Prof. Dr. Lydia Murmann, University of Hamburg, Germany
murmann@erzwiss.uni-hamburg.de

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Exploring natural phenomena

Abstract

Pre- and elementary school children are increasingly introduced to science early. They are encouraged to follow own interests and are confronted with prepared material, experimental tasks and offers.

Between exploring natural phenomena playfully and systematic scientific experimentation lies a wide field of exploratory, incidental, and knowledgeable hands-on possibilities. The more sophisticated programmes are in terms of introducing "science" the more they tend to focus on experimentation solely as a means of testing hypotheses, i.e. ideas derived from theory. This is not what children (can) do, when they explore unknown phenomena. But, neither is it what scientists do when they enter a field of research of which they have little knowledge so far. According to modern views of science (e.g. Rheinberger 2006), exploratory (as opposed to theory-driven) experimentation is common in laboratories and fundamentally necessary for the development of theory. This is a content related reason on top of pedagogical reasons to focus on exploration in its own right, particularly on the elementary and pre-school level.

Therefore it seems worthwhile to understand the variation of motives as well as the variation of strategies that scientists and young children (age 6-8 yrs) apply when they "explore" natural phenomena. Categories of description for motives followed by children during hands-on activities have already been developed. They range from "undirected play/aesthetic involvement" to "understanding causal relationships". The variation of strategies applied is being focused on now. Both will be presented and compared with incidents of scientific exploration in order to derive didactical orientation.

1. Introduction

Objectives of science education have been under revision in Germany for a couple of years. The development of scientific content knowledge and conceptual understanding were unchallenged goals of educational efforts in science classes for a long time. The implicit assumption is that science knowledge leads to knowledgeable judgement and the ability to practically apply it. Lately, ideas about intended outcomes of science education classes in Germany shifted. Teachers are now asked explicitly to focus on their pupils' "competencies", meaning abilities, capabilities, and also motivational and volitional readiness to deal with tasks. Due to the federal structure of the educational system, curricula have been differing considerably across the country. School curricula are still designed separately by 16 local governments, but recently a system of national standards for curriculum developers was designed for various subjects. So far, national standards for grade 4[1] have only been formulated for German and Math, there are no legal standards for elementary science education. Nonetheless there are national standards, for instance, for intended outcomes of physics classes in grade 10. The physics standards are divided in four fields: 1. content knowledge / conceptual understanding ("Fachwissen") is related to theoretical knowledge and concepts; 2. Gaining knowledge ("Erkenntnisgewinnung") is closely related to observation and experimentation, 3. Communication ("Kommunikation") focuses on the ability to communicate knowledge, present evidence, and discuss ideas; 4. Judgement ("Bewertung") aims at the competency to use scientific knowledge for decision-making as well as the ability to discern and acknowledge limits of scientific reasoning for personal and political judgement in complex situations.

Obviously discourse about scientific literacy, as well as discourse about output-criteria has reached the administrative level. And the administrative action is accompanied by a scientific effort to discern specific competencies and to model the development of competencies.

[1] Grade four marks a point of selective measures, because in general, elementary school ends at this level and children are distributed to different types of secondary schools.

Our research is concerned with modelling children's competencies to gain knowledge about natural phenomena, particularly within the domain of physics. We wish to understand motives and strategies of children's explorations of phenomena, in order to differentiate ways of going about the task *to find out more about a phenomenon experimentally.*
The study is therefore closely related to area 2, "Gaining knowledge", of the national physics standards (grade 10).

