should be provided for children with different initial levels of basic competencies. To this end, procedures for measuring basic competencies should be applied in addition to instruments for measuring knowledge of science and knowledge about science (see Sections 2.2 and 2.3).

Moreover, basic competencies should be measured in evaluation studies by means of pretest-posttest comparisons in order to determine whether, or to what extent, the educational offerings of the "Haus der kleinen Forscher" Foundation have not only specific effects on domain-specific and domain-general knowledge of science and scientific thinking, but also more general effects on language, cognitive, and social competencies.

With regard to the long-term outcomes of early science education, the question arises as to whether early science-specific competencies or early general competencies, such as intelligence, language, and cognitive behavioural control, are predictive of the individual's later competence level in scientific thinking and reasoning. Little longitudinal research has been conducted on this question. Bullock et al. (2009) found moderate correlations between measures of scientific reasoning and intelligence measures. In addition, the authors found that specific correlations between scientific reasoning skills in early childhood and the level of reasoning in early adulthood emerged longitudinally, and that these correlations were unrelated to general intelligence. However, no domain-specific science competencies in physics, chemistry, or biology were measured within the framework of their study.

2.4.1 Cognitive Competencies

Mayer (2012) investigated the correlations between domain-general scientific thinking skills and basic cognitive skills (reading comprehension, intelligence, problem solving, inhibition, spatial thinking, formal-operational skills) in a sample of N = 285 second-, third-, and fourth-grade children. Although reading comprehension and intelligence correlated with scientific thinking, scientific thinking skills could be distinguished as a separate construct. This finding is particularly important because scientific thinking skills were measured in a paper-and-pencil group test, and it could be ensured that the age-related and individual differences found were not attributable merely to differences in reading skills. Among the basic cognitive skills, problem-solving skills, measured by means of a planning task titled the "Tower of London," was an outstanding predictor; spatial thinking also contributed – albeit to a lesser extent – to explaining the variance. These findings indicate that planning skills should be taken into account as a correlate of (domain-general) thinking, and that training studies are needed to determine whether the fostering of general planning and problem-solving skills helps primary school age children to benefit from science education offerings.

Other research points to correlations between social perspective taking (theory of mind) and scientific thinking in younger primary school children (Astington, Pelletier, & Homer, 2002). Moreover, because the development of planning skills, cognitive flexibility, and social perspective taking are closely correlated in children of pre-primary and early primary school age (Kloo & Perner, 2008), it can be assumed that these basic competencies are both predictive of the development of scientific thinking and, as correlates of scientific thinking, can be fostered through appropriate educational offerings.

We therefore recommend that *planning or problem-solving skills* and *perspective-taking skills* should be measured as a secondary goal of science education, and that *reading comprehension* and *non-verbal intelligence* should be measured as a control variable.

Measurement

A number of standardised procedures exist for measuring intelligence at primary school age. From around the end of grade 2, group intelligence tests can be administered. To measure basic competencies, it should suffice to use the non-verbal intelligence test CFT 20-R (German Culture Fair Intelligence Test; Weiß, 2006) and a measure of reading comprehension; the ELFE test of reading comprehension is particularly suitable for this purpose (Lenhard & Schneider, 2006). Because reading comprehension tests correlate highly with verbal intelligence, it should not be necessary in most cases to measure verbal IQ as well.

There are no standardised instruments for measuring social perspective taking, cognitive flexibility, and planning skills. However, it may be worthwhile to use tasks developed in cognitive developmental psychology (see Mayer, 2012; Sodian & Thoermer, 2006).

2.4.2 Social Competencies

Social competencies is an omnibus term for various facets that refer, on the one hand, to the adaptation to social norms and rules, and, on the other hand, to the assertion of the individual's own needs (see Kanning, 2001). Caldarella and Merrell (1997) distinguish the following dimensions: formation of positive peer relations, self-management, social cooperation, social assertion, and skills in the context of school-based learning (e.g., the ability to listen to the teacher). Conspicuous or problematic social behaviour constitutes a separate dimension. It is of particular relevance in the school sector because not only is there a risk that behavioural problems will get worse in the course of the child's development (Campbell et al., 1996), but also these problems are linked to the development of cognitive competencies and to the individual's entire academic development (Jerusalem & Klein-Heßling, 2002). In the case of problematic social behaviours in children, internalising and externalising symptoms can be distinguished (see Achenbach & Rescorla, 2000). Internalising symptoms refer mainly to excessive social withdrawal and anxious behaviour, whereas externalising symptoms comprise aggressive and delinquent behaviours.

Although, for measurement purposes, social skills are not a priority goal of the offerings of "Haus der kleinen Forscher" Foundation, they are nonetheless relevant in many respects. On the one hand, social skills are related to the development of cognitive performance (see above). On the other hand, it can be assumed that children who exhibit more pronounced prosocial behaviour have better prerequisites for availing of the learning opportunities afforded by the "Haus der kleinen Forscher" Foundation. This explains the status of social skills as a control variable within the framework of outcome research at the level of the child. However, it can be assumed that the learning opportunities and forms of learning (e.g., collaborative exploration of phenomena, experimenting) afforded by the Foundation also foster the development of pro-social behaviour or collaborative skills. The relevance of this competence domain for outcome research is derived from this.

Measurement

Several tried-and-tested procedures already exist for measuring social skills or conspicuous social behaviour at primary school age. Most of these are rating procedures that make use of assessments provided by parents, teachers, or other adults in the child's environment. There are also a number of observation-based procedures.

Mention can be made here of the Child Behaviour Checklist (CBCL), for example, which is based on the Achenbach Scales (e.g., social withdrawal, attention deficits, aggressive behaviour; Achenbach, 1991; Arbeitsgruppe Deutsche Child Behaviour Checklist, 1998). The Strengths and Difficulties Questionnaire (SDQ) for children from age four (Goodman, 1997) has also proved its worth. This test covers the age range 4–17 years. It measures the following aspects: emotional problems, conduct problems, hyperactivity, peer problems, and prosocial behaviour. There a number of other instruments with similar conceptualisations; some general development tests also include scales for measuring the level of social development. The use of these and other tests could be of interest within the framework of outcome research, because social competencies are broadly correlated with cognitive-behavioural control, which is of great importance for school-based learning.

2.4.3 Language Competencies

It is widely documented that language acquisition is particularly important for child development (see Weinert, Doil, & Frevert, 2008). The ability to understand, produce, and use language is very important, not only for cognitive development but also for social development. Language is the prerequisite to participation in a speaking world.

Language abilities and skills are made up of a number of different, and only partially separable, components. They include the rhythmic and prosodic component (stress, elongation, intonation), the phonological component (semantically differentiating sound categories), the morphological component (word formation), the syntactic component (word order), the lexical semantic component (meaning structure), and the pragmatic component (rules of language use; Grimm & Weinert, 2002).

The relevance of language competencies as a goal dimension to be taken into account in the context of the "Haus der kleinen Forscher" Foundation is ex-

plained by their relevance for cognitive development as a whole. Hence, also in the case of primary school age children, we consider it absolutely essential that language competencies be measured as a control variable within the framework of outcome research.

Moreover, we assume that engagement with the environment, as promoted by the “Haus der kleinen Forscher” education initiative, may also have a positive impact on children’s language competencies. However, the initiative’s potential effect on general language competencies is assumed to be secondary to its effect on science-specific language competence.

Because metacognitive verbs (e.g., assume, suggest, prove, substantiate, etc.) are particularly important for understanding scientific relationships, which most children of primary school age (and some children of secondary school age) still find difficult, we recommend that understanding of metacognitive language be specifically measured (Astington, 1998; Astington & Olson, 2008).

Measurements

There are a number of validated instruments with which language abilities and skills can be measured in a reliable and valid way. However, some of these instruments were developed as screening tools for language-related special needs, and they therefore differentiate mainly at the lower levels of performance. The following types of instruments can be distinguished:

(a) general language tests that measure receptive and expressive aspects of different language components;

(b) language tests that measure specific abilities and skills (e.g., expressive or receptive vocabulary); and

(c) language-related subtests of tests of development or tests that measure general cognitive abilities.

Examples of such tests include the General German Language Test (ADST; Steinert, 2011), the Heidelberg Language Development Test (*Heidelberger Sprachentwicklungstest;* Grimm & Schöler, 1991), and the Potsdam-Illinois Test of Psycholinguistic Abilities (P-ITPA; Esser et al., 2010).

2.4.4 Mathematical Competencies

Like the acquisition of language competencies, the acquisition of mathematical competencies is considered essential for cognitive and later academic development (e.g., Duncan et al., 2007). Individual mathematical abilities and skills have great conceptual proximity to science competencies. This explains why it can be assumed that the learning opportunities afforded by the “Haus der kleinen Forscher” initiative also have a positive influence on mathematical competencies, and that mathematical competencies, in turn, influence the acquisition of science competencies. Overall, however, mathematical competencies can play only the role of a control variable within the framework of accompanying research.

Measurement

Various tests for measuring mathematical competencies in primary school age children are now available also in the German-speaking area. As purely mathematics-related tests, mention can be made here of the *Heidelberg Rechentest 1-4,* a standardised maths test for children of primary school age (Haffner et al., 2005); the German Mathematics Tests (DEMAT; Krajewski, Liehm & Schneider, 2004); and the *Rechenfertigkeiten und Zahlenverarbeitungsdiagnostikum 2-6,* a diagnostic instrument for the measurement of mathematical skills and number processing (Jacobs & Peterman, 2006). International studies frequently have recourse to the Kaufman Assessment Battery for Children (KAB-C), a German-language version of which is also available. The mathematical skills subtest of the KAB-C has proved particularly sensitive to the effects of learning support into primary school age (see Anders, Grosse et al., 2013).

3. Goals at the Level of the Pedagogical Staff

3.1 Motivation, Interest, and Self-Efficacy in Engaging With Natural Phenomena

Yvonne Anders

Knowledge and beliefs are cognitive components of educators' professional action competence. In recent years, however, modern competence models have stressed the significance of motivational and emotional aspects (Baumert et al., 2011). Teaching, in particular, is a profession that calls for a sustained high level of commitment. Teaching is a complex activity with a high degree of self-regulation. In the case of activities such as this, it is assumed that motivational factors make a large contribution to the quality of professional actions (e.g., Pintrich, 2003). This assumption is informed by motivational psychology studies of self-efficacy (e.g., Bandura, 1997; Schmitz & Schwarzer, 2000) and intrinsic motivation (Frenzel et al., 2009; Kunter et al., 2008; Ryan & Deci, 2000).

The leading assumption is that persons who experience their professional activity as something positive, pursue it with greater effort and perseverance, and therefore also achieve better outcomes (Ryan & Deci, 2000). With regard to education professionals, this means that this positive experience is associated with a higher quality of the learning opportunities they provide and with higher instructional quality. In what follows, four aspects are addressed that are considered especially important for the implementation of the "Haus der kleinen Forscher" initiative at the level of the pedagogical staff at after-school centres and in extracurricular afternoon programmes at primary schools, and that thus constitute goals of the initiative. The importance of these aspects has already been highlighted in the case of education professionals in early childhood education settings (see pre-primary report in this volume). In the present report, they are related to the pedagogical staff at after-school centres and in extracurricular afternoon programmes at primary schools.

3.1.1 Emotional Attitude to, and Interest in, Science

Emotional attitude towards science is an affective component of attitude, and is closely related to pedagogical and epistemological attitudes. Studies indicate that certain science subjects have negative connotations for primary teachers. Brigido et al. (2010), for example, showed that emotions towards biology and geology were positive among pre-service primary teachers, whereas emotions towards physics and chemistry were very negative. Emotions towards a subject can be transmitted to children and to their attitudes towards science, both when these emotions are positive (e.g., science is experienced as enjoyable) and when they are negative (e.g., science induces fear or aversion). Moreover, research findings indicate that educators' emotional attitudes to a subject also influence the quality of their instruction (Erden & Sönmez, 2011; Gellert, 1999). A negative attitude may also lead educators to avoid "hard" science in lessons (Landwehr, 2002; see also Blaseio, 2004).

Interest in the sense of a psychological disposition refers to the active effort to expand one's competence (Muckenfuß, 1995). Understood in this sense, interest is a component of the self-concept and is characterised by proaction, cognitive engagement with the object field, and a selective assessment of content areas. It can be assumed that interest in, and enjoyment of, engaging with specific content are closely related. Accordingly, educators who impart science content should also develop a deep interest in, and enjoyment of, engaging with science. On the one hand, it can be assumed that this interest and enjoyment will also be reflected in enthusiasm for designing and implementing science education situations and thus have an impact on children's competence development. On the other hand, interest and enjoyment may also be transmitted directly to the children, thereby fostering their intrinsic learning motivation.

An open, positive emotional attitude to science, and *a great interest in and enjoyment of engaging with science* can be regarded as goal dimensions at the level of educators who undergo professional development within the framework of the "Haus der kleinen Forscher" programme. Ways of measuring these dimensions are described in Section 4.2.1 below.

3.1.2 Enthusiasm for Designing and Implementing Science Lessons

There are several quite vague definitions of enthusiasm in connection with teachers' professional activities. They overlap partly with interest in the subject, the emotional attitude to the job, and the subject taught. The definition used here is one that has proved accessible to empirical investigation and that can be clearly delineated from other motivational aspects. According to this definition, *enthusiasm* in the work context is the *stable, positive experience of the professional activity.* In this sense, teacher enthusiasm reflects the degree of positive emotion experienced during the activity of teaching (Baumert & Kunter, 2011, p. 44). The aforementioned authors showed that teachers' enthusiasm for the subject taught correlated with instructional quality. This explains why this competence facet is also relevant for pedagogical staff at after-school centres and in extracurricular afternoon programmes at primary schools. It can be assumed, that their enthusiasm is associated with their emotional attitudes to, and beliefs about, the importance of science learning at school. It can further be assumed that their enthusiasm influences the development of children's science competencies, motivation, enjoyment of learning, and interest in science.

Hence, enthusiasm for *designing and implementing science lessons* can be regarded as a goal at the level of the educators who undergo professional development within the framework of the "Haus der kleinen Forscher" programme.

3.1.3 Perceived Self-Efficacy With Regard to the Facilitation of Children's Science Learning Processes

Perceived self-efficacy refers to a person's belief in his or her ability to master demands (see Bandura, 1997). Tschannen-Moran and colleagues define *teacher efficacy* as "a teacher's belief in her or his ability to organize and execute the course of action required to successfully accomplish a specific teaching task in a particular context" (Tschannen-Moran & Woolfolk-Hoy, 2001, p. 117). Thus, it is a conviction about a person's own action. What is particularly noteworthy about this definition is the fact that it is always linked to a specific context (e.g., the professional activity or the subject of instruction). Perceived self-efficacy is one of the best investigated motivational aspects of teachers' professional action competence. Various studies have shown that a high level of self-efficacy is associated with high instructional quality, more effective instruction methods, and greater professional commitment outside school hours.

With regard to pedagogical staff at after-school centres and in extra-curricular afternoon programmes at primary schools, perceived self-efficacy with regard to the *design and implementation of science learning processes* can be emphasised in the context of the "Haus der kleinen Forscher" programme. The goal here is that these educators should have a strong belief in their own abilities to design and implement science learning processes.

Measurement

Various studies have used different methodological approaches to investigate the aforementioned motivational and emotional aspects in primary teachers or in science teachers in higher grades. There are also studies from the mathematics domain, which are included here because of the proximity between mathematics and science. Thus, there are a number of more or less tried-and-tested instruments for the domains of:

- emotional attitude (e.g., Benz, 2008; Cavallo et al., 2002; Downing et al., 1997; Thiel, 2010);

- interest and enjoyment (e.g., Benz, 2010; Downing et al., 1997; Alao & Guthrie, 1999; see also the project *Entwicklung naturwissenschaftlicher Kompetenz in der Grundschule* [Development of scientific competence at primary school]) conducted by Möller et al.);
- enthusiasm (e.g., Kunter, 2011); and
- perceived self-efficacy (e.g., Mavrikaki & Athanasiou, 2011; Buss; 2010).

Nonetheless, the existing instruments must be specifically adapted to the content and philosophy of the “Haus der kleinen Forscher” Foundation.

3.2 Epistemological Attitudes and Beliefs

Yvonne Anders, Ilonca Hardy, & Mirjam Steffensky

Teachers’ attitudes and epistemological beliefs are perceived as central facets of *professional competence*. At the same time, epistemological beliefs and attitudes are not always easy to distinguish from components of *professional knowledge* (see Section 3.3). It is assumed that teachers’ epistemological beliefs (e.g., pedagogical ideas, educational ideals, attitudes with regard to the importance of specific educational content, attitudes to their own role) structure their interactions in teaching and learning settings and influence their perceptions, goals, and behaviour. Thus, they can influence process quality in educational institutions and, in consequence, influence children’s development and learning processes. Some studies have also shown that teachers’ beliefs about teaching and learning affect the way in which reforms are implemented (Gregoire, 2003).

Epistemological beliefs and attitudes are very broad and comprehensive constructs, and they are sometimes rather imprecisely defined in the literature. In what follows, we address aspects of these constructs that are relevant for the promotion of science competencies at primary level or for the implementation of the “Haus der kleinen Forscher” initiative by pedagogical staff at after-school centres and in extracurricular afternoon programmes at primary schools, and that must therefore be evaluated as goals of the initiative.

In many studies, epistemological beliefs and attitudes are assessed in a domain-specific manner in order to obtain more insights into the complex relationships between attitudes and beliefs, pedagogical processes, and (domain-specific) child development (see Staub & Stern, 2002; Stipek, Givvin, Salmon, & MacGyvers, 2001).

Accordingly, when it comes to providing pedagogical support in the science domain, educators' specific beliefs about science, science learning, or the meaning and importance of early science education are more crucial than their general and domain-general pedagogical beliefs. It should be noted that comparably few studies have dealt with attitudes towards science or towards imparting knowledge of science, whereas many more studies in this regard have been conducted for the domain of mathematics, for example. Nonetheless, the research approaches and theoretical concepts can, at least in part, be applied well to the promotion of science competencies at primary level.

The following goal dimensions can be distinguished at the level of the education professionals:

- epistemological beliefs about the nature of science and the nature of knowing
- beliefs about science teaching and learning
- beliefs about the importance and content of science education at after-school centres and primary schools, for example, about the science competencies that primary school children should develop

3.2.1 Epistemological Beliefs About the Nature of Science and Nature of Knowing

Epistemological beliefs about the nature of science can be divided into two categories: traditional beliefs and constructivist beliefs. According to the *traditional view,* science is a closed system of knowledge that reflects truth. It follows from this that it is theoretically possible to acquire all science knowledge. *Constructivist beliefs,* by contrast, assume that knowledge of science comes about through engagement with the environment, that science explains relationships and natural phenomena, and that knowledge of science therefore undergoes constant change and further development (e.g., Brickhouse, 1990).

Conceptions of science influence engagement with the subject, and thus teaching behaviour. The static, traditional view suggests that new content should be introduced gradually and transmissively. The *modern, constructivist view,* on the other hand, allows for children to develop and reflect on knowledge of science themselves, and it challenges them to engage in communicative exchanges. This explains its importance as a goal of science learning.

3.2.2 Beliefs About Science Teaching and Learning

In addition to epistemological beliefs, teachers' beliefs about how students learn influence instructional quality and children's learning (see Dubberke et al., 2008; Staub & Stern, 2002). *Behaviourist/transmissive* beliefs (children are passive recipients in the learning process, and knowledge must therefore be prescribed and received) can be differentiated, in particular, from *constructivist* beliefs (knowledge is actively constructed by the learners themselves) and *hands-on* beliefs ("hands-on" is the most important principle in elementary science education; Kleickmann et al., 2016). These beliefs are linked to beliefs about adaptivity that inform the design and implementation of learning processes. Thus, an educator may hold more child-development-oriented beliefs whereby learning processes should be aligned with the individual development of the child. This contrasts with beliefs whereby learning processes should be aligned with specific goals (Renne, 1992).

Several studies show that constructivist beliefs (epistemological beliefs about teaching and learning) are associated with pedagogical content knowledge, instructional quality, and student learning (Voss et al., 2013). Therefore, it would be desirable for the "Haus der kleinen Forscher" programme to support pedagogical staff in developing these types of beliefs.

3.2.3 Beliefs About the Importance and Content of Science Education at After-School Centres and Primary Schools

The educational offerings provided by after-school centres and extracurricular afternoon programmes at primary schools can supplement regular classroom instruction. At primary school, science is taught mainly within the framework of *Sachunterricht* (see Footnote 1). In Germany, as in many other countries, there seems to be a tendency to prioritise biology topics over the physical sciences (Möller, 2004; Einsiedler, 1998; Strunck et al., 1998, Appleton, 2007). The authors of this report regard the learning opportunities afforded by the "Haus der kleinen Forscher" initiative as supplements to school instruction. Against this background, it is an aim of the "Haus der kleinen Forscher" programme to foster science learning, with a focus on the physical sciences. Moreover, it is assumed that the pedagogical staff at after-school centres and in extracurricular afternoon programmes at primary schools need adequate knowledge of the primary school science curriculum in the domain of science and of the science competencies to be developed at primary school age (see Section 3.3.3, Pedagogical Content Knowledge – Knowledge of School-Based Learning, and Sections 2.2 and 2.3), so that they can design and implement supplementary and more in-depth learning opportunities.

Measurement

Measurement tools for assessing beliefs are described in Brickhouse (1990), Stipek Dubberke et al. (2008), Staub and Stern (2002), Kleickmann et al. (2016), and Möller (2004; see also Liang, Chen, Chen, Kaya, Adams, Macklin, & Ebenezer, 2006).