2. Different types of "experiment"

At least two different types of scientific experimentation can be discerned. One represents the standard view of experimentation, that is, to conduct experiments in order to test hypotheses. In these cases a hypothesis founded in a given theory is formulated and an experimental setup is designed to prove expectations right or wrong. The outcome of the experiment is decisive for theoretical conclusions; either the underlying theory is supported or it needs revision and possibly new questions arise. A prerequisite for this type of experimentation is an existing theory that can be transformed into a testable expectation; otherwise it would not be adequate to speak of a hypothesis but rather of a guess. The other type of experimentation aims at generating theory rather than testing it. This type, exploratory experimentation, is not an alternative but a strategy taken up by scientists for different reasons and under different circumstances than theory driven experimentation.
According to Steinle (2005), exploratory experimentation in the natural sciences aims at formulating regularities, correlations, and laws. Conclusions may include "restructuring of basic categories, concepts, facts, and means of representation". Laboratory procedures for exploratory purposes typically include a broad and systematic variation of many experimental parameters and provide the experimenter with experience and detailed knowledge about observable processes. Experiments designed to test or refine a stable theory, on the contrary, typically need a specified and optimized apparatus for best performance concerning a narrow question.
Modern views of laboratory work and contemporary understandings of experimentation have challenged the standard view, implying that scientists do not primarily experiment in order to test theory against reality. While the standard view may or may not be true for psychological experiments; it certainly was not the main activity that led to the body of knowledge produced by the natural sciences.
The primary indicator for the suitability of either exploratory or theory driven experimentation lies in the epistemic preconditions of the person conducting the experiment. A lack of theory and experience clearly indicates a necessity for *explorations*.
Remarkably, exploratory experimentation in science classes is not respected for scientific but for educational reasons. It is considered time consuming and of relatively little impact in terms of learning science. Still, it can easily be argued, that learning science should include learning *about* science as a human endeavour (Höttecke 2007). Systematic *explorations* can convey the idea of theory emerging from experience, while testing hypotheses by experimenting can convey criteria for the necessity to revise theories.
Concerning actual scientific work in laboratories, Rheinberger states with reference to Ludwik Fleck (1980/1935): "a scientist usually does not deal with isolated experiments that are supposed to test one, and only the one, theory but with experimental arrangements he designed to allow him to generate knowledge he did not have before." (Rheinberger 2006, 24-25) A clear distinction between testing hypotheses and exploratory experimentation does not necessarily reflect experimental reality both are idealised ideas marking two extremes of experimental possibilities.
Typically, and for good reasons, experiments in science classes are also used to illustrate theory by demonstrating processes and effects. In these cases experiments typically assume a

function of convincing students of certain ideas and of relating theory to practical incidents. This kind of "experiment" represents a third type; it is a means of communication.

2. The research question

We believe that exploratory skills with respect to natural phenomena are subject to learning processes, and we expect that the development of strategies can be supported. Unfortunately, competencies in experimentation have so far been modelled in close relation to the standard view of experimentation. This implies a focus on reasoning skills, namely the ability "to generate precise hypotheses, design and implement efficient experiments, and analyze data systematically" (Siegler & Liebert 1975). Findings from cognitive psychology that are concerned with children's ability to coordinate theory and evidence in general refer to the standard view of experimentation (for an overview see Zimmerman 2007). Hammann (2004) developed a model for experimentation competencies for pupils between 5th and 10th grade. He analysed pupils' performance with respect to various experimental tasks and categorised competencies. Hammann also referred to the learning objectives mentioned above (formulation of hypotheses, design and implementation of experiments and data analysis): Unsurprisingly the model has little to say about young children's competencies since they were categorised as "confounding variables" and "unable to formulate testable hypotheses".
We strongly believe that exploratory activities in elementary school should clearly be preferred against experimental activities that are closely related to the standard view (Murmann 2007). Therefore we are interested in the development of competencies related to self-guided *exploration*.
The ability to conduct self-guided experimentation is necessarily accompanied by motives and strategies, no matter, whether the hands-on activities are theory driven or exploratory. Figure 1 illustrates the logic behind the idea to grasp motives and strategies in order to model competencies: from a research point of view we cannot decide whether a learner conducting hands-on activities is oriented towards gaining knowledge or towards something else. Therefore, the first question we pose is concerned with motives; we wish to understand what the observed individual activities aim at and what kinds of actions children take to reach their goals.

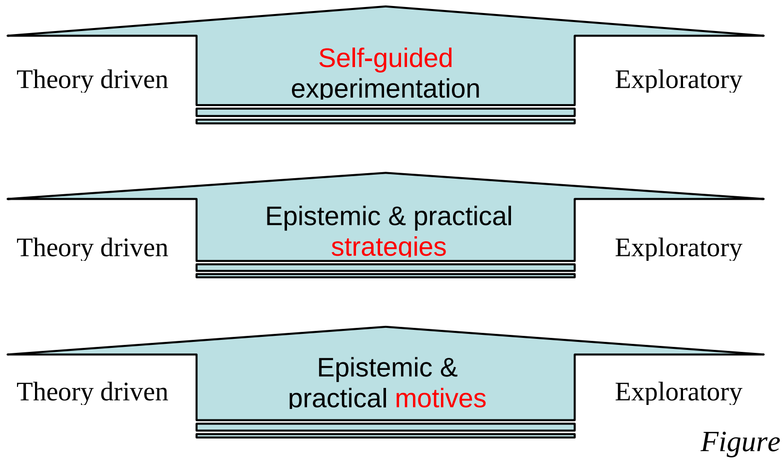

Figure 1

We focus on children's approaches while they deal with the task to *find out more about a given and unexpected phenomenon*, since we believe that their way of tackling an exploratory task offers information about their conceptions of ways to gain knowledge from experimentation and their ability to draw arguable ideas from experience. This is clearly not the same as formulating hypotheses, but a creative conceptual enterprise, leading to personal ideas about the phenomenon at hand. A specific exploratory activity may or may not be suited to provide meaningful experience; this is critically dependent on its relatedness to personal prior experience, corresponding knowledge and interest. So, naturally, strategies may not only differ between individuals but also with respect to the concrete situation, i.e. the phenomenon at hand. In terms of competencies we expect to model children's ability to gain reliable information and sound experience about a given phenomenon that is interesting, surprising or irritating to them.