3.3 Science Content Knowledge, Knowledge About Science, and Pedagogical Content Knowledge

Overview of Domain-Specific Professional Knowledge

Mirjam Steffensky & Ilonca Hardy

In this section, we describe domain-specific knowledge elements that are considered to have an important impact on instructional quality and student progress. We do not aim to outline the knowledge required for every possible content area. Rather, we describe knowledge on a superordinate level, and concretise it using selected examples. As already mentioned in the introductory chapter, it can be assumed that there is a great discrepancy between the actual domain-specific professional knowledge of pedagogical staff at after-school centres and in extracurricular afternoon programmes at primary schools and the knowledge that they should ideally have. The aim of the present report is to describe what educators who design and implement science education for children between the ages of six and ten in the aforementioned settings should ideally know, or what they should be able to learn within the framework of the "Haus der kleinen Forscher" professional development programme, in order to be able to provide learning environments and corresponding learning facilitation for children of primary school age as a supplement to *Sachunterricht* (see Footnote 1 above) at primary school.

As in the case of our expert report on the goals of science education at pre-primary level, we refer in our exposition on the professional knowledge of teachers to the models of professional competence and the professional knowledge contained therein proposed by Shulman (1987) and Baumert and Kunter (2013). These models divide professional knowledge into several components, of which content knowledge, pedagogical content knowledge, and pedagogical knowledge are assumed to be of particular relevance for classroom practice (Bromme, 1997; Baumert & Kunter, 2013; Woolfolk Hoy, Davis, & Pape, 2006; see also Chapter 1). As the two domain-specific components play a much more central role than general pedagogical knowledge in the present treatment of the "Haus der kleinen Forscher" programme at the level of the pedagogical staff, they are the focus of attention here.

Content knowledge and pedagogical content knowledge are not always perceived as two separate knowledge domains. For example, Ball and her research group (Hill, Rowan, & Loewenberg Ball, 2005) did not differentiate this knowledge, but rather conceptualised and measured it as *mathematical knowledge for teaching* (Ball & Bass, 2003). Other studies, such as the COACTIV research programme or the TEDS_M study, measured content knowledge and pedagogical content knowledge as two distinct factors that correlated highly with each other (Baumert et al., 2010; Blömeke et al., 2011). Beliefs, for example about the structure of the knowledge domain to be taught or about teaching and learning, which are described in Section 3.4, cannot always be differentiated from professional knowledge. However, knowledge must be distinguished from the observed behaviour in teaching-learning situations. For example, a person may have extensive pedagogical content knowledge of instructional strategies, but may not act accordingly in the concrete situation because he or she does not use situation-specific skills or because certain situational constraints are present (Blömeke, Gustafsson, & Shavelson, 2015).

3.3.1 Knowledge of Science

Mirjam Steffensky & Ilonca Hardy

Content knowledge describes a deep understanding of the structures of a subject. It is thus much more elaborate than purely factual knowledge or disconnected pieces of knowledge, and it includes, for example, knowledge of fundamental, cross-topic *core concepts* (also known as big ideas or key ideas; National Research Council, 2012; Harlen, 2015). An understanding of core concepts enables one to relate and structure a variety of topics, thereby facilitating the development of more integrated knowledge. For example, one aspect of the particle concept of matter is that substances have specific properties that characterise their behaviour. These different properties can be investigated in different thematic contexts, for example floating and sinking, combustion, solutions, conductivity, and magnetism. The particle concept of matter can therefore enable connections to be established between the different topics. Thus, density, combustibility, solubility, conductivity, or magnetic properties can be understood in terms of the structure of matter, specifically the atomic and molecular constituents present and the forces within and between them.

At the same time, core concepts may also represent organisational structures that enable people to classify new facts, procedures, or explanations. This function is also assumed to be important for pedagogical staff at after-school centres and in extracurricular afternoon programmes at primary schools. It cannot be assumed that these educators have in-depth knowledge of the diverse topics that are considered to be relevant. Hence, knowledge of core concepts (and practices) can be helpful in order to develop new knowledge that has to be acquired for a new topic.[17]

Even though core concepts may be given different names and be differentiated to a greater or lesser extent, the following concepts (Table 5) can be found in almost all conceptions (Bybee, McCray, & Laurie, 2009; EDK, 2011; KMK, 2004; AAAS, 2004). Because the "Haus der kleinen Forscher" initiative focuses on the physical sciences, only those core concepts are presented here. The content areas highlighted in the right-hand column are those that are mentioned in many primary school curricula. As it is assumed that, at least in part, the "Haus der kleinen Forscher" offerings for primary school students take up and explore more deeply the topics dealt with in *Sachunterricht,* these are the domains in which the pedagogical staff require detailed content knowledge.

It would be unrealistic to expect pedagogical staff at after-school centres and in extra-curricular afternoon programmes at primary schools to have in-depth scientific knowledge of all core concepts. Nonetheless, the aim should be that they understand the underlying ideas and the meanings of the core concepts and the associated central concepts. This would mean, for example, that they would be familiar with the conservation of matter as a basic concept and could explain it using a simple example of a physical change, such as evaporation. Even if they do not have differentiated knowledge of chemical reactions, they should at least understand that the conservation of matter applies in this context, too. In other words, they should be capable of explaining that, although the substance is destroyed in a chemical reaction (e.g., wood is destroyed during burning), the particles (e.g., carbon atoms) are conserved. However, they do not have to be able to explain the mechanism that underlies the reaction. This knowledge of core concepts is comparable to the conceptualisation of knowledge of science in PISA (Hamann, 2006; Bybee et al., 2009).

17 This is not meant to imply that core concepts should be explicitly designated as such when they are introduced to the students.

Table 5. *Core concepts of science content knowledge*

Core concept (big idea or key idea)	Selection of important associated concepts and key terms (only a few of which are relevant for primary school instruction)	Examples of topics from primary science in which these concepts are relevant
Matter	Structure and properties of matter Changes of matter (both physical and chemical changes) Conservation of matter	Water cycle Combustion Solutions Air
Forces and interactions	Forces and equilibrium Types of interaction Stability and instability in physical systems Waves and their properties	Balance, seesaw Lever Electric circuit Magnetism Light and shadow Sound
Energy	Energy sources Energy transport Energy conservation Energy conversion	Wind, water, sun, oil, biogas, wood Food as a source of energy Qualitative energy conversion, e.g., on a marble run

Nevertheless, teachers are expected to develop in-depth content knowledge that goes beyond the content taught. For example, they should be familiar with, and be able to draw on, the content of the adjoining educational level in order to facilitate cumulative learning pathways (i.e., vertical interconnections). This implies that pedagogical staff who deliver after-school programmes require conceptual knowledge that corresponds to that of science teaching at lower secondary level (but not upper secondary). This knowledge includes, for example, the explanation of phenomena with physical or chemical models in an evidence-based way.

No investigations have been conducted to date on the science content knowledge of pedagogical staff at after-school centres. Generally, the level of content knowledge is expected to be rather low at primary level because primary teachers – and, presumably even more so, educators at after-school centres – often lack opportunities for learning science.

Table 6 presents an example of what are considered to be core concepts in the domains of floating and sinking and states of matter.

Table 6. *Core scientific knowledge concepts*

Floating and Sinking
Whether an object will float or sink can be predicted by comparing the **density** of the object to the density of the surrounding liquid, for example water. Objects that have a lower density than water, will float; objects that have a higher density than water will sink. Density describes the relationship of mass to volume (unit: kg/m^3). The density of a **solid object** is a substance-specific property. The density of a **hollow body**, for example a ship, is the so-called **average density**, which is derived from the density of the surrounding body, for example the steel hull of a ship, and from the density of the substance in the cavity, for example air. Although density can be used to predict the buoyancy of a body, it is not possible to explain buoyancy by density alone. Rather, the role of the water must also be taken into account. Floating and sinking can be explained by a comparison of forces: Whether an object will sink, be suspended, or will float in a liquid depends on whether the **buoyant force** is less than, equal to, or greater than the **weight force** of the object. The buoyant force is the upward force that the liquid exerts on the immersed object; it depends on the volume of the liquid displaced by the object and on the density of the surrounding liquid. Weight describes the gravitational force between an object and the Earth.
States of matter
Like substances in general, water can exist in three different states of matter: **solid**, **liquid**, and **gaseous**. These states differ from each other in terms of certain properties, for example compressibility and density. These different properties can be explained with a simple particle model. Although the particles are in motion in all three states, the spacing and degree of relative motion differ substantially between the three states: In a solid substance, for example ice, the particles are confined to a specific location around which they can vibrate in all directions, and there are strong attractive forces between them. The attraction is weaker in a liquid substance, and the particles can move freely. That is why liquids can be poured, and why they take the shape of their container, whereas solid substances are more rigid by comparison. The particles in a gaseous substance move at great speed; the attraction between them is very low, and they thus spread evenly throughout the space available. Transitions between the states of matter are reversible physical changes. The following transitions are distinguished: **melting/freezing** (solid ↔ liquid); **evaporation/condensation** (liquid ↔ gaseous); and sublimation/deposition (solid ↔ gaseous). For the phase transitions *melting, evaporation,* and *sublimation,* energy must be expended; in the other phase transitions, energy is released. The transitions take place at specific temperatures (melting temperature and boiling temperature). The speed of the changes of state can be influenced, for example, by the ambient temperature, the quantity of the substance, or the surface of the substance.

Measurement

Tests for the assessment of (primary) teachers' content knowledge are described, for example, in Ohle, Fischer, and Kauertz (2011), Sadler, Coyle, et al. (2013), and McConnell, Parker, and Eberhardt (2013).

3.3.2 Knowledge About Science

Beate Sodian & Ilonca Hardy

Besides content knowledge and pedagogical content knowledge, pedagogical staff who deliver after-school programmes also need knowledge about science in order to be able to act appropriately in teaching-learning situations. Knowledge about science refers, on the one hand, to the *understanding of the nature of science,* that is, epistemological knowledge. On the other hand, it refers to *methodological knowledge* (knowledge of methods of scientific thinking and working) of procedures that are appropriate for scientific work at primary level, and that form part of the conceptions of scientific competence at primary level, in the sense of *scientific literacy*.

The core areas of scientific thinking and working methods lie in the elements of the *inquiry cycle,* which describes the circular procedure in science that is oriented towards empirical testing. Key elements of the inquiry cycle include the formulation of questions; the formation of hypotheses; the planning of experiments; observation; the measurement and documentation of data; and scientific justification and reasoning (see Section 2.2). It should be emphasised that the order of the aforementioned elements is not fixed, nor can they always be separated from each other.

In close alignment with the goals at the level of the children, it can be expected of the pedagogical staff that their actions in science-learning situations should be guided by specific hypotheses that can be tested in simple inquiry activities (while controlling for possible influencing variables). Moreover, they can be expected to be able to derive information regarding the confirmation or falsification of their hypotheses (use of evidence) from the results and to draw further-reaching conclusions with regard to possible follow-up investigations. Researchers in the field of the didactics of science have investigated, for example, the different forms of experimentation competence that can be found among secondary school students (Schreiber, Theyßen, & Schecker, 2009). Experimentation skills can be differentiated according to hypothesis formation, generation of experimental designs, measurement of results, and interpretation of results at different levels of understanding.

For the pedagogical staff, the aim is to achieve *advanced methodological competence*. This includes a reflexive understanding of theories, knowledge of methods of hypothesis testing, evidence evaluation, and self-directed learning through exploration processes.

The educators should not only be capable of using these *methods of scientific thinking and working,* they should also have a *superordinate understanding* of these methods of working. For example, they should understand (a) that, irrespective of the type of measurement used, it always involves comparison with a standard unit in order to make more objective and quantifiable statements, and (b) why measurement errors must be taken into account when interpreting results. In addition, they should be capable of designing and interpreting simple inquiry activities/experiments, and of interpreting and constructing simple forms of data presentation used in science, such as tables, bar charts, and coordinate systems.

To date, no studies have been conducted on the *understanding of the nature of science* among pedagogical staff at after-school centres and in extracurricular afternoon programmes at primary schools. Only a few studies have been conducted on primary teachers' understanding of the nature of science (Pomeroy, 1993; Lunn, 2002). Most of the literature deals with understanding of the nature of science on the part of secondary teachers who have studied science at university (Lederman, 1992). In the German-speaking area, Günther (2004; see Günther, Grygier, Kircher, Sodian, & Thoermer, 2004) investigated primary teachers' understanding of the nature of science in several interview studies. A modified form of the Nature of Science Interview developed by Carey et al. (1989) was used (see also Section 2.2.6). Moreover, Günther et al. (2004) collected concept maps (i.e., networks of key epistemological terms produced by the subjects themselves).

The following levels of understanding of the nature of science were distinguished:

1a	science as the description of the environment
1a	science as an activity
1b	science as a collection of objective facts
1.5	science as the search for answers, correlations
2	science as the search for verifiable explanations
3	elaborate understanding of the nature of science: understanding of framework theories

The results revealed a great heterogeneity in the levels of understanding of the nature of science, which did not covary with age or work experience (pre-service teachers versus experienced teachers). Over half (around 60%) of the teachers responded consistently at Level 1.5 or higher; Level 3 was almost never reached; and only one person responded consistently at Level 2. Some 20% of the subjects responded mainly at Level 1a or 1b, and not one of these persons responded at Level 2. It should be noted that respondents were selected samples of teachers who had registered for a further training course in science lasting several weeks.

As a result of the epistemologically oriented further training through curriculum development, most participants' understanding of the nature of science improved significantly: In the posttest, over half of the participants responded consistently at Level 2. The findings of the concept mapping were consistent with the interview findings, and they confirm the effects of further training towards an integrated understanding of basic epistemological concepts. Overall, these findings indicate that, although the majority of primary school teachers did not spontaneously engage in naive-realistic thinking (1a, 1b), they had problems articulating their prior understanding of the relationship between theory, hypothesis, experiment, and evidence. The effect of suitable continuing professional development measures can be considered beneficial.

In order to be able to justify the role of experiments and inquiry activities in learning arrangements and to productively take it into account in learning processes, we consider that the necessary goal for pedagogical staff at after-school centres and in extra-curricular afternoon programmes at primary schools is to achieve an *advanced level of understanding of the nature of science (at least Level 2),* in which *science is perceived as a search for explanations.* The quality of reasoning that is to be expected (see level of the child, Section 2.3) is also derived from the level of understanding of the nature of science. The pedagogical staff should use at least relational reasoning by drawing on commonalities between observations as a basis for justifications, or they should establish regular (i.e., rule-based) correlations. With regard to scientific thinking, it should also be emphasised that an understanding of the fundamental importance of empirical evidence (i.e., also the role of the experiment) should be apparent in the thinking and actions of the educators. This means that the verification or verifiability of justifications is always questioned, and that such relational or rule-based justifications are used, and considered superior, because they are based on empirical data.

Measurement

Little research has been conducted to date on teachers' knowledge about science. Besides the Nature of Science Interview developed by Carey et al. (1989), instruments for primary school teachers have been developed within the framework of the Science-P project (see Koerber et al., 2015). They are aimed at measuring understanding of the nature of science, and pedagogical content knowledge of methods of scientific thinking and working. When assessing understanding of the nature of science, recourse can also be had to the internationally validated scale Student Understanding of Science and Scientific Inquiry (SUSSI; Liang, Chen, Chen, Kaya, Adams, Macklin, & Ebenezer, 2006).

As the domain of pedagogical content knowledge of methods of scientific thinking and working/ understanding of the nature of science is little researched, it is unclear whether it is a dimension in its own right. Overall, it must also be determined whether the few available instruments are also valid for pedagogical staff at after-school centres and in extracurricular afternoon programmes at primary schools.

In the domain of methodological competence, there is a paper-and-pencil test instrument developed by Lawson et al. (1978; 2000) that measures scientific thinking (e.g., inductive and deductive reasoning, control of variables, proportional thinking) in secondary students, but which could be adapted for administration to adults. Initial findings are available on the measurement of evidence use or evidence-based reasoning (e.g., Furtak et al., 2010 in the special issue of *Educational Assessment* devoted to "Evidence-Based Reasoning in School Science"), which focus mainly on coding systems for classroom situations. However, it is conceivable that these categories could be applied to interviews with, or paper-and-pencil tests for, pedagogical staff.

3.3.3 Pedagogical Content Knowledge

Mirjam Steffensky & Ilonca Hardy

Pedagogical content knowledge describes the *knowledge that teachers need in order to enable learners to develop the targeted domain-specific competencies*. In various models, pedagogical content knowledge as defined by Shulman (1986) has been assigned a number of facets (Grossmann, 1980) that can be found also in the science-specific models (Magnusson, Krajcik & Borko, 1999; Park & Oliver, 2008; Gess-Newsome, 2015). They include knowledge of student cognitions and knowledge of instructional strategies,[18] which can be considered to be key elements of pedagogical content knowledge (Park & Oliver, 2008). There is evidence in support of (a) an association between these knowledge facets and student achievement (Baumert et al., 2010; Hill, Rowan, & Loewenberg Ball, 2005), and (b) the separability of the constructs *content knowledge* and *pedagogical content knowledge* (Baumert et al., 2010). Overall, pedagogical content knowledge is considered to be highly relevant for the design and implementation of high-quality learning opportunities, the selection of tasks, and the adaptive support of students.

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18 The delineation of student cognitions and instructional strategies is knowledge-related; in the learning situation itself, the two components cannot be clearly delineated. For example, the diagnosis of student cognitions and the corresponding reaction to them (instruction) often merge.

Knowledge of student cognitions

Aspects subsumed under "student cognitions" include, for example, knowledge of

- student (mis)conceptions in specific content areas and the diagnosis of these (mis)conceptions,
- learning difficulties inherent in concepts in certain content areas.

Knowledge of instructional strategies

Aspects subsumed under "instructional strategies" include, for example, knowledge of

- experiments that are suitable for developing an understanding of a phenomenon,
- multiple representations and explanations,
- suitable contexts for the application of concepts and the fostering of interests,
- appropriate sequencing of learning processes.

Table 7 below concretises this knowledge using the domains of floating and sinking and states of matter as examples. The sub-aspects listed are taken from research works on the domains of floating and sinking (e.g., Hardy et al., 2006) and states of matter (e.g., Steffensky, Nölke, & Lankes, 2011).

Table 7. *Pedagogical content knowledge of floating and sinking and states of matter (lists only a selection of aspects)*

Floating and Sinking	
Student Cognitions	*Typical naive conceptions of younger children include:* Objects filled with air float. Light objects float; heavy objects sink. Small objects float; big objects sink. Flat objects float. Objects with holes in them sink. Heavy objects displace more water. Displacement of water depends on the material that the immersed object is made of. Displacement of water depends on the shape of the immersed object. Buoyancy force is stronger when there is a lot of water (e.g., in a container). *Diagnosis of student cognitions* Ask questions, for example: What floats and what sinks? What would happen if I made a hole in a floating wooden plank? How come a big heavy ship does not sink? What could I do to make a piece of plasticine float? Use the predict-observe-explain procedure as an effective strategy for eliciting and promoting discussions of students' conceptions (White & Gunstone, 1992). This strategy involves students in predicting the results of an inquiry activity, explaining their prediction, observing, and finally explaining any discrepancies between their prediction and their observation. Have the students make drawings, for example: Mark the changes in the water level when a wooden ball and a steel ball of the same size are immersed in a glass of water. *Learning difficulties* inherent in concepts (to which special attention should be paid): Students often have difficulties understanding density as a proportional variable. In order to explain floating and sinking, various aspects must be considered and integrated.

Floating and Sinking	
Instructional Strategies	Sequencing[19] of the learning process, for example: Check for students' prior knowledge, which is a prerequisite for understanding (e.g., knowledge of the concept of material, the conception of air as matter). If this knowledge is lacking, impart it. Divide tasks into sub-tasks. For example, have students first develop the meaning of the concept of material and then focus step by step on buoyancy and displacement. Support the students in the first instance in constructing connectable first conceptions that can be developed in subsequent lessons into ideas with a higher explanatory power (e.g., the concept of material, which can be developed into a concept of density). Density should not be constructed as the ratio of the mass of an object to its volume, but rather as the ratio of the weight of an object to its volume.[20] Activities to construct an understanding of a phenomenon, for example: Testing the sinking/floating behaviour of objects that are filled with air yet still sink (e.g., ceramic mugs) Inquiry activities about displacement (e.g., comparing stones of different sizes or different-shaped lumps of plasticine) Inquiry activities about buoyancy (e.g., immersing a pot in water, or immersing different-sized plastic beakers) Representations of density (where appropriate, a provisional concept of density) with drawings that have different numbers of mass units (dots, flowers, animals, etc.) in the same space or the same number of mass units in different-sized spaces. Everyday contexts to make connections with everyday experiences or to apply what has been learnt, for example, letting ships or other objects float in the bath; experiencing buoyancy in a swimming pool; the role of air in buoyancy (water wings, air bed, floating bath toys, air cavities in a ship, swim bladder, ship load lines, etc.).

19 *Sequencing refers both to the sequencing of a specific instructional unit and to the sequence of steps in the development of core concepts over a period of several years.*

20 *The concept of mass often leads to confusion. Weight is a more everyday term. The two variables do not represent the same thing, but it is often suggested that the physically incorrect term weight be used (or left unchallenged) instead of mass, and that a reinterpretation be undertaken at secondary level.*

States of Matter

Student Cognitions

Typical naive conceptions of younger children include:

- Water and ice are different substances.
- Water disappears during evaporation (no conservation).
- During evaporation, water is absorbed by the ground, the tyres, the blackboard, etc. (change of location but not form).
- During evaporation, water becomes air (change of location and form, but no conception yet of the conservation of the matter of the water).
- Situation-specific explanation of condensation, for example, drops on the lid come from water splashing.