3. Design of the study

In order to understand children's motives and exploratory strategies we designed a setting, to initiate and observe explorations of natural phenomena. All phenomena are related to the domain of physics.

Groups of four children, each, from a second grade classroom (age 6-8 yrs) took part in a series of learning sessions. All sessions followed the same scheme: 1) Presentation of a phenomenon intended to draw children's curiosity; 2) An invitation to find out more about the phenomenon by exploring it hands-on (exploration & speculation); 3) A conversation about findings and ideas; 4) follow-up explorations and experiments considering the ideas mentioned. Each session took between 45 and 60 minutes, phase 2 was terminated when children's interest in further explorations noticeably decreased which was usually the case after about 20 minutes.

A total of three different phenomena was used in different sessions: 1) a table tennis ball floating on water was covered with a glass held upside down and pressed down to the ground of an aquarium where it kept floating within the glass; 2) two coloured liquids were layered on top of one another; 3) a container filled with water, with one hole on the bottom and another on top was emptied stepwise by covering and uncovering the top hole with a thumb. The interviewer did not provide children with ideas, but tried to get children involved in thinking about the phenomenon, showed interest, encouraged any kind of exploration, offered additional material and acted as a moderator if needed. Also, the children were not restricted in case they turned to playful activities or activities not dealing with the phenomenon that had been presented at first.

Eight sessions, two per group, were videotaped and analysed phenomenographically in order to identify different motives and strategies that lend orientation to the activities. Instructions that the children were asked to follow were kept at a minimum. The intention was simply to provide them with a frame that should confront them with something interesting and invite them to investigate the situation further by getting involved in hands-on activities and conversation.

4. Observations during phase two & focus

After the respective phenomenon had been presented, children were asked to voice impressions and to comment on aspects, they considered surprising or worth mentioning. Apart from the phenomenon presented, a number of unintended side-effects were noticed and mentioned, for instance optical effects (distorted impressions of items behind glass or in water, reflections etc.). This first phase of presentation and conversation about what the children found peculiar, usually did not exceed 10 minutes. No matter whether they focused on what had been intended to draw their attention or not, they were then invited to find out more about the aspects mentioned.

All children got involved in hands-on activities; some were noticeably unsure of what to do at first, others enjoyed to indulge in exploration of material and possibilities. We observed instances of quiet exploration, instances of excited interaction, and fights about material, as well as pupils who commented on nearly everything they did and noticed or tried to draw their neighbours' and the supervisor's attention to their pursuits, pupils copying the activities of others, and pupils who apparently undisturbed and quietly followed their own ideas.

Our interest in pupils' motives is not comprehensive. While obviously a considerable amount of children's activities is motivated socially (e.g. to get others involved in ones own project, to cooperate, to impress or annoy others, etc.), we decided to focus on motives and intentions associated to the relationship between individuals and the phenomena they dealt with.

5. Results

Four Categories of description, each representing different orientations while dealing with the task were developed.

A. Fiddling around and Play

The activity means to do something with the material, irrespective of characteristics of the phenomenon mentioned before. This can be realised either in a way of entertaining play or in a way of aimless or indiscriminate and variable activities.

B. Figure out "how" something works – produce an effect

The activity means to find out how the phenomenon can be reproduced, whether it can be reproduced by me, so that I know how to do it (best). This can be done playfully. Afterwards I know how to produce the effect and once I know it I'm done.

C. Getting to know "why" something works

The activity means to reproduce the phenomenon, to explore its limits, for instance with different items, i.e. to identify conditions and to figure out under which circumstances the phenomenon cannot be reproduced. Afterwards I know conditions for the effect to come about and I know conditions under which the effect will not come about. I can explain, what needs to be done in order to produce the effect and I can name reasons (Establishing if-then-regularities).

D. Getting to understand "why" something works

The activity means to gain an understanding about reasons for the effect to occur. I want to be able to argue why the effect comes about, so I can explain causal coherences. (Developing "why-ideas").