Diagnosis of student cognitions
Ask questions that the students should answer individually, for example:
Where did the water from the blackboard go to?
How did the droplets of water get on the (cold) glass?

Use the predict-observe-explain procedure as an effective strategy for eliciting and promoting discussions of students' conceptions (White & Gunstone, 1992) This strategy involves students in predicting the results of an inquiry activity, explaining their prediction, observing, and finally explaining any discrepancies between their prediction and their observation.

Have the children make drawings, for example:
Draw where the water goes to when a puddle dries.

Learning difficulties inherent in concepts (to which particular attention should be paid)
Compared to evaporation/condensation, melting/freezing are assumed to be relatively easy concepts (at the phenomenon level) because both states of matter are observable. It is more difficult to develop an understanding of the process of evaporation and condensation, because the gaseous state is not directly perceptible.
Melting and dissolving are confused because, in both cases, a solid becomes "liquid" (e.g., a lollipop "melts" in the mouth).
Solids can become liquids but not vice versa.

States of Matter	
Instructional Strategies	*Sequencing of the learning process, for example:* Check for helpful prior knowledge. If such knowledge (e.g., the conception of air as matter) is lacking impart it. Have the children process sub-questions. For example, have them first construct an understanding of the terms and states *solid* and *liquid* and then an understanding of transition. Have the children construct connectable conceptions that will be developed further in subsequent lessons, for example water goes into the air as invisible water. This conception can then be differentiated into gaseous water. *Activities* to construct an understanding of a phenomenon, for example: Comparison of solid, liquid, and gaseous states (e.g., with three bags containing ice, water, and air, respectively) Inquiry activities about changes in states of matter (e.g., drawing around the outline of puddles with chalk and observing evaporation; melting ice cubes; condensation on a mirror or a saucepan lid, etc.) Inquiry activities to explore changes in states of matter (e.g., the influence of temperature, light, quantity, surface, etc.) Inquiry activities on melting and boiling temperatures (e.g., comparing the boiling points of water and perfume) Materials for the purposes of illustration (e.g., a phase transitions schema) *Contexts* to make connections with everyday experiences and apply what has been learnt (e.g., ice cubes in a drink; a snowman; other melting processes such as cheese on pizza; drying washing; drying hair with a hair dryer; letting a water colour painting dry; etc.)

Knowledge of school-based learning

Because it is assumed that the offerings of the "Haus der kleinen Forscher" initiative also take up school content (*Sachunterricht,* see Footnote 1), the pedagogical staff at after-school centres and in extra-curricular afternoon programmes at primary schools should have knowledge of curricula, goals, and target competencies at the level of the children (see Chapter 2, goals at the level of the children) and typical instruction materials. This knowledge can be regarded as a prerequisite for suitable coordination between school lessons and the extracurricular afternoon programmes. As it is further assumed that *Sachunterricht* is very heterogeneous in different classes and schools, we recommend that the pedagogical staff at after-school centres should purposefully collaborate with teachers from the relevant schools in order to realise coordination between school and after-school learning environments.

Ability to design and implement effective learning environments

As already discussed in the section on children's knowledge of science, classroom research has highlighted that supporting learners within constructivist learning environments plays an important role in building up adequate conceptions and has a positive impact on individual domains of motivation and perceived self-efficacy (Blumberg, Hardy, & Möller, 2008; Hardy, Jonen, Möller, & Stern, 2006; Vosniadou, Ionnides, Dimitrakopoulou, & Papademetriou, 2001; Schneider & Stern, 2010; Windschitl, Thompson, Braaten, & Stroupe, 2012; Roth, Garnier, Chen, Lemmens, Schwille, & Wickler, 2011). Therefore, besides having knowledge of topic-specific student cognitions and instructional strategies, pedagogical staff should also be cognizant of their own *constructive and active role in the learning process*. It must be assumed that the implementation of learning opportunities is also influenced by general attitudes (in the sense of beliefs or stances) towards teaching and learning (see Section 3.2). As described in Section 3.2.1, *constructivist-oriented beliefs about science learning* are particularly desirable for children's competence development, whereas practicistic attitudes (hands-on but not minds on) or laissez-faire attitudes (strong emphasis on self-directed learning and rejection of support measures on the part of the teacher) are not very helpful (e.g., Kleickmann, 2008).

It is known from classroom research that, when it comes to designing and implementing learning environments, sight structures (e.g., observable instructional arrangements such as group instruction) are less effective than *deep structures* of instruction. Key deep structures of learning environments are classroom management (Emmer et al., 2001), cognitive activation, and a supportive climate or learning support (Kunter & Voss, 2013; Lipowsky, 2009; Fauth, Decristan, Klieme, & Büttner, 2014), all of which have been shown to be effective in student learning. These three dimensions overlap with the three factors of the CLASS scoring system (Pianta & Hamre, 2009): classroom organisation, instructional support, and emotional support. We focus in what follows on the content-specific aspects of instructional quality (cognitive activation and structuring, as one element of learning support).

In an effective learning environment, children are challenged by measures that have the potential for *cognitive activation*. Such measures include, for example, (a) exploring student conceptions, (b) pointing out contradictions in these conceptions, and (c) asking open-ended questions. By using empirical evidence, or counter-evidence, as a "conflict strategy," pedagogical staff can intentionally enable children to question their naive conceptions and create space in their minds for new explanations (Troebst, Hardy, & Möller, 2011). The encouragement of comparisons between similarities and dissimilarities in specific phenomena can

also cognitively activate children and support them in developing more generalised knowledge.

At the same time, children often need support in order to actively participate in challenging learning environments. Structuring measures aim to reduce the complexity of the learning situation in such a way that cognitively activating learning opportunities can be mastered and used by as many children as possible (Pea, 2004; Reiser, 2004). These measures include, for example, appropriate sequencing or the use of suitable illustrations, representations, and models that can make the structural commonalities and differences between different procedures particularly clear through visualisation, and can thus support the construction of correlational knowledge (for a summary, see Hardy & Koerber, 2012). In the context of "floating and sinking," for example, it has been shown that different forms of representation, such as the beam balance and student-generated forms or matrices, help third-graders to build up a conceptual understanding of density (Hardy, Schneider et al., 2005; Hardy & Stern, 2011; see Tytler & Prain, 2010). Structuring also includes adaptively supporting the children, for example, through structuring measures in classroom discourse such as the underscoring of relevant statements, or knowledge that focuses the learners' attention (Einsiedler, 2009; Pea, 2004; Reiser, 2004). Cognitive activation and structuring show similarities to concepts described under the labels "scaffolding" (Reiser, 2004) and "sustained shared thinking".

Pedagogical staff should therefore have *knowledge of ways of supporting learning,* in the sense of measures with the potential for cognitive activation and content structuring. In some studies, correlations have been found between pedagogical content knowledge and aspects of the design and implementation of instruction, such as cognitive activation (Kunter & Voss, 2013; Kersting, Givvin, Thompson, Santagata, & Stigler, 2012; Hill, Rowan, & Loewenberg Ball, 2005).

To sum up, the facets *knowledge of student cognitions* and *knowledge of instructional strategies* are recommended as goal dimensions in relation to pedagogical content knowledge. For the "Haus der kleinen Forscher" initiative, *knowledge of school-based learning* is also important. These knowledge facets can be regarded as a prerequisite to high process quality. At the same time, they should be accompanied by the *ability to design and implement effective learning environments and interactions*.

Measurement

Tests for the assessment of teachers' pedagogical content knowledge in the context of science teaching are described, for example, in McConnell, Parker, & Eberhardt (2013); Sadler, Coyle, et al. (2013); Roth et al. (2011); Vogelsang & Reinhold (2013); Lange et al., 2012; and Meschede, Fiebranz, Möller, & Steffensky (in press).

Rating instruments could be used to measure the ability to design and implement effective learning environments (process quality of learning situations). Such rating instruments are available, for example, for measuring the quantity and quality of specific pedagogical interactions (sustained shared thinking: Siraj-Blatchford et al., 2003, Siraj- Blatchford, Kingston, & Melhuish, 2015; Hopf, 2011; see also instruments from classroom research, e.g., Rakoczy & Pauli, 2006; Kobarg & Seidel, 2003; Kunter, 2005).

3.4 General Aspects of Professional Role Perception and Self-Concept

Yvonne Anders

The hitherto described goals of the "Haus der kleinen Forscher" initiative at the level of the pedagogical staff at after-school centres and in extracurricular afternoon programmes at primary schools encompass aspects that relate specifically to science. However, the Foundation programme also targets aspects of general professional role perception and self-concept, which, like attitudes and beliefs (see Section 3.2), can be regarded as components of the professional attitude. At this point, only those aspects that play a relevant role in the content of the Foundation's professional development offerings, and that are described as crucial in the scholarly literature on teachers' professional competencies, are proposed as goals of the educational initiative. These aspects are: reflective ability, collaborative ability, and the desire to develop one's own professionalism.

3.4.1 Reflective Ability

Demands on educators in the preschool, school, and extracurricular education domains have grown in recent years. Among the greatest demands described in the literature are the considerable diversity and complexity of the tasks. In order to be able to appropriately master these tasks, a range of competencies are called for, for example, the ability to reflect both on oneself in one's own role, and on the teaching-learning process. Reflection can take place both mentally and in writing. Following Dauber (2006, p.13), self-reflection is understood in everyday parlance as a type of mental inspection of one's own thoughts, inner feelings, fantasies, past experiences, and expectations for the future.

The ability to view one's own practice from other perspectives in a relatively unbiased way can be termed *reflective distance.* Reflective ability is considered to play a decisive role in the further development of pedagogical practice. Accordingly, the type of role perception and self-concept that can be described as a goal dimension at the level of the pedagogical staff is one in which they critically and constructively assess their own role, pedagogical concepts, and pedagogical action.

3.4.2 Collaborative Ability

In school effectiveness research, especially at international level, collaboration between teachers is considered to be a key characteristic of good and effective schools (see, e.g., Fend, 1998; Sammons, Hillmon & Mortimore, 1995; Steinert et al., 2006; Teddlie & Reynolds, 2000). Collaboration between teachers can refer to various aspects, for example school organisation, human resource management and professionalisation, and the organisation of instruction (Steinert et al., 2006).

Collaboration in relation to *school organisation* refers, for example, to a shared target concept, the coordination of different educational offerings, school-internal information and communication, and task distribution and decision-making processes. With regard to *human resource management and professionalisation,* the following areas of collaboration are discussed: (a) continuing professional development and training for teachers, and (b) recruitment and supervision. And finally, collaboration refers also to the *organisation of instruction,* namely, to the coordination of content, on the one hand, and to methodological aspects of instruction and collegial advice in the case of individual support for students, on the other.

It is assumed that, in schools that achieve a high level of collaboration, the quality of instruction and the quality of the school is also high, and that this has a correspondingly positive effect on the children's development (for an overview, see Steinert et al., 2006).

A high level of school-based collaboration requires, first, that teachers exhibit a high degree of collaborative ability. Following Spieß (2004), collaboration is characterised by reference to other goals or tasks that can be achieved with joint effort. Moreover, collaboration is intentional, communicative, and requires both trust and a certain degree of mutual commitment (see Schmich & Burchert, 2010). Empirical studies point out that the level of collaboration between teachers is often low, and relates only to a few aspects, such as the exchange of instructional material or conversations about students' learning development (Schmich & Burchert, 2010). In his doctoral thesis on collaboration in the domain of science at *Gymnasien* (for a definition, see Footnote 2), Kullmann (2009) also came to the conclusion that the collaboration culture still had considerable room for improvement.

If one examines the structure of the "Haus der kleinen Forscher" programme, one can clearly see that it implies a high degree of collaboration, especially at primary school level. This refers not only to collaboration between pedagogical staff at after-school centres or in extracurricular afternoon programmes at primary schools, but also, and in particular, to collaboration between these educators and primary school teachers. *Collaborative ability* can thus be considered to be an especially relevant goal. When implementing the offerings of the "Haus der kleinen Forscher" Foundation, pedagogical staff should have the ability and the desire to communicate, interact, and collaborate with actors in their professional environment and with other relevant actors. Moreover, they should have the ability to impart subject matter or didactic content to different target groups (e.g., professional colleagues, parents, interns).

3.4.3 Development of Professionalism

As is the case with other professions, it is assumed that, in the teaching profession, the further development of professional competencies is not only relevant during (basic) training but also in professional practice. It is further assumed that teachers' professional competence is fundamentally shaped and developed in professional practice situations (Oser, Achtenhagen, & Reynold, 2006). Accordingly, teachers should endeavour to master their professional demands reliably and sustainably.

This development of professionalism can also be defined as a goal at the level of the pedagogical staff, for example at after-school centres and in extra-curricular afternoon programmes at primary schools. Ideally, they should be capable of recognising their continuing professional development needs and organising and sustainably managing their continuing professional development. They should have strong learning competence and perceive the development of their professionalism as a lifelong process. Moreover, they should be willing to undergo professional development and to bring their own content knowledge and abilities up to date, and they should recognise that this is a necessity.

Measurement

All three aspects of professional role perception have been studied in teacher research, also in the German-speaking area. Accordingly, various qualitative and quantitative instruments are available.

The development of teachers' reflective ability is, for example, a core topic in the project "Standarderreichung beim Erwerb von Unterrichtskompetenz im Lehrerstudium und im Übergang zur Berufstätigkeit" (Reaching standards when acquiring instructional competence while studying to be a teacher and in the transition to employment"; Baer et al., 2010, 2011). The research programme COACTIV (Kunter et al., 2011) focused intensively not only on the structure of professional competencies but also on their emergence and development, and developed instruments for their measurement (Richter et al., 2011).

There is substantial research and literature on the aspect of collaboration, and thus there are also (often questionnaire-based) instruments, some of which have been well validated (for an overview, see Steinert et al., 2006). When measuring the above-mentioned aspects of role perception and self-concept, accompanying research on the work of the "Haus der kleinen Forscher" Foundation that relates also to pedagogical staff at after-school centres and in extra-curricular afternoon programmes at primary schools should take into account the specific function and role of these educators. This means that existing instruments can only be a starting point for the development of a new instrument or for the further development of existing instruments.

4. Conclusion and Recommendations

Yvonne Anders, Ilonca Hardy, Beate Sodian, & Mirjam Steffensky

In this report, we describe goals of the "Haus der kleinen Forscher" initiative at the level of the children and the pedagogical staff. For the further work of the Foundation, and for possible accompanying research, we prioritise those goals

- that are given high priority in the offerings of the "Haus der kleinen Forscher" Foundation;
- that, from an empirical perspective, are of key importance for the promotion of science education; and
- whose measurement appears feasible, for example because suitable instruments are already available.

In the present conclusion, the prioritised goals are briefly characterised.

4.1 Prioritised Goals for Primary School Children

4.1.1 Motivation, Interest, and Self-Efficacy

As explained in Section 2.1, the following goal dimensions are recommended:

- motivation and enjoyment of learning when engaging with natural phenomena
- interest in science
- perceived self-efficacy when engaging in inquiry activities

Measurement: With regard to motivational and emotional aspects, it can be noted that, for children of primary school age, several studies, also in the German-speaking area, have successfully measured aspects similar to the above-mentioned goals of the "Haus der kleinen Forscher" initiative. Measurement often takes place via questionnaires or interview instruments. Nonetheless, these instruments would have to be adapted to the specific goals of the "Haus der kleinen Forscher" initiative at primary school level, so that (further) development is needed in this regard.

Development of children's science competencies

In contrast to pre-primary level, there has been recent research on the development of scientific competence at primary school age, which forms the basis for the development of measurement instruments that could be suitable for evaluating the measures of the "Haus der kleinen Forscher" initiative. We distinguish between knowledge of science (content knowledge) and knowledge about science.

4.1.2 Knowledge About Science and the Scientific Process

Knowledge about science comprises two components, *understanding the nature of science* and *methodological competencies* (see Section 2.2). Analogous to the acquisition of knowledge of science, the acquisition of competence can be represented as a process of restructuring naive conceptions to form scientifically adequate conceptions, in the course of which the individual passes through several intermediate conceptions. Individual scientifically adequate conceptions about methods of hypothesis testing can already be demonstrated at primary school age under supportive task conditions. In the domain of the broader understanding of the nature of science, naive conceptions prevail, but intermediate conceptions and individual scientifically adequate conceptions can be achieved through instruction.

The following goal dimensions are recommended:

- reflective understanding of theories
- knowledge of methods of hypothesis testing
- evaluation of evidence
- self-directed learning through processes of exploration
- understanding the nature of science and insight into the inquiry process

Measurement: Valid and economical test procedures for measuring methodological competencies and the understanding of the nature of science have been developed in recent years (e.g., in the Science-P project). They could be adapted for use in a possible evaluation. Moreover, instruction in the domain of knowledge about science has proved conducive to primary school students' acquisition of knowledge of science (Grygier, 2008). This finding could provide impetus both for curriculum development and for formative evaluations of the "Haus der kleinen Forscher" Foundation offerings.

4.1.3 Knowledge of Science

Knowledge of science is understood here as conceptual knowledge that is coherent, elaborated, and applicable, or that can be classified as individual conceptions of specific phenomena. According to conceptual change theory, the development of this knowledge is described as the differentiation and restructuring of naive conceptions in the direction of scientific conceptions. This process is often characterised by different intermediate conceptions that are capable of interpreting some phenomena, but that still have limited explanatory reach. Moreover, especially at the beginning of the learning process, combinations of different conceptions often occur, which are sometimes also referred to as fragmented knowledge. *Everyday conceptions* and *initial scientific conceptions* are a target at primary school (see Section 2.3). The form that children's knowledge of science takes can be assumed to be a key indicator of scientific competence, and is thus a particularly important goal of the "Haus der kleinen Forscher" initiative.

The following goal dimensions are recommended:

- everyday conceptions (for younger primary school children) or initial scientific conceptions (for older primary school children)
- evidence-based reasoning about specific content

Measurement: Valid and economical tests of knowledge are now available for selected content areas such as "floating and sinking," and "evaporation and condensation" (e.g., from the Science-P project or Ohle, Fischer, & Kauertz, 2011; Ohle, 2010). They could be used (and, if necessary, adapted) for a possible evaluation.

As the "Haus der kleinen Forscher Foundation" develops pedagogical materials and professional development concepts for various science domains, rating scales that allow the students' competence levels to be measured should be developed for each domain, similar to the procedure adopted in the aforementioned research projects (e.g., Science-P). This presupposes the development and testing of a large number of content-valid items that reflect the theoretically postulated levels of naive conceptions, everyday conceptions, and scientifically adequate conceptions. Alternatively, accompanying research could focus on just one content domain (e.g., water).

4.1.4 Basic Competencies

As explained in Section 2.4, we recommend that the following dimensions should be considered as potentially relevant moderator variables:

- cognitive competencies
- social competencies
- language competencies
- mathematical competencies

Measurement: Instruments or batteries of tests are available, which could be used to measure basic competencies as control variables or moderator variables.

4.2 Prioritised Goals for Pedagogical Staff

It should be emphasised that no research has been conducted to date on the targeted competencies of the specific group of educators who are the subject of the present report (i.e., pedagogical staff at after-school centres and in extracurricular afternoon programmes at primary schools). Hence, the presentation of the state of research draws mainly on research on primary teachers, who, however, differ fundamentally from the aforementioned pedagogical staff by reason of their education and training alone. We therefore recommend broad-based studies of the domain-specific professional knowledge of these educators and of the other competence facets. These studies should precede the actual evaluation research.

4.2.1 Motivation, Interest, and Self-Efficacy

As explained in Section 3.1, the following goal dimensions are recommended:

- emotional attitude to, and interest in, science
- enthusiasm about the facilitation of science learning processes
- perceived self-efficacy with regard to the facilitation of science learning processes

The current state of research on teachers suggests that those competencies that directly relate to pedagogical interactions (in this case, enthusiasm and perceived self-efficacy) also have a greater (because direct) influence on the quality of pedagogical interactions. Accordingly, it can be assumed that they are more strongly associated with child development.

Measurement: With regard to the motivational and emotional aspects described above, it should be noted that, in some cases, there are instruments that measure these aspects in primary teachers. However, for accompanying research on the Foundation, these instruments would have to be specifically adapted for administration to pedagogical staff at after-school centres and in extracurricular afternoon programmes at primary schools.

4.2.2 Epistemological Beliefs and Attitudes

As outlined in Section 3.2, the following goal dimensions are recommended:

- conceptual beliefs about the nature of science
- epistemological beliefs about the acquisition of science competencies
- beliefs about the importance and content of science education at after-school centres and primary schools

Measurement: Several studies have investigated the aspects described above, also in the German-speaking area (Brickhouse, 1990; Dubberke et al., 2008; Staub & Stern, 2002; Kleickmann, 2008; Strunck et al, 1999; Möller, 2004). However, the corresponding – often questionnaire-based – instruments would have to be adapted to the specific content and educational goals of the “Haus der kleinen Forscher” Foundation.

4.2.3 Domain-Specific Professional Knowledge

In line with the findings of research on the teaching profession, content knowledge and, in particular, pedagogical content knowledge are assumed to be important for the design and implementation of effective teaching-learning situations (see Section 3.3). **Content knowledge** is understood here as conceptual knowledge that includes (a) knowledge of core concepts and of the structure of the domain, and (b) an in-depth knowledge of primary-school-relevant content areas at lower secondary level. This knowledge includes knowledge of relationships that are not directly visible; it uses evidence-based explanations to explain the regularity of phenomena. Hence, it also includes more complex knowledge and explanations, for example particle models. We recommend the following goal dimensions:

- knowledge of scientific core concepts
- in-depth knowledge of selected science content

Measurement: As there are only a few instruments with which primary school teachers' science content knowledge can be measured (Ohle, 2010), an obvious solution would be to additionally adapt or use student performance tests that are geared towards core concepts, and with which corresponding primary school topics can be measured.

Besides science content knowledge, we also consider **knowledge about science** to be a relevant component of professional knowledge. Knowledge about science refers to methodological competencies, on the one hand, and to an understanding of the nature of science, on the other. On the basis of research approaches adopted within the framework of the Science-P project, we assume methodological knowledge that includes the evidence-based justification of assumptions in the form of controlled experiments and appropriate forms of representation. We recommend the following goal dimensions:

- advanced methodological competence
- advanced understanding of the nature of science

Measurement: Instruments for measuring the understanding of the nature of science include, for example, the Student Understanding of Science and Scientific Inquiry scale (SUSSI; Liang et al., 2006) and the instruments for measuring pedagogical content knowledge aspects of methodological knowledge in teachers, which were developed and tested within the framework of the Science-P project. In the domain of methodological competence, an instrument that was developed by Lawson et al. (1978; 2000) for research with secondary school students could be adapted.

We differentiated **pedagogical content knowledge** into two facets:

- knowledge of instructional strategies
- knowledge of student cognitions
  (See Baumert et al., 2010; Magnusson, Krajcik, & Borko, 1999; Park & Oliver, 2008; Gess-Newsome, 2015.)

Measurement: There are a few instruments in selected content areas that could be used. They include, for example, instruments from the PLUS and ViU projects. Moreover, further topic-specific tests could be developed in the style of these instruments. Tests for the assessment of teachers' pedagogical content knowledge in the context of science teaching are described, for example, in McConnell, Parker, & Eberhardt (2013); Sadler, Coyle, et al. (2013); Roth et al. (2011); Vogelsang & Reinhold (2013); Lange et al., 2012; and Meschede, Fiebranz, Möller, & Steffensky (in press).

Based on the assumption that the extracurricular offerings for after-school centres and extra-curricular afternoon programmes at primary schools that are provided by the "Haus der kleinen Forscher" initiative are oriented towards science-related *Sachunterricht,* we suggest as a further relevant facet of pedagogical content knowledge

- knowledge of school-based learning.

Subsumed under this term is knowledge of primary school curricula and typical primary school topics and implementations.

Measurement: To measure this facet, it would be necessary to develop a specific new instrument from scratch.

Besides the measurement of these knowledge components, instruments that measure

- ability to design and implement effective learning environments and interactions

could possibly be used for the evaluation of the programme. This component relates to the *process quality of the learning situation,* such as the interactions between teacher and learner, and the effectiveness of the designed learning environment.

Measurement: There are corresponding rating instruments, for example, for measuring the quantity and quality of specific pedagogic interactions (sustained shared thinking: Siraj-Blatchford et al., 2003; Siraj, Kingston, & Melhuish, 2015; Hopf, 2011; see also instruments from classroom research, e.g., Rakoczy & Pauli, 2006; Kobarg & Seidel, 2003; Kunter, 2005).

4.2.4 General Aspects of Professional Role Perception and Self-Concept

As explained in Section 3.4, we recommend the following goal dimensions:

- reflective ability
- collaborative ability
- development of professionalism

Collaborative ability can be regarded as a particularly relevant dimension in the context of the "Haus der kleinen Forscher" Foundation.

Measurement: There is a great need to develop instruments for measuring the general aspects of professional role perception and self-concept. The existing studies on education professionals' role perceptions and self-concepts do not refer to the specific structure of the "Haus der kleinen Forscher" initiative. Moreover, the development and implementation of a reliable and valid measure of these dimensions would appear to be so time-consuming that it would hardly be suitable for use in more large-scale accompanying research.

4.3 Summary and Outlook

The targeted measurement of competencies both at the level of the children and at the level of the pedagogical staff is very broad. Instruments that cover the main competence domains are available for measuring goals at the level of the children. They could be used for an outcome study. The need for the development of instruments for measuring goals at the level of the pedagogical staff at after-school centres and in extra-curricular afternoon programmes at primary schools is greater. However, in some cases, at least, recourse can be had to instruments designed for primary school teachers, which can be adapted. Overall, a comprehensive measurement of the outcomes of the offerings of the "Haus der kleinen Forscher"

Foundation at primary school level appears to be feasible on the basis of the current state of research.

In addition to purely evaluating an educational measure, studies on the outcomes of science education at primary school age can contribute essentially to basic research in this area and are therefore desirable from the perspective of developmental and pedagogical psychology, the didactics of science, and primary school pedagogy.

C Process-Related Quality Criteria for Science Teaching: Ten Criteria for Effective Didactic Action at Pre-Primary and Primary Level

Jörg Ramseger

1. Introduction

The present contribution seeks to establish general quality criteria for didactic action in the science classroom, which primary teachers, early childhood educators, and educators at after-school centres and in extra-curricular afternoon programmes at primary schools can use as a basis for determining the appropriateness, or inappropriateness, of their curricular or extracurricular efforts to promote scientific literacy at pre-primary or primary level. In the present context, the term *science teaching* refers to all curricular and extracurricular educational opportunities at pre-primary and primary level aimed at fostering the science competencies of children between the ages of three and ten.[21]

Before establishing quality criteria for professional action in the science classroom, it is first necessary to obtain clarity about the goals of teaching (Chapter 2). Next, it is a question of (a) compiling recognised principles of effective teaching and learning in the respective disciplines that have been developed in general pedagogical research over the last 200 years and in subject didactics research over the last 20 years, and (b) relating these principles to the previously determined goals (Chapters 3 and 4). These principles can be expressed in the form of *general* criteria for successful didactic action (Chapter 5), which in turn provide orientation for the construction and evaluation of teaching-learning situations in the context of curricular and extracurricular educational opportunities. However, these criteria are not all of equal importance, but rather can be hierarchically ordered according to their relevance for the success of science education processes in the above-mentioned age range (Chapter 6).

The set of ten quality criteria "at an intermediate level of abstraction" presented in Chapter 5 are justified partly with recourse to learning theory and education theory and partly on the basis of the function and mandate of the educational institutions. My intention in speaking of an "intermediate level of abstraction" is to imply that this set of criteria can, or will, by no means be a substitute for the extensive studies on competence assessment in science education that are currently being conducted at diverse research institutions, and that are generating, or have generated, very complex findings (see Anders, Hardy, Pauen, & Steffensky, 2017a and Anders, Hardy, Sodian, & Steffensky, 2017b) in the present volume; see also Doll & Prenzel, 2004). However, the competence tests developed within the framework of these research projects are not usually intended for use by the teachers and educators themselves. Rather, they serve to generate new knowl-

21 *I thank Dr Janna Pahnke of the "Haus der kleinen Forscher" ("Little Scientists' House") Foundation for the valuable suggestions and food for thought that she provided during the process of producing this contribution. I found the intensive professional dialogue that we conducted about this manuscript very rewarding.*

edge in the domains of subject didactics and educational science or to monitor the success of the education system. The quality criteria that underlie these competence tests target verifiable *teaching outcomes in learners,* and thus endeavour to render teaching success measurable in learners. The TIMSS scales are a current example of such outcome-oriented estimation scales.

By contrast, the quality criteria developed in what follows relate to the *didactic action of teachers and educators,* for which there are also profession-specific standards of success – in addition to the teaching outcomes in learners. These criteria are aimed at qualitatively assessing the *process structure* of teaching rather than the outcomes. However, with regard to the general pedagogical research and the subject didactics research that underlies these criteria, the present contribution assumes that the targeted growth in competence can more likely be achieved through teaching that meets the subject-didactic and general pedagogical criteria than through teaching that ignores these criteria. Whether this assumption is tenable will be a matter for further research.

For pragmatic reasons, ten criteria should be sufficient to enable individual teachers or educators to use them as a guide when planning lessons, and to enable teams of teachers or educators to use them to self-evaluate science learning opportunities with a view to assessing the *didactic quality* of their own work. In addition, there are, of course, the *subject-specific and process-related competencies* targeted in the federal states' *(Laender)* education plans and curricula for primary schools – for example, the goal that students should become familiar with the aggregate states of water, or that they should learn how to carry out more or less exact measurements or what terms such as *bouyancy* and *density* actually mean. However, these topic-specific individual goals and competencies will not be addressed in what follows.

2. The Goal of Science Teaching

There are probably only a few school subjects where there is almost global consensus on the main general goal of teaching. This can be asserted in the case of science, where, in line with research in the didactics of science, most educational administrations formulate the goal of science teaching in a similar way, namely as *scientific literacy* or science literacy (Bybee, 1997; Bybee, McCrae, & Laurie, 2009).

A somewhat older, yet still frequently cited, and thus highly influential, formulation from Project 2061 – Science for All Americans (AAAS 1989, pp. xvii + xviii) describes scientific literacy in the following dimensions:

- “being familiar with the natural world and appreciating its unity;
- being aware of some of the important ways in which mathematics, technology, and the sciences depend on each other;
- understanding some of the key concepts and principles of science;
- having a capacity for scientific ways of thinking;
- knowing that science, mathematics, and technology are human enterprises, and knowing what that implies about their strengths and limitations;
- being able to use scientific knowledge and ways of thinking for personal and social purposes” (DeBoer, 2000, p. 590).

A number of strong objections can be raised to this extremely popular definition of the goal of science teaching. For example, since the dawn of the human race, man has always manipulated the supposedly “natural world”. And since the Trinity Test in the New Mexico desert on 16 July 1945, at the latest – the first-ever atmospheric testing of a nuclear device (nicknamed “the Gadget”) – there has been no such thing as nature untouched by human hand. For the radionuclides spread throughout the globe, and they can be detected in polar ice to this day.

The second objection relates to the “unity of the natural world” postulated in the AAAS definition. This unity has never existed. Rather, following Darwin, the natural world is characterised by positively breathtaking biodiversity, competition, and displacement struggle between the species, by continuously changing conditions of life, and by constant adaptation of the species to these changed conditions. Therefore, while one can “appreciate” the diversity of nature, one cannot appreciate its “unity”.

Moreover, “knowing that science, mathematics, and technology are human enterprises” is not as easy as the AAAS “facets of science literacy” would suggest, because the natural world itself is not a human enterprise, but rather exists independently of human perception and interpretation. The regularities in the natural world, which humans believe that they know through science, are constructions of their minds. At the same time, however, they are dependent on the regularities that prevail in the natural world. In his introduction to the *Principles of Mechanics,* Heinrich Hertz expressed this dialectic of world and knowing mind as follows: "We form for ourselves images or symbols of external objects; and the form which we give them is such that the necessary consequents of the images in thought are always the images of the necessary consequents in nature of the things pictured" (Hertz, 1899, p. 1).

And finally, the assertion that children should be "able to use scientific knowledge and ways of thinking for personal and social purposes" confuses science with technology, on the one hand, and with ethics, on the other. After all, gravity or evolution can hardly be used for "social purposes".

The only thing that is right about the AAAS concept is its tendency to assume that scientific literacy is not aimed primarily at mere content knowledge. Rather, following Gräber, Nentwig, Koballa, and Evans (2002), scientific literacy is a complex bundle of competencies (Gräber et al., 2002, p. 137). It is not so much a question of acquiring comprehensive knowledge, nor is it primarily a matter of acquiring mere factual knowledge, but rather of self-actively constructing an understanding of individual and subjectively significant questions and problems in a connectable and thorough way in genuinely scientific discourse (see Möller, Jonen, Hardy, & Stern, 2002, p. 415).

Four interrelated distinguishing features of scientific literacy were formulated within the framework of the 2006 PISA study:

- "(...) an individual's scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science-related issues;
- understanding of the characteristic features of science as a form of human knowledge and enquiry;
- awareness of how science and technology shape our material, intellectual, and cultural environments;
- willingness to engage in science-related issues, and with the ideas of science, as a reflective, constructive, concerned citizen" (OECD, 2006).

Thus, the PISA Consortium cannot do without a normative component of scientific literacy either, namely the desirable behaviour of the scientifically literate citizen.

Duit, Häußler, and Prenzel (2001; cited in Prenzel, Rost, Senkbeil, Häußler, & Klopp, 2001, p. 195) took a much more objective approach, assuming that the competencies associated with scientific literacy could be assigned to four superordinate domains:

- scientific concepts and principles (knowledge or understanding of core science concepts)
- scientific inquiry methods and ways of thinking (understanding scientific processes, basic skills, attitudes)
- beliefs about the nature of science (understanding the *nature of science,* epistemological beliefs, knowledge of the limitations of science)
- beliefs about the relationships between science, technology, and society (understanding "scientific enterprise" in a social, economic, and ecological context)

This list is more appropriate than those of the AAAS and the PISA Consortium insofar as it refrains from enlisting science for normative ethical and social purposes, and it restricts itself to "beliefs," while at the same time allowing the complexity of the scientific literacy project to shimmer through. For there is *no one science* (e.g., causal science), but rather there are many ways of looking at, and thinking about, the natural world, all of which are justified from the perspective of the inquirer and for the generation of knowledge for humanity. What is more, the acquisition of these diverse ways of thinking and perceiving is subject to complex interrelationships between experience, thinking, and learning, which are difficult to capture with a simple definition of a goal and a simple set of competencies (see Benner, 2008 and 2012).

This holds true for all more recent definitions of the central goal of science education, scientific literacy. Hackling and Prain (2008, p. 7) graphically represented scientific literacy with a context model in which the multi-dimensional construct of scientific literacy (SL) comprises the intersection of conceptual understandings, knowledge of science processes, specific attitudes towards reality, and factual knowledge of the individual science disciplines ("literacies of science") – always in relation to a specific substantive context (see Figure 5).

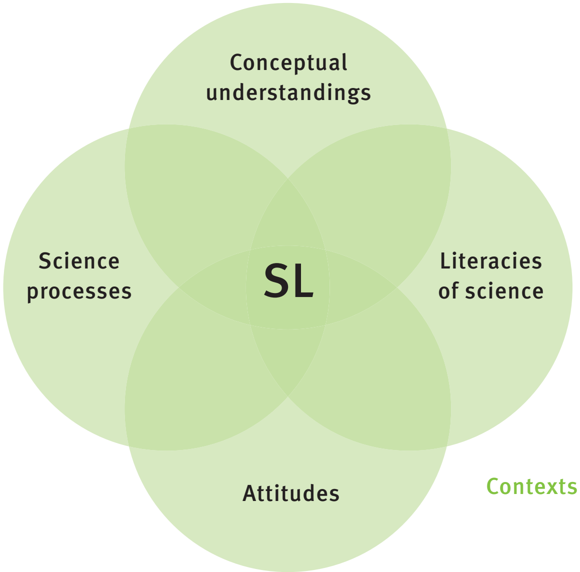

Figure 5. *Context model of scientific literacy following Hackling and Prain (2008, p. 7)*

This multidimensionality of the central goal, scientific literacy, is also reflected in the goals of science education proposed by Anders et al. (2017a, b in this volume; here, see Section 1.2, Expert Report B). In addition to the aforementioned conceptual and epistemological goals, the authors cite a set of *basic competencies,* "an omnibus term for general abilities such as *cognitive, language, mathematical, and social competencies* that are assumed to have a moderating effect on the development of science competencies" (Anders et al., 2017b, p. 104; for a detailed description, see Section 2.4 of that report).

Contrary to what some teachers and educators may think – and to what many didactic manuals suggest – scientific literacy does *not* focus on *experimenting* but rather on *questioning, observing,* and *reasoning* (see Wagenschein 2010 [1968], which is still a groundbreaking work). The goal here is twofold: on the one hand, a genuine understanding of the science of nature and, on the other hand, an understanding of the nature of science. Or, to put it another way, an understanding of how nature works and of the questions that can be answered with scientific methods and procedures. For example, scientists can, as a rule, answer only "how" questions – that is, they can make statements about *how* something behaves *under specific circumstances.* But children very often ask "why" questions (e.g., "Why does gravity exist?" or "Why do female worker bees live for only a few weeks?") or "where from" questions ("What came before the Big Bang?"). However, these two types of questions are not ones that can be answered by scientific means, so that the only honest answer to such questions is: "Nobody knows!"

Because all educational processes in adolescence and adulthood build on educational processes in early childhood, the multi-dimensionality of science education also applies in principle to the educational efforts of parents, early childhood educators, and teachers and educators at primary school level, even though comprehensive science education can, of course, be acquired only in passage through the entire education system.

3. Learning-Theory and Didactic Premises

3.1 Constructivist Concept of Learning

I propose that learning should not be understood as a stimulus-response schema but rather as "experiential learning" in the classical sense. My starting point is John Dewey's concept of learning. Following Dewey (1916, p. 140), "to learn from experience is to make a backward and forward connection between what we do to things and what we enjoy or suffer from things in consequence. Under such conditions, doing becomes a trying; an experiment with the world to find out what it is like; the undergoing becomes instruction – discovery of the connection of things." According to Dewey – and later, using different terminology, to Vygotsky, Piaget, and Bruner – learning takes place when learners in a given problematic situation mentally process their existing experiences or cognitive schemas on the basis of the consequences of their own acts and the reactions of the external world to those acts, and when they build up increasingly complex mental structures, which, in turn, prove their worth in more complex acts. Or, to use Piaget's terminology, learning takes place through the continuous (adaptive) accommodation of established schemas to new experiences, and the assimilation of new experiences to existing schemas.

According to this understanding of learning, the thinking of pre-primary and primary school children is always linked to their own mental actions. This corresponds to the call for *structured self-activity* in the learning process, which has time and again been declared indispensable by general didacticians since Rousseau, and by contemporary subject didacticians with constructivist leanings since Vygotsky, at least (for current positions, see Möller, 2004; Einsiedler, 2005; Hardy, Jonen, Möller, & Stern, 2006). If the goal of science education is "real understanding" of the science of nature and the nature of science, four principles can be clearly derived from such a concept of learning:

1. Educative teaching always begins with a problematic situation that raises *a question about nature*. Because children are not usually aware of the (scientific) questions that are present in a problematic situation, the first task of the teacher is to co-construct these questions with them, so that they can be processed. *Didactics* is the art of teaching, and it may well be necessary to "point out" to the children things that they would not themselves see or ask about.
2. Science teaching is basically about *understanding* and not primarily about experimenting.

3. Experiments are only a means towards the end of *investigating a question* about nature. They are by no means the main purpose of science teaching, but rather should serve to enhance understanding.
4. Children should not be given predefined experiments. Rather, *experiments should be developed with the children* when they are needed to clarify a question.

However, the fourth principle raises doubts as to whether children of primary school age are already capable of independently developing hypothesis-testing procedures – of course only within the framework of age- and experience-typical questions. There are contradictory assessments in this regard. In the *prima(r)forscher* ("primary researchers") school development programme for science in the primary years, for example, we certainly experienced situations in which primary school children developed their own experimental designs (see Internationale Akademie, 2011, Section 3.2, pp. 30–38). And Beate Sodian notes "in relation to the goal dimension *knowledge of methods of testing hypotheses* that initial competencies are already present at primary school age, and that the use of adequate strategies to test causal hypotheses can be achieved through targeted support" (Anders et al., 2017b, p. 118 in this volume). On the other hand, however, Sodian also refers to studies conducted by Bullock and Ziegler (1999), who found that "only from grade five onwards was a controlled test produced by around one third of the subjects. And only at age 17 did 80% of the subjects spontaneously produce a controlled experiment" (Anders et al., 2017b, p. 117 in this volume).

Primary school students obviously need specific guidance when carrying out hypothesis-testing procedures. In my view, this guidance should always ensure that these procedures refer to the context of the question underlying the experiments. If teachers and educators do not want to wait until the children come up with their own adequate experimental designs with which to test their hypotheses, or if the children do not succeed in producing these experimental designs themselves, it may make sense to offer them experimental designs. However, this should be done only on one condition, which we can add as a fifth principle to the set of principles outlined above, namely:

5. If teachers and educators introduce an experiment themselves, the children should at least be aware, or become aware through instruction, of the question about nature to which this experiment is supposed to provide an answer.

Teachers and educators should always be conscious of the dual nature of experimentation. For children's experience when conducting experiments is twofold: on the one hand, they experience the engagement with a phenomenon and the variables that determine it; on the other hand, they experience the didactic arrangement of the experiment as a pedagogic means of teaching something that obviously could not be experienced without the experiment. Not all teachers and educators are aware of this dual structure of experimental action.

3.2 Suitable Teaching-Learning Arrangements

In recent years, researchers in the didactics of science have made very clear statements about how learning situations should be constructed in order to enable students to develop a real understanding of the nature of science. With regard to primary school research in Germany, mention should be made here of the works of Kornelia Möller, Beate Sodian, Elsbeth Stern, and Ilonca Hardy and colleagues. In groundbreaking research studies, they have identified what constitutes "good" science teaching at primary level (see Ewerhardy, Kleickmann, & Möller, 2009; Jonen, Möller, & Hardy, 2003; Möller, 2004; Möller et al., 2002; 2006; Sodian, 2002; Stern & Möller, 2004). Research on the general goal of science teaching, *scientific literacy,* and research in primary school didactics, stresses the necessity of teaching-learning arrangements in which children can work on science topics in a self-active, problem-oriented, and lifeworld-oriented way (see Einsiedler, 2009; Fischer, Klemm, Leutner, Sumfleth, Tiemann, & Wirth, 2003; Lauterbach, Hartinger, Feige, & Cech, 2007; Treagust, Chittleborough, & Mamiala, 2002; Tyson, Venville, Harrison, & Treagust, 1997). Accordingly, in the primary science classroom, instructional approaches where teachers give children an opportunity to independently propose, try out, test, and revoke hypotheses are considered to be particularly effective.