6. Comments on the categories of description

Activities that were categorised under A did either appear incoherent or indifferent towards any of the aspects mentioned in the conversation before, respectively. Fiddling about or Play means to use the material for completely different purposes than presented before without drawing a connection or to do things with additional material, seemingly aimless. For instance a small group of children happily indulged into filling water from the aquarium into a second container, ignoring the table tennis ball altogether. In this case, children displayed indifference towards exploring any kind of effects.

Activities that were categorised under B included reproduction of the phenomenon observed before or production of other effects (in many cases these were repeated a couple of times). For instance finding perfect ways to layer liquids by using spoons or straws were compared. Children tended to comment on effects that were related and showed one another "how it works". Play was very common in terms of a playful interaction with effects being focused on. Some children tried to imitate activities of others in order to produce same or similar results. After having achieved this goal, interest in the activity and/or the phenomenon vanished. Children's awareness was focused on realising effects.

Activities that were categorised under C were sometimes commented by children with, "when I …, then …" or "See? Because I did it this way, it worked that way." In short: children's awareness was directed towards conditions and variations. They argued relationships and correlations between their own actions and variable effects. Ideas did not leave the reference level of observable effects and conducted activities, except in cases of associations with similar experiences, which were then told.

Activities that were categorised under D included active explanation in terms of thinking about reasons and redirection of activities with reference to ideas about causal relationships. In a few instances hypotheses were formulated and tested. For instance one girl argued that an effect occurred due to the water temperature. She then fetched an electric kettle to heat water and repeated her activity.

7. Discussion

Motives and strategies can only be discerned analytically. When interpreting children's activities the detection of motives and strategies is dialectically intertwined: Only if activities appear to be targeted or satisfactory to the person conducting them do we presume that an objective is pursued. In other words, we already perceive a strategy when we draw conclusions about motives from observed action. On the other hand, we can only understand in which sense the observed activity reflects a strategy against the background of imputed motives.

The view that the categories describe orientations of exploration that are related to competencies may well be challenged. First, we can not eliminate the possibility that we observe differences in interest and motivation, while we try to discern exploratory motives and strategies with respect to competencies. For one, this should not be a problem, since instances of children acting one way or another are not quantified but bring to surface a variation of possibilities; secondly, I would not argue against the plea that the same person could act according to different categories in different situations. What seems important to me is the fact that all approaches described above could be observed, they are of different epistemic complexity and it was possible to plausibly discern them in terms of intentional focus.

Second, one could argue that actually differences in understandings of the task (cf. Säljö 1975, Hounsell 1984) were studied instead of differences in motives and strategies. But since the instructions were very open, space left for interpretation of the task was so broad, that own ideas and motives could easily be brought to effect or rather had to be brought to effect, which is exactly what we intended. Admittedly we can not exclude the possibility that the "orientation" described as aimless fiddling, might actually express a failure to identify and follow expected instructions. This would still not interfere with our results.

8. Literature

Fleck, Ludwik (1980): Entstehung und Entwicklung einer wissenschaftlichen Tatsache. Eine Einführung in die Lehre vom Denkstil und Denkkollektiv. Frankfurt a.M. First published Basel 1935.

Hammann, Marcus (2004): Kompetenzentwicklungsmodelle. MNU 57/4, 196-203.

Höttecke, D. (2007): How Do Physics Teacher Students Understand the Nature of Science? An Explorative Study of a Well Informed Investigational Group. Paper presented at the

Ninth International History, Philosophy, Sociology & Science Teaching Conference (IHPST), Calgary, Canada, June 28 - 31, 2007

Hounsell, D. (1984): Learning and essay-writing. In: Marton, F./Hounsell, D./Entwistle, N. (Hrsg.): The experience of learning. – Edinburgh, pp. 103-123.

Rheinberger, Hans-Jörg (2006): Experimentalsysteme und epistemische Dinge. Ffm: Suhrkamp taschenbuch wissenschaft.

Säljö, R. (1975): Qualitative differences in learning as a function of the learner's conception of the task. – Göteborg.

Siegler, R. S. & Liebert R. M. (1975): Acquisition of Formal Scientific Reasoning by 10- and 13-Year-Olds: Designing a Factorial Experiment. *Developmental Psychology*, vol. II, No. 3, 401-402.

Steinle, F. (2005): personal communication.

Steinle, F. (2006): „Das Nächste ans Nächste reihen“: Goethe, Newton und das Experiment. In: Grebe-Ellis, Johannes/ Theilmann, Florian (Eds.): open eyes 2005 – Ansätze und Perspektiven der phänomenologischen Optik. Berlin: Logos 179-202.

Zimmerman, C. (2007): The development of scientific thinking skills in elementary and middle school. *Developmental Review*, vol. 27, no. 2, June, pp. 172-223