As a rule, these processes should – and this is crucial – be supported by structured facilitation, scaffolding, and a correspondingly stimulating (constructivist) learning environment. Moreover, against the background of Dewey's (1916, p. 14) above-mentioned postulation that the basis of learning processes is constituted by what learners "enjoy or suffer" as a consequence of the natural world's impact on, or reaction to, their actions, it becomes clear that instructionally guided learning processes are never purely one-directional in the sense of direct instruction.[22] "Suffering" also implies disappointment, irritation, and phases of incomprehension that cannot be overcome by action on the part of the learners alone, or simply by the teacher doing the thinking and acting for the children. Rather, it can be overcome only through joint, co-constructive thinking on the part of the learners and the teacher.

22 For the "teaching-learning short-circuit" in didactics and in competence research, see Holzkamp, 1996.

Communication about children's activities in the classroom plays a very important role in the construction of their knowledge. Kornelia Möller (2004) summed up in just two sentences the entire findings gained in research in subject didactics over the past 20 years, thereby setting fundamental standards for the quality of primary science instruction:

> *In order to build up applicable, integrated, and consistent knowledge, the students must actively question existing concepts; they must test them against experience; they must discard old ideas and develop new ones, which they must then test, apply in different situations, and present in their own language. Collaborative learning and thinking processes in the learning group play an important role in this regard (Möller, 2004, p. 153).*

Here, learning is conceived of as co-construction on the part of the teacher or educator and the learners, and on the part of the learners among themselves; the process of learning is integrated into the social context of the classroom (Widodo & Duit, 2004). It is assumed that co-constructive learning processes are also sustainably effective on the cognitive and motivational levels – especially when processes of action and understanding are closely interwoven (Beinbrech, Kleickmann, Tröbst, & Möller, 2009; Möller, 2004; Möller et al., 2002, 2006). Accordingly, teaching should be structured in such a way that it constitutes a combination of self-active trying out and experimenting, on the one hand, and systematic, sustained shared thinking, on the other (see Siraj-Blatchford 2009 and Brodie 2014). However, the suggestion that "consistent knowledge" is possible seems problematic because consistency exists only in the case of certain forms of knowledge, and, as the history of science shows, knowledge consistency is always provisional.

In the ideal case, teaching takes as its starting point the children's questions about the phenomenon in question; it makes these questions the topic of instruction; and it addresses them in an inquiry cycle similar to that followed in an "ideal" scientific research project: from a question about the natural world, through hypothesis formation and testing and the documentation of results, to the discussion of the findings (see Ramseger, 2010 and 2011; see also the inquiry cycle following Marquardt-Mau [2011], on which the "Haus der kleinen Forscher" Foundation's inquiry cycle method is based).[23]

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23 *See http://www.haus-der-kleinen-forscher.de/home/practice/inquiry-cycle-method/*
I am quite aware that this "ideal" scheme of a research process is rarely used in real-world scientific research, where several steps in the process may be taken simultaneously, and back-and-forth movements also occur. However, for didactic reasons – especially with regard to the early years – the cycle model has proved quite useful both for the children and for the teachers and educators.

However, this ideal case is rarely achieved in pre-primary and primary teaching. For such an *inquiry cycle* presupposes, first, that the children are capable of independently formulating the questions about nature that are inherent in the natural phenomena. As a rule, however, children need the help of their teacher or educator, who must first show them how, or help them, to formulate topic-appropriate questions. And this ideal model presupposes that the teachers and educators themselves have a genuine understanding of scientific thinking and acting and the necessary content knowledge and didactic foresight to resolve children's questions into new knowledge in processes of inquiry and thinking. These processes are usually of long duration, and they are not always orderly. Children are not scientists at first, and, as a rule, their teachers or educators are not always scientists either. If they have not studied science, teachers and educators sometimes lack any conception of what constitutes a genuinely scientific knowledge construction process, which always presupposes scientific reasoning.

4. Scientific Reasoning at Primary School Age

To determine the competencies required for scientific literacy, it is useful to draw on an overview proposed by Jürgen Mayer (2007, p. 178), who arranged the competence constructs typically cited in the scientific literacy literature as follows (see Figure 6):

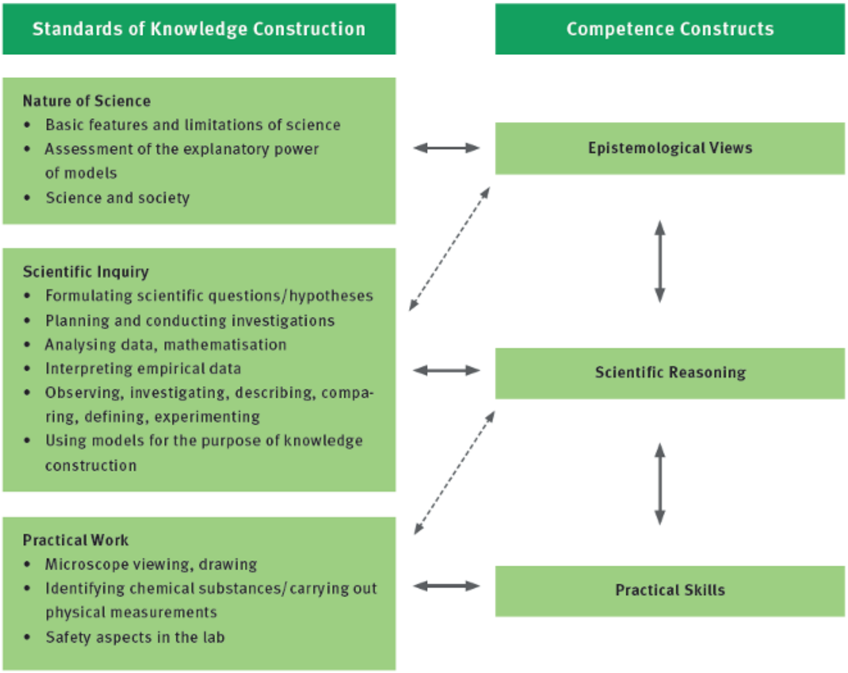


Figure 6. *Framework concept of scientific competencies following Mayer (2007)*

Of course, Mayer's framework concept refers to trained scientists or professional researchers, and it does not distinguish between lifeworld, historical, scientific-causal, and ideology-critical forms of knowledge. However, if one assumes that every competence is initiated and formed in a process of lifelong learning, Mayer's grid is also relevant when it comes to asking what competencies can be initiated as early as pre-primary or primary school age.

If one reads Figure 6 from top to bottom, one can gauge the aspects that can be achieved at pre-primary and primary school levels. I maintain that lessons or extracurricular learning opportunities that are limited mainly to *action-oriented lab-type work* – as advocated by numerous popular books and the many experiment instructions that circulate on the Internet – are primarily suitable for imparting practical skills in handling the most basic instruments and devices, and perhaps also simple scientific procedures. These skills include, for example, handling bottles, funnels, measuring beakers, candles, and simple measuring instruments, such as yardsticks, wind gauges, thermometers, etc. Experiment tasks and instructions, which are usually given to the children without their asking (!), always run the risk of neglecting – or, indeed, even preventing – understanding of the phenomena discussed, because children are expected to achieve a level of understanding that is hardly possible in the short time available and in view of their age-appropriate conceptions of the natural world and its laws.

In contrast to the imparting of basic practical skills, I consider the initiation of a genuine *understanding of the nature of science,* in the sense of "epistemological views" or beliefs, to be a major challenge not only for children of pre-primary and primary school age but also for most teachers and educators, unless they have studied science during their professional training. However, the average primary teacher is not usually sufficiently qualified to facilitate real understanding of the nature of science. Nor are the majority of the many educators who provide children with science experiments at early childhood education and care centres, after-school centres, and in extracurricular afternoon programmes at primary schools. A *tacit* understanding of the nature of science may possibly be built up at pre-primary and primary school age. However, as research in subject didactics over the last 20 years has shown, an understanding of the nature of science calls for systematic reflection on, and systematically guided discourse *about,* science. This, in turn, requires years of experience of dealing with, and solving, scientific questions in genuinely scientific teaching-learning situations. Following Sodian (2002), the ability to differentiate between hypotheses and evidence can hardly be expected of primary school children, as they often have difficulties understanding the purpose and aim of hypothesis testing (Hellmich & Höntges, 2010, p. 75; on the current state of research on primary school children's knowledge building capacity, see Sodian's contribution in Anders et al., 2017b, pp. 109–123 in this volume).

The competence construct on the middle level in Figure 6 – scientific reasoning – is an appropriate target for children of pre-primary and primary school age. It implies *joint reflection* on specific questions about nature, their answerability, and the observations and actions carried out to answer them.

Scientific reasoning

What is scientific reasoning? In what follows, I present four definitions of this construct.

Einsiedler describes scientific reasoning in its simplest form as "asking for reasons and evidence for assertions" (1992, p. 484; cited in Beinbrech et al., 2009, p. 140).

Tytler, Hubber, and Chittleborough (2012, p. 3) define scientific reasoning as follows: "Deliberative thinking that involves choices, leading to a justifiable claim. The setting of identifiable and generative relations between entities. It is often associated with high order thinking, (…) solving non-standard problems, claim backing using evidence."

Shemwell and Furtak (2010; cited in Tytler, 2011, p. 3) distinguish:

- "claim-based reasoning: a statement of what something will do in the future (prediction), or is happening in the present or past (conclusion or outcome)
- data-based reasoning: a claim backed up by a single observable property
- evidence-based reasoning: a claim supported or backed up by statements describing a contextualized relationship between two observable properties, or a contextualized relationship between a property and an observable consequence of that property"

In the EQUALPRIME project (Hackling, Ramseger, & Chen 2017),[24] the following indicators were used to determine situations in which scientific reasoning takes place.

Scientific reasoning is deemed to occur when children

- articulate their prior knowledge of, and their own assumptions about, a phenomenon;
- formulate their own hypotheses and have to defend them against probing;
- develop and justify their own inquiry activity designs on the basis of their hypotheses;
- recognise and discuss sources of error, contradictions, or events that are contrary to expectations in their inquiry activities or inquiry activity designs;
- formulate and/or explain their own justifications for phenomena they observe;

24 EQUALPRIME – Exploring quality primary education in different cultures: A cross-national study of teaching and learning in primary science classrooms. *A research project of the Australian Research Council 2009–2013. Principal Investigators: Prof. Dr Russell Tytler, Deakin University, Melbourne; Prof. Dr Mark Hackling, Edith Cowan University, Perth; Prof. Dr Hsiao-Lan Sharon Chen, National Taiwan Normal University, Taipei; Prof. Dr Chao-Ti Hsiung, National Taipei University of Education, Taipei; Prof. Dr Jörg Ramseger, Freie Universität Berlin. See Hackling, Ramseger, & Chen 2017.*

- discursively agree on a description, justification, or interpretation;
- act on the basis of a finding (observable objectivations of knowledge gains in concrete action); and
- reflect on their own learning pathways (metacognition).

Only teaching that plans and ensures the realisation of such argumentative, discursive, and metacognitive phases, and that combines questioning, enjoying and suffering, acting, and thinking in a targeted way can, in my view, be understood as "educative teaching" in the true sense of the word (on the distinction between "educative" teaching and merely "informative" teaching – or even "preaching"– see Ramseger, 1991).

5. Quality Criteria

Ten criteria for successful science teaching are presented in what follows. They were developed on the basis of the concept of learning outlined above and the multi-dimensionality of the guiding principle *scientific literacy,* and they condense into simple short assertions the diverse and extremely differentiated findings from research in the didactics of science over the past 20 years (see overview in Table 8). These are *criteria for the qualitative assessment of the process quality of teaching*. The core thesis proposed by Möller, which has already been cited in Chapter 3 above, serves as a guiding formula for a good process structure of teaching-learning situations:

> *In order to build up applicable, integrated, and consistent knowledge, the students must actively question existing concepts; they must test them against experience; they must discard old ideas and develop new ones, which they must then test, apply in different situations, and present in their own language. Collaborative learning and thinking processes in the learning group play an important role in this regard (Möller, 2004, p. 153).*

It is, of course, a bold undertaking to condense the entire research findings in the didactics of science into such brief sentences as those presented below. Researchers themselves justifiably tend to stress the tentative nature of their own statements, the complexity of the subject matter, and the enormous need for further research before any recommendations for practice may be made. However, the present contribution assumes that educational practitioners need precisely this type of easily understandable yet scientifically grounded sentence in order to be able to assess the meaningfulness of their own efforts and to have some kind of yardstick for their instructional action. Arguments about what desirable teaching reality should look like may possibly be much more fruitful with these criteria than without.

Overview of the ten criteria

Table 8. *Overview of the ten quality criteria for science teaching*

1) Make nature "question-able" Good science teaching takes as its starting point a natural phenomenon that elicits wonder in the children, and, together with the children, it formulates a question about nature in such a way that they can find a meaningful answer.
2) Incorporate prior knowledge Good science teaching first collects the children's preconceptions of the phenomenon in question, takes them up, and confronts them with new questions, new observations, and new (experimental) experiences.
3) Develop experiments together with the children Good science teaching develops – where possible together with the children themselves – the experimental design that yields an answer to their question. If the children are not yet capable of this, and the teacher or educator therefore gives them a predefined experiment, they should at least be aware, or should become aware through instruction, of the question about nature that this experiment is supposed to answer.
4) Practise working in a precise way Good science teaching practises with the children how to look closely at things, to carefully document experiences, and to differentiate between questions, assumptions, assertions, and observations.
5) Foster scientific discourse Good scientific teaching practises orderly discourse with the children about their assumptions, observations, and findings. From this perspective, it is a form of language teaching.
6) Use models and representations Good science teaching develops suitable graphical representations and models together with the children.
7) Take the social and historical embeddedness of scientific phenomena into account Good science teaching broadens the children's view of the phenomenon in question by giving them an insight into its historical, cultural, and social significance.
8) Point out that science is open to change Good science teaching points out to the children that our answers to our questions about nature are always tentative and that science is always a work in progress.
9) Ensure learning gains Good science teaching brings about an increase in children's competence.
10) Facilitate perceived self-efficacy Good science teaching enables children to experience that they can solve a question about nature by means of their own thinking.

These ten criteria will be explained in detail in what follows.

1st criterion: Make nature "question-able"
Good science teaching takes as its starting point a natural phenomenon that elicits wonder in the children, and, together with the children, it formulates a question about nature in such a way that they can find a meaningful answer.

The first criterion echoes the belief formulated by Rousseau, Herbart, and later, as mentioned above, by John Dewey, and emphasised once again in more recent publications on science teaching, for example by Ansari (2009, 2012) and Marquardt-Mau (2011), namely that learning does not take place unless a problem or a question first arouses our minds, causes us to doubt our existing understanding of the world, and challenges us to reorganise our existing cognitive schemas. All learning presupposes a question about the world, and the learner must be aware (or be made aware) of this question (Ramseger, 2011; see also National Research Council, 2012). This does not usually happen spontaneously, but rather presupposes corresponding didactic action on the part of the teacher or educator in a classroom situation where questions are developed.

2nd criterion: Incorporate prior knowledge
Good science teaching first collects the children's preconceptions of the phenomenon in question, takes them up, and confronts them with new questions, new observations, and new (experimental) experiences.

If the goal and the outcome of learning is conceptual change – and there is consensus on this point among experts – it is imperative to first identify the children's preconceptions of the phenomenon in question, to have the children articulate them in the classroom, and to use them as a launching point for further learning efforts (Morrison & Lederman, 2003; Lohrmann & Hartinger, 2012).

However, learning does not occur by repeating existing experiences, but rather by confronting them with new experiences and antitheses, and with assumptions, hypotheses, or observations that deviate from the learner's own beliefs. Therefore, good science teaching first collects the children's preconceptions of the phenomenon in question, takes them up, and – without deriding them – confronts them with new questions, new observations, and new (experimental) experiences.

3rd criterion: Develop experiments together with the children

Good science teaching develops – where possible together with the children themselves – the experimental design that yields an answer to their question. If the children are not yet capable of this, and the teacher or educator therefore gives them a predefined experiment, the children should at least be aware, or should become aware through instruction, of the question about nature that this experiment is supposed to answer.

Many teachers and educators are under the misconception that scientific work manifests itself primarily in experimenting. Therefore, they often offer a plethora of experiments, without the children always being aware of what is actually happening in each case. What these teachers and educators fail to realise is that the scientific process requires first and foremost mental work. This involves the laborious translation of a question about nature into a testable hypothesis that must by no means always be clarified through experiment, but rather – one need only think of astronomy – can often be clarified through intensive observation, careful documentation of natural phenomena, and deductive reasoning alone.

Nowadays, the experimental approach is, of course, the most common method of testing hypotheses in science. But it is always only a *means towards an end* and not the actual *purpose* of science, which consists in producing knowledge. Science teaching that limits itself mainly to experimenting often fails to recognise that it is necessary to place the experiment, as *one method among many,* into the meaning context of the question about nature that is to be clarified by means of the experiment (see Ramseger, 2010). In that case, however, teaching runs the risk of eliciting wonder but not understanding, and of ultimately forfeiting any claim to be educative. In the ideal case, therefore, good science teaching does not give the children predefined experiments, but rather develops – where possible – together with the children the experimental design that yields an answer to their question.

However, children of pre-primary and primary school age are capable only to a limited extent of inventing experimental designs to clarify their questions about nature that produce robust results (see Chapter 2 above). Hence, it may well make sense for teachers and educators to introduce experimental designs to the children. What is of decisive importance here is that the children should be aware – or should be made aware through instruction – of the question about nature to which the experiment is supposed to yield an answer.

4th criterion: Practise working in a precise way

Good science teaching practises with the children how to look closely at things, to carefully document experiences, and to differentiate between questions, assumptions, assertions, and observations.

Initially, children are not scientists. They are spontaneous, lively, and always ready to simply drop what they are doing and devote their attention to something else that they find more attractive. Their discipline is limited, and their ability to make unbiased judgments, which is typical of causal science, develops only in the course of their passage through the education system. Children are often satisfied with a quick answer and big concepts (e.g., "black holes"), the implications of which they do not understand.

It is the mandate of schools to make the classification systems and procedures that we call "science" gradually accessible to children. Good science teaching therefore practises with the children how to look closer at things, to carefully document their experiences, and to differentiate between questions, assumptions, assertions, and observations.

5th criterion: Foster scientific discourse

Good scientific teaching practises orderly discourse with the children about their assumptions, observations, and findings. From this perspective, it is a form of language teaching.

The extensive studies conducted by Tytler and Petersen (2004), Hardy, Jonen, Möller, and Stern (2006), Beinbrech (2010), and Tröbst, Hardy, and Möller (2011) have demonstrated how comprehensively teaching-learning situations with primary school children must be planned and implemented if they are to meet "scientific" requirements and produce sustainable understanding. Scientific work requires an attitude that is quite the opposite of childlike spontaneity.

This attitude includes the scientific "work virtues," such as the exact use of terms and language. For example, the *mass* and the *weight* of a body are not one and the same thing. And a biologist may understand something different by the term *energy* than a physicist. In science teaching, precise language is essential. For without the unequivocal articulation of observations, assumptions, and findings, a coherent cognitive schema cannot be developed. Good science teaching practises orderly discourse with children about their assumptions, observations, and findings. From this perspective, it is a specific form of language teaching.

6th criterion: Use models and representations

Good science teaching develops suitable graphical representations and models together with the children.

Hardy, Jonen, and Möller (2004) and Hubber, Tytler, and Haslam (2010) have stressed in empirical studies the importance of graphical representations of scientific explanations and the use of models for building up knowledge in science. In mechanics, for example, forces that are not directly visible but can only be felt, or forces that are visible only through their consequences, are usually represented with the help of graphical representations, arrow representations, or force diagrams. Physical representations – for example, when the children imitate in role play the dual motion of the earth as it rotates on its own axis and revolves around the sun, and they almost get dizzy doing so – support the process of understanding. Such graphical representations, tables, gestures, and physical representations are generally considered to be extremely useful for building up understanding:

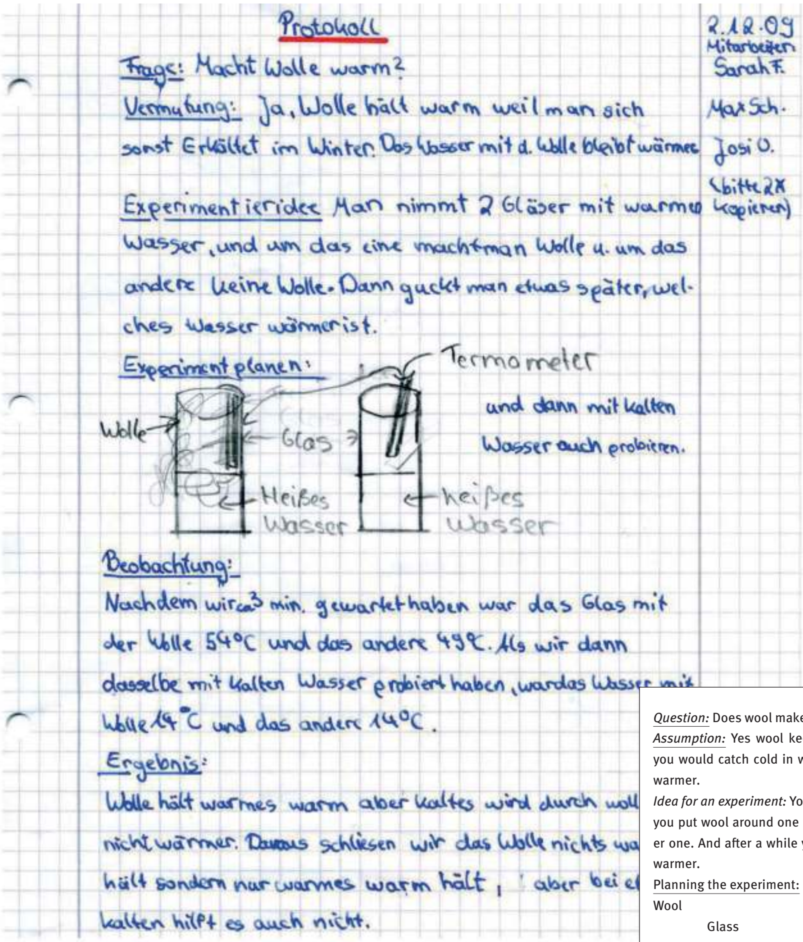
> *According to the teachers, the explicit negotiation of and discussion of representations of force led to a richer range of classroom discussions and opened up lines of inquiry that were closed in earlier versions of the unit. The requirement on students to generate and coordinate representations led to refinement of ideas in shared classroom discussion (Hubber et al., 2010, p. 24).*

The effectiveness of representations and models is attributed to the fact that learning always involves an abstraction from individual cases that is stored in symbols. However, following Hubber et al., it is essential that the children should, where possible, come up with appropriate representations themselves, and should explain and defend them in group discussions. This corresponds to the overall co-constructive arrangement of modern science teaching:

> *There is a need for a strong sense of student agency in generating, negotiating and refining representations, and this aligns with previous claims by members of the research team [...] that supporting*

and challenging students to refine and coordinate their representations leads to them achieving increased coherence and flexibility in developing understanding (Hubber et al., 2010, p. 24f.).

Hence, good science teaching develops together with the children suitable graphical representations and models that foster their understanding (see example in Figure 7).



Protokoll

2.12.09
Mitarbeiter
Sarah F.
Max Sch.
Josi O.
(bitte 2x kopieren)

Frage: Macht Wolle warm?

Vermutung: Ja, Wolle hält warm weil man sich sonst Erkältet im Winter. Das Wasser mit d. Wolle bleibt wärmer

Experimentieridee: Man nimmt 2 Gläser mit warmen Wasser, und um das eine macht man Wolle u. um das andere keine Wolle. Dann guckt man etwas später, welches Wasser wärmer ist.

Experiment planen:

Beobachtung:
Nachdem wir ca. 3 min. gewartet haben war das Glas mit der Wolle 54°C und das andere 45°C. Als wir dann dasselbe mit kalten Wasser probiert haben, war das Wasser mit Wolle 14°C und das andere 14°C.

Ergebnis:
Wolle hält warmes warm aber kaltes wird durch woll nicht wärmer. Daraus schliesen wir das Wolle nichts wa hält sondern nur warmes warm hält, aber bei e kalten hilft es auch nicht.

"Protocol"

Question: Does wool make things warm?

Assumption: Yes wool keeps things warm because otherwise you would catch cold in winter. The water with the wool stays warmer.

Idea for an experiment: You take two glasses of warm water and you put wool around one of them and no wool around the other one. And after a while you take a look to see which water is warmer.

Planning the experiment:

Wool Termometer [sic]

Glass and then try it out with cold water

Hot water Hot water

Observation:

After we waited for around 3 minutes the glass with the wool was 54° and the other glass 45°. When we tried it out with cold water, the glass with the wool was 14° and the other was 14°.

Result:

Wool keeps warm things warm but it does not make cold things warmer. We conclude from this that wool does not keep anything warm [sic] but only keeps warm things warm but in the case of something cold it does not help.]

Figure 7. *Graphical representation of an idea for an experiment developed by a group of primary school students (following Wimmer, 2011). Source: Deutsche Telekom Stiftung & Deutsche Kinder- und Jugendstiftung (Eds.) (2011).* Wie gute naturwissenschaftliche Bildung an Grundschulen gelingt. Ergebnisse und Erfahrungen aus prima(r)forscher *[How good science education succeeds at primary schools. Results and experiences from the prima(r)forscher (primary researchers) project]. Berlin, Bonn*

7th criterion: Take the social and historical embeddedness of scientific phenomena into account
Good science teaching broadens the children's view of the phenomenon in question by giving them an insight into its historical, cultural, and social significance.

Science is not isolated, but rather is embedded in a historical and social situation. It does not always owe its existence to human inquisitiveness alone, but frequently enough also to the interests of its funders. These interests may be economic, military, technical, or epistemological in nature, and they often serve to retain or expand power. One only has to think of the European mariners' voyages of exploration between the 15th and the 18th centuries for the purpose of colonising distant territories or countries, and the race to the Poles in the early 20th century, which were funded by the Spanish and British monarchies, respectively, and were primarily imperialistically motivated.

However, research funding does not always serve particular interests but sometimes also global purposes, for example the preservation of natural living conditions on our planet for future generations in the domain of renewable energy or electromobility. Since the publication of the Brundtland Report in 1987 – or since the United Nations Conference on Environment and Development in Rio de Janeiro in 1992, at the latest – Education for Sustainable Development (ESD) has been a key element of school teaching in all grades, and, as the Agenda 21 publications show, it can also be effectively initiated in extracurricular educational programmes. It is clear that this goal of mankind can be realised only through joint economic, ecological, political, scientific, and technological efforts.

If one understands science education in a comprehensive, transdisciplinary sense as a contribution to "general education," it would certainly not be enough to limit the topic of magnetism in the primary classroom to the attraction and repulsion of different poles and the detection of force field lines using iron filings. Rather, it would also be necessary to address in detail the historical and social benefits of the discovery of the magnetism of the earth. For not only in technology is magnetism of vital importance for us (e.g., in the form of mechanic switch elements).

What is almost more important is the historical dimension: Without the discovery that little magnetite stones ("lodestones") – floating in water or suspended so that they can turn – always and everywhere point towards the North Star, the Spanish Conquistadores would hardly have ventured across the great ocean and sailed to distant continents, as this would have been too risky before the discovery of the compass. And without this discovery, Europeans would probably still be unaware of the existence of America. In our everyday lives, we use satellite navigation systems, all of which are based on those early discoveries, including geometrical astronomy developed in Babylon and ancient Greece. These connections should be discussed with the children when addressing magnetism in the science classroom, and when the aim is to give children access to comprehensive general education (see also Misgeld, Ohly, Rühaak, & Wiemann, 1994; Rieß, 1998).

8th criterion: Point out that science is open to change
Good science teaching points out to the children that our answers to our questions about nature are always tentative, and that science is always a work in progress.

Things become exacting when we consider the hypothetical character of the laws of nature, and understand that scientific statements are always "tentative" and can be superseded at any time by knowledge on more complex levels of reasoning. The model of the atom is still proving its worth in explaining the basic structure of matter and the way substances react with each other. It also continues to prove its worth in the production of electricity and nuclear weapons. However, particle physicists are penetrating further and further into the atom and discovering ever smaller components of matter. Perhaps one day they will replace the current atomic model with a different, more complex, model that explains reality better, just as Kepler, Copernicus, and other astronomers overcame the geocentric world view and replaced it with a heliocentric world view.

It is very difficult to make this meta-understanding of the nature of science accessible to children of primary school age or even younger. They often believe that researchers know everything, can find out anything, and are always right. Perhaps teachers and educators will not be able to do much more than weave the words "as far as we know today" into scientific explanations once in a while. For example: "*As far as we know today,* dinosaurs became extinct as a result of a giant cosmic impact." This topic, which children usually find fascinating, might be a suitable vehicle for addressing at least once during children's time at primary school the tentativeness, the limited range, and the continuous updating of scientific explanations.

9th criterion: Ensure learning gains
Good science teaching brings about an increase in children's competence.

The second-last quality criterion presented here, which may appear trivial at first glance, can be explained by the purpose of educational institutions. Of course, all educational opportunities should enhance children's competence. However this increase in competence cannot always be easily measured. Many research studies are currently addressing this problem. The expert reports by Anders et al. (2017a, b in this volume) come to the conclusion that valid instruments have yet to be developed for measuring many competencies and many of the goals of successful early science education.

These instruments will probably be developed initially for use by educationalists rather than by teachers and educators. Hence, today's teachers and educators will have to continue measuring the success of their educational efforts with informal tests and homespun procedures for monitoring teaching success. Such instruments do not usually meet psychometric standards regarding exact measurement. However, the very fact that teachers and educators try to measure learning success as well as possible under everyday circumstances is also a component of, and a quality criterion for, good teaching – as faulty and subjective this monitoring of learning progress may be in individual cases. If, at the end of an instruction unit, teachers and educators do not measure what the children have actually learnt, they cannot measure whether the children have actually learnt anything at all or whether the entire teaching process has perhaps been ineffective. Good science teaching should always bring about a tangible (and sometimes measurable) increase in children's competence. Just as it is important to collect children's preconceptions at the beginning of an instruction unit, their learning progress should be monitored at the end. These tests do not have to be graded, but they should provide the teacher or educator with information about whether, and what, the children have actually understood.

10th criterion: Facilitate perceived self-efficacy
Good science teaching enables children to experience that they can solve a question about nature by means of their own thinking.

We come now to the last and most important criterion – which is superordinate to all the preceding criteria, and thus indispensable. It refers to the process of knowledge construction as a whole, which teaching aims to set in motion, and which is always an individual process. The reasoning behind this criterion is that all learning is linked to independent thinking, for which teaching can provide only material and opportunity, but which it cannot force. Whereas in the first quality criterion above, I formulated the premise that all teaching in science must take as its starting point a question about nature, the tenth criterion covers both the entire teaching process and the objective of the educational efforts by stating that good science teaching enables children *to experience that they can solve a question about nature by means of their own thinking*.

This criterion refers to the importance of both general and domain-specific *perceived self-efficacy* when learning. It assumes that no teaching is really effective unless it brings about perceived self-efficacy. This fact is well supported in research (on the importance of perceived self-efficacy for learning success, see de Laat & Watters, 1995; Rittmayer & Beier, 2008; Britner & Pajares, 2006; Lange, Kleickmann, Tröbst, & Möller, 2012; Lohrmann, Görz, & Haag, 2010; Rechter, 2011).

This criterion points to fact that, in practice, science teaching must not only provide children with opportunities for action but also with *occasions for thought*. In the ideal case – see the quote from Kornelia Möller (2004) at the beginning of Chapter 4 – (joint) thinking is the focus of the entire teaching process and is only supported and prompted by experimental action and practical trying out.

"Own thinking" means that the children exchange their ideas and thoughts about the phenomenon in question, rather than simply grasping thoughts that have been pre-thought for them by the teacher or educator. It is the task of the teacher or educator to *trigger and structure thought processes* by means of suitable learning opportunities, questions, and provocations. These thought processes must happen in the children. To this end, they usually need the support of the teacher or educator, who helps them to organise their thoughts and to examine them time and again. This facilitation of the organisation of children's thoughts is probably the most demanding contribution that teachers and educators can make to children's learning processes. What teachers and educators cannot do, however, is to do the learning for the children.

6. Relevance and Hierarchy of the Individual Criteria

It is obvious that the simultaneous consideration of all ten criteria is an extremely demanding requirement that will succeed with children of pre-primary and primary school age only in extremely felicitous cases. Teachers and educators can presumably consider themselves lucky if they succeed in realising at least three or four of the criteria in a concrete teaching project.

However, for a successful process of science education, it probably suffices to realise one or other of the criteria at different times, because domain-specific competencies and general education do not develop in one-off sessions but rather in a long-term process during children's passage through the entire education system. This process presupposes many different perspectives on the phenomenon under investigation, many iterations, and opportunities to practise things. In view of the children's age, and considering science education along the entire education chain, the more basic criteria, (1) *Make nature "question-able,"* (2) *Incorporate prior knowledge,* (4) *Practise working in a precise way,* (5) *Foster scientific discourse,* (6) *Use models and representations,* and (9) *Ensure learning gains,* should be assigned more weight than the very demanding criteria (3) *Develop experiments together with the children,* (7) *Take the social and historical embeddedness of scientific phenomena into account,* and (8) *Point out that science is open to change*. Teachers and educators may only sometimes endeavour to meet the latter three quality criteria at pre-primary or primary level. However, they should be especially emphasised and addressed at secondary level.

Nonetheless, in order to be able to react in good time should the one or other criterion *never* be met, all ten criteria should be kept in mind when planning and evaluating lessons. And ultimately, no teaching can be described as "educative" if it *never* meets the fifth and the tenth criteria – that is, if it permanently fails to foster *scientific discourse* with the children, and if it permanently fails to enable them to *experience that they can solve a question about nature by means of their own thinking,* thereby enabling a sense of perceived self-efficacy.

7. Outlook

When they read the above-mentioned process criteria as a list, and they note the underlying educational-theory and didactics of science considerations, some teachers and educators at pre-primary and primary level may be overcome by despondency and may think: “I’m supposed to pay attention to, and achieve, all that? Without having studied science myself? That’s too much for me!”

Here, the “Haus der kleinen Forscher” Foundation can play an effective supportive role – not by lowering its ambitions and withholding the criteria from the teachers and educators, but rather by systematically collecting, categorising, and publishing testimonies, reports, and examples of successful teaching at pre-primary and primary school level and by demonstrating in their pedagogical resources and workshops how the teachers and educators in these examples have already met these quality criteria without always being aware of it.

It could be worthwhile to fund a qualitative field research project that supplements the diverse efforts to measure competence in the science domain in a reasonable and practicable way with a collection of groundbreaking examples from practice – groundbreaking in the sense of the set of criteria developed above. Anyone who has already conducted such field research themselves will know that such examples can be found all over the country. They just have to be looked for, documented, and disseminated.

Conclusion and Outlook – How the "Haus der kleinen Forscher" Foundation Uses These Findings

"Haus der kleinen Forscher" Foundation

1. Recommendations from the Expert Reports as a Basis for the Foundation's Substantive Offerings
2. Contribution of the Foundation to Professionalisation in Early Education in the Educational Domains of Science, Technology, Computer Science, and Mathematics
3. Further Development of Process Quality Through the Foundation's Certification Procedure
4. Outlook: Measurement of the Outcomes of Science Education

1. Recommendations from the Expert Reports as a Basis for the Foundation's Substantive Offerings

The expert reports in this volume make recommendations that are highly relevant to the work of the Foundation.[25]

The recommended goals of early science education serve the Foundation as a guide for its substantive offerings, both at the level of the children and of the primary teachers and early childhood professionals. Whether it be a question of conceptualising continuing professional development offerings, pedagogical resources, or other pedagogical formats, these goals help the Foundation to specify the exact goals that should be targeted with a specific format. Moreover, the model of the goals constitutes the theoretical and empirical basis for the accompanying scientific research on, and the assessment of, these goals, and for ongoing internal quality monitoring.

The pedagogical goals of the work of the Foundation and their implementation in the various offerings are described in detail in what follows (see also the current edition of the brochure *Pedagogic Approach of the "Haus der kleinen Forscher" Foundation – A Guide to Facilitating Learning in Science, Mathematics and Technology,* "Haus der kleinen Forscher" Foundation, 2015c).

The Foundation pursues the following goals at the level of the children:

- enthusiasm, inquisitiveness, and interest
- an inquiry-based approach and problem-solving skills
- a grasp of basic concepts

The goals of the Foundation at the level of the primary teachers and early childhood professionals are:

- enthusiasm for collaborative inquiry
- pedagogical strategies for action

25 *In order to also adequately represent the thematic spectrum of the Foundation's work in corresponding dimensions beyond the domain of science, the goals of early technology education (see Volume 7 of this series, Stiftung Haus der kleinen Forscher, 2015, available only in German) and of early mathematics education (see Volume 8 of this series, Stiftung Haus der kleinen Forscher, 2017a, available only in German) were developed by two expert groups. An expert report addressing the goals of computer science education will be published in German in late 2017 or early 2018.*

- an inquiry-based and questioning approach
- professional role perception and self-concept
- a grasp of basic concepts

Figure 8 summarises the goals that the Foundation pursues at the level of the children and of the teachers and early childhood professionals.

Figure 8. *Goals of the Foundation's work at the level of the children, and of the teachers and early childhood professionals*

All substantive formats of the Foundation are aimed at strengthening the development of children between the ages of three and ten in relation to the above-mentioned goals. Most of the offerings are routed via the teachers and early childhood professionals who are responsible for the children's learning and development processes at the educational institutions. Therefore, the focus of the present chapter is on the target group of teachers and early childhood professionals and on the formats that the Foundation provides to support them in expanding their pedagogical action competence in science education.

Goals are currently being developed for the Foundation's trainers, who conduct workshops for teachers and early childhood professionals in the local networks throughout the country. The interdisciplinary expert group entitled "Goals for Multipliers in Early STEM Education" is composed of representatives from the fields of adult education, early childhood education, education research and competence measurement, and the didactics of the individual STEM subjects. They are collaboratively developing a model for the goals of successful trainers in the STEM education domains. The expert recommendations will serve the Foundation as a basis for expanding its offerings for trainers, and for supporting them in their individual development in an even more targeted way.[26]

Following the successful expansion of its offerings for children of primary school age, the Foundation now also provides formats that address the children directly (e.g., exploration cards for children and a website for primary school children, www.meine-forscherwelt.de) in order to enable further ways of implementing its goals at the level of the children.

1.1 Inquisitiveness, Interest, and Enthusiasm for Collaborative Inquiry

The first goal of early science education that Anders, Hardy, Pauen, Sodian, and Steffensky (2017, in this volume) specify for pre-primary and primary level both at the level of the pedagogical staff at early childhood education and care centres, after-school centres, and primary schools and at the level of the children is "motivation and interest in engaging with natural phenomena". The Foundation has adopted this recommendation, and it regards these motivational and emotional aspects as key goals of its work both at the level of the children and of the adults who collaborate with them in their inquiry activities.

The "Haus der kleinen Forscher" Foundation considers enthusiasm, inquisitiveness, and interest to be essential keys to a positive approach to science, technology, computer science, and mathematics. As a rule, the children's perspective is characterised by inquisitiveness and is, at first, completely unprejudiced. This can lead, via an interest in the respective phenomena, to the development of an understanding of fundamental scientific, technological, computer science, or mathematical relationships. Findings from brain research indicate that positive

26 The expert report produced by this expert group will be published in German in the present series in 2018.

feelings have a positive effect on concentration (Kiefer, Schuch, Schenk, & Fiedler, 2007). Enthusiasm and inquisitiveness thus support learning.

Adults, on the other hand, have often lost some or all of their inquisitiveness and enthusiasm for scientific topics in the course of their educational careers. Together with the "Haus der kleinen Forscher" Foundation, teachers and early childhood professionals set out to integrate science, technology, computer science, and mathematics topics into everyday life at their primary schools, after-school centres, or early childhood education and care centres. What is important here is an open-minded attitude. Almost all the Foundation's formats pursue this goal. Inquiry may, and should, be enjoyable.

Implementation of this goal in the Foundation's offerings

The *continuing professional development workshops*[27] for teachers and educators, which are designed by the Foundation and provided in collaboration with its network partners, are always aimed at enabling the participants to take a positive approach to the topics in question (once again) and to develop an open-minded, inquiring attitude. A study by Spindler and Berwanger (2011) suggests that this succeeds even from the first workshop onwards. The authors conclude that one strength of the "Haus der kleinen Forscher" lies in the "motivational and easy accessibility" aspect. They note that (a) both the early childhood professionals and the children experienced a motivational start in the educational domains of science and technology, (b) the educators succeeded with exceptional ease and without trepidation in acquiring the necessary professional competencies and in implementing them directly at their institutions, and (c) the children then approached the topics with great motivation and interest, and acquired knowledge about natural phenomena and relationships between phenomena (p. 48). The

27 *Each year, at least four continuing professional development topics are offered. In addition to the basic workshops on the topics of water and air, in which the pedagogic approach of the Foundation is addressed in detail, teachers and early childhood professionals can attend two workshops a year on an ongoing basis. These workshops cover scientific, technological, computer science, and mathematical topics (e.g., carbon dioxide or electricity and energy) with pedagogical focuses (e.g., language learning or educational partnerships with families).*

teachers and early childhood professionals themselves also report a change of attitude as a result of the professional development offerings. As the Foundation's Spring Surveys reveal, reservations towards science and technology are significantly reduced as a result of participation in the education initiative, and interest in these topics is fostered (see Stiftung Haus der kleinen Forscher, 2010, 2011a).

1.2 Inquiry-Based and Questioning Approach, Problem-Solving Skills

Following Anders, Hardy, Pauen, Sodian, and Steffensky (2017, in this volume), the goal "knowledge about science and the scientific process" is of great importance for science education, both in the case of children at pre-primary and primary levels and of their teachers and educators.

This emphasis on a process-oriented, inquiry-based approach is also reflected in six of the ten quality criteria for science teaching developed by Ramseger in his expert report: *Make nature "question-able"; Incorporate prior knowledge; Develop experiments together with the children; Practise working in a precise way; Use models and representations; Foster scientific discourse.*

The application of the inquiry-based method is a key objective of the Foundation – both at the level of the children and of the adults. An inquiry-based approach includes, for example, the ability to consciously experience and perceive phenomena, to observe and describe them, and to compare experiences. Children can then derive expectations and assumptions from this, which they can test by trying things out and experimenting. Children's own experiences contribute to an understanding of basic scientific, technological, computer science, and mathematical relationships, and prompt further deliberations. The cyclical approach to inquiry enables children to expand their methodological competence and problem-solving skills; they learn to find their own answers to their questions.

Implementation of this goal in the Foundation's offerings

Through their own actions and questions when investigating scientific, technological, computer science, or mathematical questions at the professional development workshops and in practice, the teachers and early childhood professionals apply an inquiry-based, processual, and cyclical approach: they compare and evaluate experiences, develop expectations, and make assumptions; they try ideas out, experiment, and reflect on their observations.

The Foundation's *inquiry cycle method* (see Figure 9), which has featured in the workshops, thematic brochures, card sets, and other pedagogical resources since 2011, is aimed at encouraging children and adults to grasp relationships between phenomena through their own activities and an inquiry-based approach, and to expand their understanding of the nature of science. The inquiry cycle describes scientific thinking and action that takes as its starting point the inquirer's own questions and assumptions.[28]

Figure 9. *The inquiry cycle represents stages in the inquiry process*

Commenting on the work of the Foundation, a report by the Organisation for Economic Cooperation and Development (OECD) stressed: "The emphasis on the scientific method in the 'research circle' shows the initiative's focus on promoting cognitive and problem-solving skills, designed to help children acquire learning skills in various disciplines, the ability to acquire knowledge themselves and sagacity" (OECD, 2012, p. 38).

28 The inquiry cycle method is explained in more detail in Volumes 2 and 4 of the present series (Stiftung Haus der kleinen Forscher, 2011b, 2012a), PDFs of which are available – in German only – for download at www.haus-der-kleinen-forscher.de.

The stages in the inquiry cycle can be related to the first six of the ten quality criteria formulated by Ramseger in his expert report in this volume (see Table 9 below).

Table 9. *Assignment of the quality criteria to stages in the inquiry cycle*

Quality Criterion from the Expert Report		Stage in the Inquiry Cycle
1st criterion	Make nature "question-able"	Ask a question about the natural world
2nd criterion	Incorporate prior knowledge	Collect ideas and assumptions
3rd criterion	Develop experiments together with the children	Try things out and conduct inquiry activities
4th criterion	Practise working in a precise way	Observe and describe
5th criterion	Foster scientific discourse	Discuss results
6th criterion	Use models and representations	Document results

In addition to the general presentation of the inquiry cycle method on a laminated card, in the brochure on the Foundation's pedagogic approach, and in other documents, concrete examples of its implementation can be found on the Foundation's *inquiry cards* (see Figure 10). Each thematic card set comprises an overview card and a number of exploration and inquiry cards. *Exploration cards* invite the children to get to know a topic; the suggestions are aimed at enabling them to gain essential foundational experiences in the domain in question and to experience phenomena as close to their everyday lives as possible. These experiences are an important starting point for further questions that can, in turn, be investigated using the inquiry cycle method. The *inquiry cards* present by way of example more in-depth learning experiences on the topic in question, which are aimed at supporting the teachers and early childhood professionals in embarking on a process of inquiry with the children. When doing so, the children should always be given the opportunity to contribute their own ideas and to test their own assumptions in inquiry activities. Experience shows that the children very soon spontaneously begin to want to try out their own ideas.

LIGHT, COLOURS, VISION – EXPLORING OPTICS

Investigating the phenomenon: **Mixing object colours**

DOES EVERYTHING END UP BROWN?

KLEINE FORSCHER

ASK A QUESTION ABOUT THE NATURAL ENVIRONMENT

When you paint with different colours, the same thing always happens: After a while, the water that you dip your brush in turns a dirty-looking black-brown colour. Does a mixture of different colours always end up brown?

COLLECT IDEAS AND ASSUMPTIONS

After they have finished painting with water colours, draw the children's attention to the water in which they dipped their brushes and to the way it has changed colour. No matter whose paintbrush water the children look at, it always looks black or brown.

What colours did the children use? Do they have any idea why everyone's paintbrush water turned a similar shade of black-brown although they painted many different pictures with lots of different colours? What ideas do the children have: Does it depend on the number of colours that were used, or are some "strong" colours responsible? How would the children like to check this?

TRY THINGS OUT AND CONDUCT INQUIRY ACTIVITIES

Have the children mix different colours on a sheet of paper. Many of them will proceed in a similar way: First they mix two initial colours, for example blue and yellow. Later, they add a third colour, for example red. Then they go back to the initial colours, and so on. They go on mixing colours in this way until they end up with a shade between brown and black.

Depending on their age, the children can also mix colours systematically. In other words, all the children mix the same two colours and compare the resulting mixed colours. Then, they all add the same third colour and compare the result once again, and so on.

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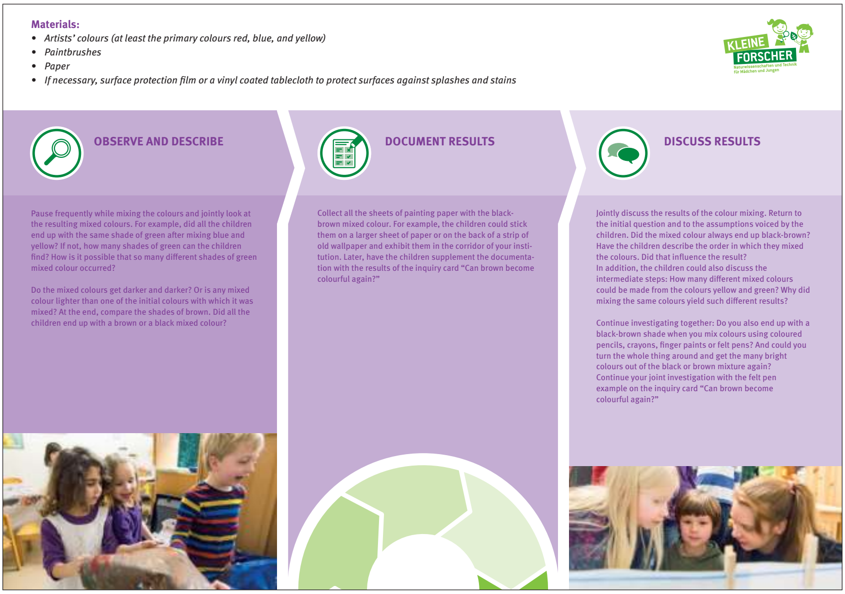

Materials:

- *Artists' colours (at least the primary colours red, blue, and yellow)*
- *Paintbrushes*
- *Paper*
- *If necessary, surface protection film or a vinyl coated tablecloth to protect surfaces against splashes and stains*

KLEINE FORSCHER

OBSERVE AND DESCRIBE

Pause frequently while mixing the colours and jointly look at the resulting mixed colours. For example, did all the children end up with the same shade of green after mixing blue and yellow? If not, how many shades of green can the children find? How is it possible that so many different shades of green mixed colour occurred?

Do the mixed colours get darker and darker? Or is any mixed colour lighter than one of the initial colours with which it was mixed? At the end, compare the shades of brown. Did all the children end up with a brown or a black mixed colour?

DOCUMENT RESULTS

Collect all the sheets of painting paper with the black-brown mixed colour. For example, the children could stick them on a larger sheet of paper or on the back of a strip of old wallpaper and exhibit them in the corridor of your institution. Later, have the children supplement the documentation with the results of the inquiry card "Can brown become colourful again?"

DISCUSS RESULTS

Jointly discuss the results of the colour mixing. Return to the initial question and to the assumptions voiced by the children. Did the mixed colour always end up black-brown? Have the children describe the order in which they mixed the colours. Did that influence the result?
In addition, the children could also discuss the intermediate steps: How many different mixed colours could be made from the colours yellow and green? Why did mixing the same colours yield such different results?

Continue investigating together: Do you also end up with a black-brown shade when you mix colours using coloured pencils, crayons, finger paints or felt pens? And could you turn the whole thing around and get the many bright colours out of the black or brown mixture again?
Continue your joint investigation with the felt pen example on the inquiry card "Can brown become colourful again?"

Figure 10. *Front and back of the inquiry card "Does everything end up brown?" ("Haus der kleinen Forscher" Foundation, 2015b)*

The cyclical process of the inquiry cycle method is aimed at making clear that inquiry does not have a fixed end, but rather that the process can be recommenced again and again with new questions. In addition to the concrete application of the individual elements of the method, this insight can be used to convey an understanding of the inquiry-based approach at the meta-level. In his eighth criterion *(Point out that science is open to change)* Jörg Ramseger describes the provisional nature of scientific explanations and the continuous renewal of knowledge during the inquiry process. Such a dynamic understanding of the nature of science is a long-term goal of the work of the Foundation at the level of the teachers and educators and, in rudimentary form, at the level of primary school children. For this reason, the Foundation's professional development programme is long-term and continuous. Instead of organising sporadic visits to the educational institutions by external experts, or purely providing pedagogical resources, teachers and early childhood professionals are given the opportunity to participate in professional development workshops in their local networks on an ongoing basis, to reflect with colleagues on their work, and to expand their understanding of the nature of science.

1.3 Knowledge of Scientific, Technological, Computer Science, and Mathematical Relationships

In order to be able to support children in understanding relationships between natural phenomena, teachers and early childhood professionals require "(domain-specific) knowledge of science" (see Anders, Hardy, Pauen, Sodian, & Steffensky 2017, in this volume). It is also a medium- and long-term goal of the work of the Foundation that children should grasp basic concepts, and that adults should have the corresponding background knowledge to enable them to do so.

During the inquiry process, children can independently gather experiences with natural phenomena. They gradually discover relationships between phenomena and acquire individual knowledge about scientific, technological, computer science, and mathematical, topics. For example, they realise that liquid water and ice are two states of one and the same substance: If it is very cold, then water freezes to solid ice. However, if it is warm, then solid ice turns to water again.

In order to be able to accompany children in the long term in developing an understanding of scientific, technological, computer science, and mathematical relationships, teachers and early childhood professionals require basic content knowledge of the inquiry topics. Equipped with this knowledge, they feel more confident and can give the children tips and information during collaborative exploration and inquiry activities.

Implementation of these goals in the Foundation's offerings

The Foundation's offerings are aimed at supporting teachers and early childhood professionals in expanding their background knowledge of scientific, technological, computer science, and mathematical relationships over time. Concrete suggestions for exploring phenomena and observing relationships between them can be found on the Foundation's *exploration cards,* which – together with the inquiry cards – are included in each thematic card set (see Figure 11). These ideas are always exemplars – in other words, many other explorations are also possible. The "Interested adults might like to know" section on the exploration cards contains scientific background information on the phenomenon in question.

In addition, the Foundation makes *thematic brochures* available to support teachers and early childhood professionals in conducting inquiry activities with the children in various content domains. Besides practical tips (e.g., for project work), references to education plans and curricula, and developmental psychology prerequisites, the thematic brochures always feature a chapter on the scientific background of the respective content domains (see Figure 12).

LIGHT, COLOURS, VISION – EXPLORING OPTICS

Explore the phenomenon: **How shadows form**

EXPLORING SHADOWS

KLEINE FORSCHER

Where do we encounter it in everyday life?

At dusk, in dimly lit rooms, and on sunny days, children experience shadows as companions. Younger children sometimes find shadows frightening, especially when they cannot assign them to a particular person or object. However, children can also have lots of fun with shadows, for example when creating funny shadow animals or a shadow play.

What it's all about

The children set off in search of shadows and investigate their own shadows and those of different objects. They discover that in order to form, shadows need two things: light and objects or persons to block the light.

What you need

- Flashlights
- A dark room with a light-coloured wall or a large sheet of white cardboard as a projection surface for the shadows
- Desk lamp as light source
- Objects that cast a shadow (e.g., kitchen utensils, plants, toys, etc.)
- Chalk
- Large sheets of white paper (e.g., the back of sheets of wallpaper or sheets of paper in A3 format) and pencils
- Umbrella
- Objects and materials with varying degrees of translucency, for example a book, a wooden board, a cup, a plastic beaker, a glass, greaseproof paper, a clear plastic exercise book cover, a loose-knit woollen scarf, a t-shirt, transparent plastic bags
- Transparent colourful objects, e.g., a coloured bottle, coloured foil

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What does the shadow of the rocking horse look like?

How many arms does the shadow monster have?

When does the shadow stick out its tongue?

SHADOW HUNT (WARM-UP)

On a sunny day, the children search outdoors for their own shadows and the shadows of objects such as bicycles, fences, balls, and plants. A suitable alternative on cloudy days is a dimly lit room where the children shine their flashlights around. Which shadow belongs to which object or to which child?

SHADOW MONSTER

The children can create a funny shadow play in the sun or on an illuminated wall in the darkened room. For example, several children can jointly bring a particularly scary monster to life. Or the children can use various utensils – for example, a cooking pot, a spoon, or a long cardboard tube – to change their silhouettes. Jointly examine the shadows of different objects. What does the shadow of the garden fence in front of the house look like? Or the shadow of a doll or a blade of grass? Outside on the asphalt, the children can use chalk to trace the shadow figures; indoors, they can lay sheets of white paper under the shadows and use a pencil to trace them. Are the other children later able to guess which silhouette belongs to which object?

Look at this: *Shadows are images of objects or living things. They change when the objects or living things change their position. In contrast to a mirror image, a shadow shows only the outline of the object or living thing. That's why it is often not that easy to guess the object or person behind the silhouette.*

Children between the ages of six and ten can use the exploration card for primary school students "Shadow Images" to explore the topic further.

LIGHT, COLOURS, VISION – EXPLORING OPTICS

KLEINE FORSCHER

When can I see my shadow? When does it disappear?

LIGHT AND SHADOW

Pay attention with the children to the light conditions under which shadows can be observed. For example, on an overcast, rainy day search for shadows outdoors with the children. Can they still be found? Have the children shine flashlights around a dimly lit room and observe the shadow images. Then turn the lights on. Where do the children think the shadows have suddenly disappeared to? The children can also examine the shadows under different light conditions: When can they be seen more clearly? When are they fainter?

Look at this: *Shadows occur only where there is light. Once all the lights have been turned off, shadows can no longer be seen in the dark room. Outdoors, the light comes from the sun. If the sun is hidden behind dense clouds, you hardly see any shadows. But when the sun is shining brightly in the sky, you can discover many dark shadows.*

INTERESTED ADULTS MIGHT LIKE TO KNOW

Shadows could be characterised as protected or shielded spaces. Like the area under an umbrella where the rain cannot reach us directly, a shadow is a space that the light from a light source does not reach directly because an object is in the way. Rays of light travel in straight lines, and unlike a jet of water, they cannot avoid an object and go around it. If a ray of light hits an object, the object stops the light by absorbing and reflecting it. As a result a "gap in the light" – or a shadow – forms behind the object. Transparent materials let part of the light pass through them. That's why the shadows cast by transparent objects are brighter than those cast by opaque objects.

SHIELDED

On a sunny day, or underneath a lamp, explore with the children the way shadows form. Compare sunlight (or lamplight) with rain: When used as a parasol, an open umbrella shields you from the light in the same way as it shields you from the rain. Jointly observe the shadow that the umbrella casts on the ground. Search together for other objects that do not let much light pass through them. To do so, have the children shine their flashlights diagonally on the objects in the darkened room. If the sun is shining, the various objects can simply be brought outdoors. Which objects prevent the light from passing through and cast shadows? Which don't? Do the children notice any differences between the shadows? Are there particularly dark, bright, or perhaps even coloured shadows? Why is that?

Look at this: *Shadows form when light hits an object. If the object is made of a particularly dense material – for example, wood, porcelain, or thick plastic – a dark shadow forms. In the case of transparent materials, the shadow looks brighter. If the object is not only transparent but also brightly coloured, coloured shadows may even form.*

Create interesting shadows with coloured foil and glasses.

Figure 11. *Front and back of the exploration card "Exploring Shadows" ("Haus der kleinen Forscher" Foundation, 2015b)*

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Figure 12. *By way of example, the cover page and the table of contents of the brochure Light, Colours, Vision – Exploring Optics (“Haus der kleinen Forscher” Foundation, 2015a)*

The examples of concepts in the domain of water (states of matter, floating and sinking) in the sections by Steffensky and Hardy in Expert Reports A and B in this volume have been incorporated into the further development of the Foundation's pedagogical resources on the focal topic of "Water in Nature and Technology". A card set and a thematic brochure on this topic have been part of the Foundation's portfolio of offerings since 2014 (Stiftung Haus der kleinen Forscher, 2014).

1.4 Pedagogical Strategies for Action

Anders, Hardy, Pauen, Sodian, and Steffensky (2017, in this volume) specify "pedagogical content knowledge and action" as an important goal of science education at the level of the early childhood professionals and the pedagogical staff at after-school centres and primary schools. The strengthening of pedagogical strategies for action and concrete skills for conducting inquiry activities with children is an essential goal of the Foundation's work in further qualifying teachers and educators.

Implementation of this dimension in the Foundation's offerings

In the *continuing professional development offerings* and *pedagogical resources* provided by the Foundation, teachers and early childhood professionals get to know concrete pedagogical action approaches, which they use to support children in their learning processes. Children's typical beliefs about specific phenomena play a role here, as does the design of suitable learning environments for children (see, e.g., the chapters "Through the Eyes of the Child" and "Suggestions for Pedagogic Practice" in the thematic brochures).

One of the main goals of the Foundation's continuing professional development programme is to strengthen pedagogical strategies for action. In addition to concrete practice phases within the reflection phases, the question of practice transfer to work with the children is always addressed. The teachers and early childhood professionals are repeatedly encouraged to see what they experience through the eyes of the children. Following on from this, the question of how the things that they have learnt can be implemented in practical work with the children is jointly addressed using different examples.

Results of the Foundation's Spring Surveys suggest that the goal of strengthening pedagogical knowledge is being achieved. Teachers and early childhood professionals report that their strong sense of competence is due to a large extent to the continuing professional development offerings provided by the programme (Stiftung Haus der kleinen Forscher, 2011b, 2012b). Moreover, the Foundation surveys reveal that teachers and early childhood professionals conduct inquiry activities very regularly with the children, and thus implement in their pedagogic action the suggestions and ideas they receive (in 75 percent of educational institutions, collaborative inquiry takes place at least once a week; in 45 percent of cases, it even takes place several times a week or daily; see Stiftung Haus der kleinen Forscher, 2012b).

In addition to the professional development programme, the pedagogical resources provided by the Foundation (e.g., the thematic brochures and the exploration and inquiry cards) are a rich pool of ideas, suggestions, and tips about how scientific, technological, computer science, and mathematical topics can be integrated – in collaboration with the children – into everyday life at the educational institutions. The current edition of the brochure Pedagogic Approach of the “Haus der kleinen Forscher” Foundation – A Guide to Facilitating Learning in Science, Mathematics and Technology (“Haus der kleinen Forscher” Foundation, 2015c), which the teachers and early childhood professionals receive when they participate in the first continuing professional development course, features concrete examples of implementing the pedagogical goals of the education initiative. These examples are drawn from the topic “Investigating Water,” and the aim is to make it easier for teachers and early childhood professionals to transfer the concepts to everyday practice.

Besides background information, the Foundation’s thematic brochures provide many practical ideas for collaborative inquiry with the children in various content domains. These brochures are distributed to attendees of the respective follow-up workshops, and, like all other pedagogic resources, they are available as PDFs on the Foundation website. One focus is project work, for example in the brochure *Light, Colours, Vision – Exploring Optics* (“Haus der kleinen Forscher” Foundation, 2015a). Finding answers to questions about nature takes time. Science education processes should therefore take place over long phases of inquiry, as is the case with projects. This connects up with Ramseger’s tenth quality criterion: “Good science teaching enables children to experience that they can solve a question about nature by means of their own thinking.”

The magazine *Forscht mit!,* which the Foundation publishes four times a year, and which is addressed to teachers and early childhood professionals, provides information about the “Haus der kleinen Forscher” programme, while at the same time taking up practical topics from everyday life. Moreover, it gives teachers and educators ideas for projects, and it features best practice reports from other educational institutions and networks. In each issue, the teachers and educators receive practical tips and suggestions for inquiry activities designed to find answers to questions about everyday natural phenomena together with the children. The main aim of the magazine is to motivate teachers, early childhood professionals, and children to engage in inquiry activities in their everyday lives.

1.5 Experience of Self-Efficacy and Self-Confidence as a Facilitator of Learning

Strengthening children's and adults' sense of self-efficacy is the lynchpin of the Foundation's work. Anders, Hardy, Pauen, Sodian, and Steffensky (2017, in this volume) recommend "self-efficacy" as a goal of science education both at the level of the children and of the pedagogical staff at early childhood education and care centres, after-school centres, and primary schools.

Ideally, children feel increasingly confident when conducting inquiry activities, communicating and finding answers to their own questions, and solving any problems that may occur along the way. In their engagement with science, technology, computer science, and mathematics, they develop a sense of self-efficacy ("Yes, I can!"). This strengthening of the children's sense of competence and self-confidence is a key goal of the "Haus der kleinen Forscher" initiative. The gain in self-confidence and inner strength is of great importance when it comes to reacting flexibly to the demands of changing situations and mastering circumstances in life that are difficult or filled with changes – for example, the transition from early childhood education and care to primary school. Current research confirms that children who are self-confident and strong cope much better with the changes and stresses of everyday life (i.e., are more resilient) than children who lack this confidence in their own competencies (see Rutter, 2000; Werner, 2000).

Implementation of this goal in the Foundation's offerings

With the help of exchanges during the *continuing professional development workshops,* the *pedagogical resources* provided by the Foundation, and especially collaborative inquiry with children in practice, the teachers and early childhood professionals can experience self-confidence in relation to facilitating children's learning processes in the domains of science, technology, computer science, and mathematics. As their understanding of fundamental substantive relationships, the scientific process, and pedagogical action strategies increases, so, too, does their perceived self-efficacy in relation to the design and implementation of science learning processes. They experience themselves as competent. This is confirmed by the results of the Foundation's Spring Surveys of teachers and early childhood professionals, among others. These surveys reveal a clear correlation between the duration of teachers' and educators' participation in the Foundation's education initiative and their perceived self-efficacy with regard to collaborative inquiry with children. This sense of competence appears to increase as a function of the number of education initiative workshops attended, the duration of participation in the initiative, and the certification status of the respondent's educational institution (Stiftung Haus der kleinen Forscher, 2013a). Moreover, the teachers and early childhood professionals report that they attribute their competence in implementing science, technology, and mathematics activities with the children mainly to their attendance at the workshops (Stiftung Haus der kleinen Forscher, 2013a).

An increased sense of competence can also generally strengthen teachers' and educators' confidence in their own abilities. For this reason, one major focus of the professional development programme and the philosophy of the "Haus der kleinen Forscher" Foundation is to enable participants to repeatedly experience their own competence and to strengthen their self-confidence.

Motivated adults with a strong sense of competence and self-confidence in relation to scientific inquiry can offer children the best prerequisites for experiencing "that they can solve a question about nature by means of their own thinking" (Ramseger, in this volume, p. 198). Moreover, by so doing, they facilitate an increase in perceived self-efficacy in the children, which Ramseger emphasises as the tenth, and most important, quality criterion for good science teaching.

This goal is of supreme importance to the Foundation. By engaging in inquiry activities, both children and adults should experience a sense of self-efficacy ("Yes, I can!"). Hence, this goal has been intentionally placed in the centre of Figure 8, "Goals of the Foundation's work at the level of the children and of the teachers and early childhood professionals".

1.6 Professional Role Perception and Self-Concept

"Aspects of the professional role perception and self-concept" and "domain-specific epistemological beliefs" are further long-term goals of the Foundation's work at the level of the teachers and early childhood professionals that are recommended by Anders, Hardy, Pauen, Sodian, and Steffensky (2017, in this volume).

In order for teachers and early childhood professionals to be able to master well the increased demands (e.g., the great diversity of tasks) that they face in pre-primary, scholastic, and extracurricular education, it is important that (a) they reflect on their role in educational processes, and (b) they critically and constructively assess individual teaching-learning processes, pedagogical concepts, and their own pedagogic action. In addition, their attitude to engaging in scientific inquiry with the children, and their collaboration with colleagues also play an important role.

Implementation of this goal in the Foundation's offerings

The development of teachers' and educators' professionalism is a lifelong process that is dependent on their willingness to undergo continuing professional development and to keep their content knowledge and abilities up to date. The continuing professional development programme of the "Haus der kleinen Forscher" initiative supports them in this process.

The experiences that the Foundation has gained in recent years from around 15,000 workshops conducted throughout the country, from various accompanying research studies,[29] and from intensive professional discourse have led to the continuous further development of its offerings. The substantive focus of the workshops and the pedagogical resources has broadened to include not only basic scientific and technological competencies and the provision of a portfolio of suggestions for inquiry activities but also a greater orientation towards pedagogical content knowledge aspects, interaction with children, reflection on attitudes when engaging in scientific inquiry, and the orientation towards basic mathematical and computer science competencies.

The permanent anchoring of a "spirit of inquiry" in the everyday lifeworld of the children and their facilitators of learning calls not only for basic content knowledge but also for an inquiry-based pedagogical attitude and for action competence. This means (a) strengthening children's inquisitiveness and their desire to engage in scientific inquiry not only through inquiry activities but also, and in particular, through discussions about assumptions and observations and a dialogic approach; and (b) encouraging children to get to the bottom of phenomena and confusing observations, to make comparisons, and to develop hypotheses. Ramseger emphasises this form of "fostering scientific discourse" in his fifth quality criterion, which addresses the special importance of talking about, and reflecting on, assumptions, observations, and findings, and which regards science education as a "specific form of language teaching" (p. 193 in this volume).

The Foundation endeavours to take increasing account of this ambitious goal in its offerings. *Discourse* is an elementary component of scientific exploration and inquiry – and especially of the reflective phases thereof. Language learning can be facilitated during inquiry activities, especially by explicitly encouraging children to express their assumptions, describe their observations, name the materials they use, and formulate their own explanations. In collaboration with *Sprachreich,* a concept for integrating the promotion of language skills into everyday life that was developed by the German Federal Association of Speech Therapists (Deutscher Bundesverband für Logopädie e.V., dbl), the Foundation has created a continuing professional development module on the topic of carbon dioxide, with the pedagogic focus "Common Basic Principles of the Promotion of

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29 See the series Scientific Studies on the Work of the "Haus der kleinen Forscher" Foundation (Wissenschaftliche Untersuchungen zur Arbeit der Stiftung "Haus der kleinen Forscher"). All volumes are available for download as PDFs at www.haus-der-kleinen-forscher.de. However, only the present volume (Volume 5) is available also in English.

Language Skills and the Facilitation of Children's Learning During Inquiry Activities". The corresponding thematic brochure *Sprudelgas und andere Stoffe – mit Kita- und Grundschulkindern Chemie entdecken und dabei die sprachliche Entwicklung unterstützen* (Carbon Dioxide and Other Substances – Exploring Chemistry with Children Between the Ages of Three and Ten and Supporting Language Development in the Process; Stiftung Haus der kleinen Forscher, 2013b; available only in German) contains various examples of how language learning can be integrated into scientific inquiry activities.

Ramseger's seventh quality criterion, which is aimed at the historical and social embedding of science teaching, is also an interesting suggestion for the Foundation. Social aspects, for example the changing role of, and demands on, teachers and educators, are repeatedly addressed during the reflective phases of the Foundation's professional development workshops. However, the historical embedding of phenomena, and their investigation at a historical level, has hardly been addressed to date, and it could be taken into account more in the further development of the Foundation's formats.

2. Contribution of the Foundation to Professionalisation in Early Education in the Educational Domains of Science, Technology, Computer Science, and Mathematics

The professionalisation of teachers and early childhood professionals – not only in the domains of science, technology, computer science, and mathematics education – is a topical issue in the current professional debate. For example, the Aktionsrat Bildung (Action Committee on Education) produced a report entitled *Professionalisierung in der Frühpädagogik* (Professionalisation in Early Education; Aktionsrat Bildung, 2012), which is aimed at a critical appraisal of the current training situation in the domain of early education. On the basis of the latest research findings, the report discusses the influence of attendance at, and the quality of, early childhood education institutions on children's cognitive and social development. Building on this, the authors make concrete recommendations for action.

The report underlines that the quality of early education institutions is determined mainly by the level of training and the competencies of the pedagogical staff. It describes target competencies that should be achieved at the level of the early childhood professionals, and distinguishes between:

(1) professional knowledge (i.e., domain-specific content knowledge, pedagogical content knowledge, and general pedagogical knowledge)

(2) pedagogical orientations and attitudes

(3) motivational and emotional aspects and self-regulatory abilities

(4) aspects of professional role perception and self-concept (i.e., reflective ability, openness, an inquiring attitude, development of professionalism, collaborative ability)

These dimensions reflect the current state of profession-related research and are consistent, in principle, with the domain-specific goals of science education described in this volume.

Although society's expectations of what early education institutions should deliver have increased clearly in recent years, this has had hardly any consequences to date for the training situation in this domain. The Aktionsrat Bildung (Action Committee on Education) therefore recommended that, for the professionalisation of early childhood educators, a coordinated overall concept for education, training, and continuing professional development should be developed at the different levels. It stressed that the focus should not be on individual education and training programmes at university of applied sciences or university level but rather on professionalising the entire labour potential of early childhood educators in an overall concept (Aktionsrat Bildung, 2012, p. 70).

Against the background of the current training situation in the domain of early STEM education, it should be taken into account that the goals described by Anders et al. and Ramseger in this volume and by the Aktionsrat Bildung represent a competence ideal. Much work still needs to be done before this ideal can be realised. Ramseger makes this very clear in relation to the implementation of high-quality science teaching when he notes in his expert report in this volume: "It is obvious that the simultaneous consideration of all ten criteria is an extremely demanding requirement that will succeed with children of pre-primary and primary school age only in extremely felicitous cases" (p. 200). Indeed, according to Ramseger:

> *Teachers and educators can presumably consider themselves lucky if they succeed in realising at least three or four of the criteria in a concrete teaching project. However, for a successful process of science education, it probably suffices to realise one or other of the criteria at different times, because domain-specific competencies and general education do not develop in one-off sessions but rather in a long-term process during children's passage through the entire education system (p. 200).*

With its nationwide continuing professional development programme, the "Haus der kleinen Forscher" Foundation wishes to support teachers and early childhood professionals in this regard, and to accompany them on their path to further qualification. The focus is on (a) supporting strategies for professional action in the domains of science, technology, computer science, and mathematics education; and (b) the professionalisation of teachers and early childhood professionals in order to enable them to fulfil their educational mission in these domains.

3. Further Development of Process Quality Through the Foundation's Certification Procedure

Besides the above-mentioned person-related offerings and continuing professional development formats, the Foundation also wishes to promote quality development at the level of the educational institutions. To this end, it has developed a certification procedure. As an instrument for quality development, and in order to value and make outwardly visible the institutions' ongoing commitment to the Foundation's education initiative, early childhood education and care centres, after-school centres, and primary schools can apply for official certification as a "Little Scientists' House" (see Figure 13).[30]

Figure 13. *Cover page of the certification brochure* Zertifizierung für Kitas, Horte und Grundschulen. So wird Ihre Einrichtung ein "Haus der kleinen Forscher" *(Certification for Early Childhood Education and Care Centres, After-School Centres, and Primary Schools. How your institution can become a "Little Scientists' House") (Stiftung Haus der kleinen Forscher, 2017b) and the certification plaque*

The Foundation decides on the award of certification in a standardised procedure that was developed in the style of the German Kindergarten Seal of Quality *(Deutsches Kindergarten Gütesiegel)* in collaboration with a team of external experts (Dr Yvonne Anders, Dr Christa Preissing, Prof. Dr Ursula Rabe-Kleberg, Prof.

30 See http://www.haus-der-kleinen-forscher.de/home/practice/certification/.

Dr Wolfgang Tietze). Within the framework of the certification procedure, both the institution management and the teachers and educators must answer questions on specific domains to which specific evaluation criteria are applied. The evaluation criteria specify on the basis of four quality dimensions what a "Little Scientists' House" should look like from the inside: *Quality of orientation* includes questions about the integration of science, technology, computer science, or mathematics education content into the pedagogical concept of the institution. *Structural quality* measures the extent to which material is available for inquiry activities, while *process quality* describes the way in which scientific inquiry is conducted at the institution. The fourth quality dimension measures *external openness* – that is, all activities that bring outsiders into the everyday life of the institution.[31]

The various quality dimensions are assigned different weights in the evaluation process. Structural quality characteristics are weighted with 30 percent; the aspects *external openness* and *quality of orientation* are each weighted with 15 percent. *Process quality* is deliberately assigned the greatest importance, and is weighted with 40 percent. It describes the "How" aspects: How are inquiry activities conducted in the institution? How do the pedagogues facilitate the children's learning? What is important here is that the children and the adults should form a learning community and develop further together.

The certification procedure thus serves the further development of educational institutions at the system level, thereby supporting them in taking further steps towards meeting the criteria for the design and implementation of learning environments and for the process of science teaching recommended by Ramseger and by Anders et al. in this volume. The certification is thus geared towards continuity and processuality. It is valid for two years, and can be extended only by submitting a new application.[32] The Foundation's certification procedure for early childhood education and care centres has already been scientifically validated (see Volume 6 of the present series; Anders & Ballaschk, 2014).

With the help of the person-related formats and offerings for strengthening individual competencies described above, and of the certification procedure that targets the process level, the Foundation wishes to fulfil its mission in the long term (for the full version of the Foundation's mission statement, see the introduction to this volume, p. 18). The various goals and measures described above thus serve to achieve the main goals of the Foundation's work, which are derived from its mission:

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31 *Regarding the terminology, see also Tietze and Viernickel (2007).*

32 *The brochure* Zertifizierung für Kitas, Horte und Grundschulen. So wird Ihre Einrichtung ein "Haus der kleinen Forscher" *(Certification for Early Childhood Education and Care Centres, After-School Centres, and Primary Schools. How Your Institution Can Become a "Little Scientists' House"), which is available in German only, can be downloaded as a PDF at www.haus-der-kleinen-forscher.de.*

Excerpt from the Mission Statement of the "Haus der kleinen Forscher" Foundation

The mission of the "Haus der kleinen Forscher" Foundation is to ...

- promote a questioning, inquiring attitude in children;
- give children the opportunity to discover at a young age their own talents and potential in the domains of science, technology, computer science, and mathematics; and
- lay the foundations for reflective engagement with technological and social changes in the sense of sustainable development.

4. Outlook: Measurement of the Outcomes of Science Education

Ramseger's ninth quality criterion focuses on the learning gains that science teaching should achieve. With its offerings, the Foundation also aims to achieve competence gains in the long term at the level of the teachers and early childhood professionals and of the children (see objectives in Figure 8).[33]

Measuring learning outcomes is a methodological and scientific challenge that the Foundation takes up within the framework of the external accompanying scientific research on its work, which is aimed at (a) gaining insights into the way in which science education opportunities influence children's learning processes, and (b) determining the substantive learning and development goals that can actually be achieved through early education offerings such as the "Haus der kleinen Forscher" initiative. The model of the goals of science education presented in this volume constitutes the theoretical and empirical basis for such outcome-oriented accompanying scientific research.

Within the framework of this accompanying research, the Foundation is co-funding two interdisciplinary studies of around three years' duration (2013–2017), which are investigating the outcomes of science education at the level of the early childhood professionals and the children. The aim of the first research project, EASI Science (Early Steps Into Science, spokesperson: Prof. Dr Mirjam Steffensky, IPN Kiel), which is being jointly funded by the "Haus der kleinen Forscher" Foundation and the German Federal Ministry of Education and Research, is to gain insight into the outcomes of science education in early childhood education and care centres. The second research project, EASI Science-L (Early Steps Into Science and Literacy, spokesperson: Prof. Dr Astrid Rank, University of Regensburg), which is being jointly funded by the "Haus der kleinen Forscher" Foundation, the Baden-Württemberg Stiftung, and the Siemens Stiftung, is investigating the language learning outcomes and the quality of interaction in the context of science learning opportunities. Both studies aim to help close the gap in outcome research on early science education and to contribute to a better general understanding of early education and interaction processes – also, and in particular, in relation to facilitating language learning during scientific inquiry activities. The results of the EASI Science and EASI Science-L studies will be published in 2018

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33 *The DVD* Kinder erforschen Energie und Strom *(Children investigate energy and electricity) features high-quality and competence-oriented real classroom situations. The films on the DVD address learning about energy at primary school and quality criteria for science teaching (Stiftung Haus der kleinen Forscher, Krümmel, & Ramseger 2015).*

in the tenth volume of the present series (Stiftung Haus der kleinen Forscher, in preparation).

Building on the knowledge gained from these and other similar projects, the non-profit “Haus der kleinen Forscher” Foundation, which sees itself as a learning organisation, will continuously expand and optimise its offerings in order to support both teachers and early childhood professionals and children in their development in the best possible way.

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Introduction –

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Conclusion and Outlook – How the "Haus der kleinen Forscher" Foundation Uses These Findings –

"Haus der kleinen Forscher" Foundation

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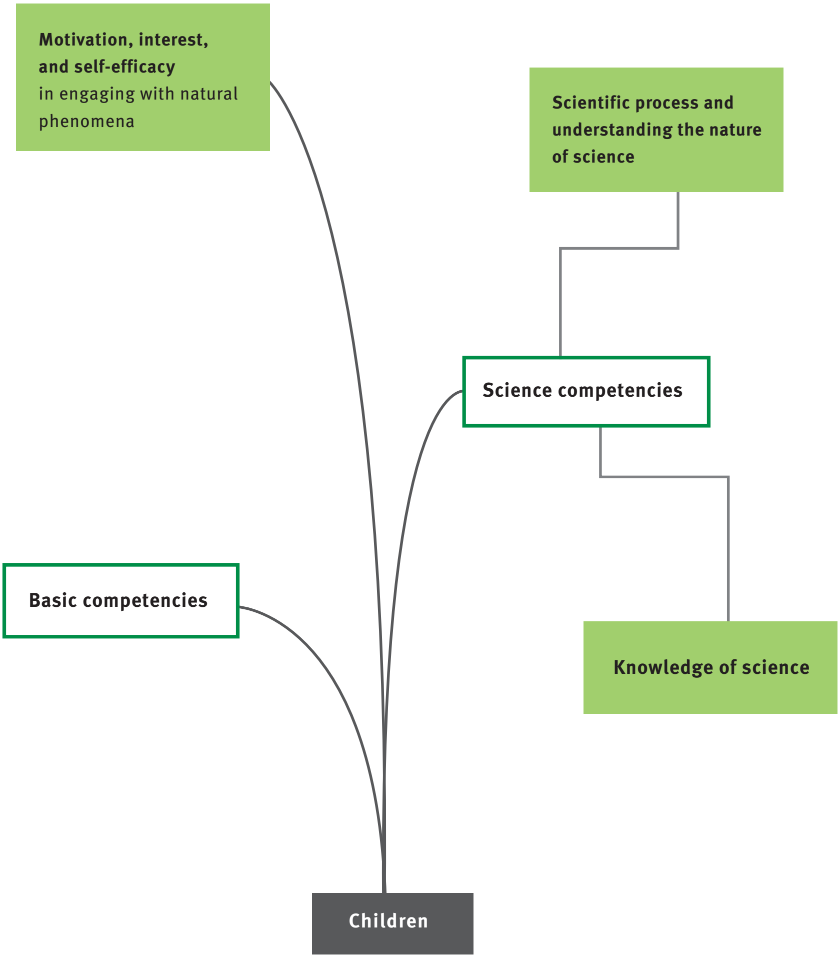
Appendix I

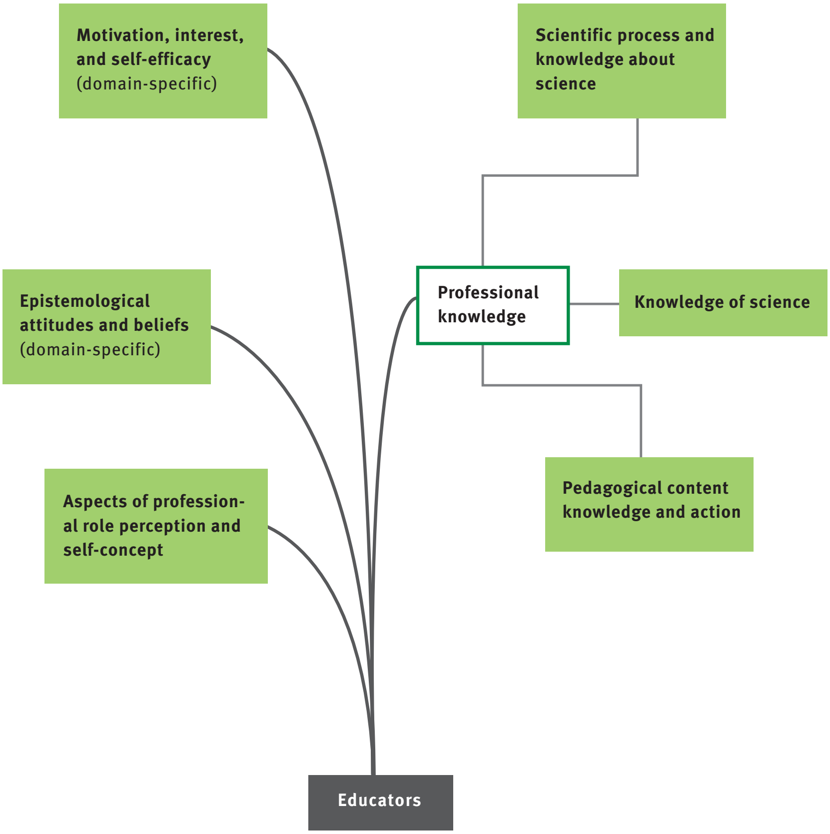
Goals of science education for children aged between three and ten years



Source: "Haus der kleinen Forscher" Foundation; following Anders, Hardy, Pauen, Sodian, & Steffensky, In "Haus der kleinen Forscher" Foundation (Ed.) (2017), *Early Science Education – Goals and Process-Related Quality Criteria for Science Teaching. Scientific Studies on the Work of the "Haus der kleinen Forscher" Foundation (Vol. 5)*. Opladen, Berlin, Toronto: Verlag Barbara Budrich.

Appendix II

Goals of science education for teachers and educators of children between the ages of three and ten years



Source: "Haus der kleinen Forscher" Foundation; following Anders, Hardy, Pauen, Sodian, & Steffensky, In "Haus der kleinen Forscher" Foundation (Ed.) (2017), *Early Science Education – Goals and Process-Related Quality Criteria for Science Teaching. Scientific Studies on the Work of the "Haus der kleinen Forscher" Foundation (Vol. 5)*. Opladen, Berlin, Toronto: Verlag Barbara Budrich.

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“Haus der kleinen Forscher” Foundation

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