Hilfert-Rüppell, Dagmar; Looß, Maike; Klingenberg, Konstantin; Eghtessad, Axel; Höner, Kerstin; Müller, Rainer; Strahl, Alexander; Pietzner, Verena

Scientific reasoning of prospective science teachers in designing a biological experiment

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Originalarbeiten

Dagmar Hilfert-Rüppell, Maike Looß, Konstantin Klingenberg, Axel Eghtessad, Kerstin Höner, Rainer Müller, Alexander Strahl, Verena Pietzner

Scientific reasoning of prospective science teachers in designing a biological experiment

Summary: In this study, we investigated how prospective science teachers plan germination experiments. Two hundred thirty-three students from three different German universities in their first to sixth year of educational studies were asked in paper-and-pencil tests which materials were necessary to germinate garden cress (*Lepidium sativum*). Two different types of tests were utilized, one test named possible materials to be used (guided response), the other one did not (open-ended response). Our hypothesis was that guided response tests would lead to plan experiments more recipe-like in the form of confirmatory experiments without control-of-variable-strategy. The participants' answers were assessed using a rubric system. The categories were classified in line with two process variables "generating hypotheses" and "planning experiments" discussed by Mayer (2007) in his model of scientific reasoning, and a third process variable we labelled "naming expected results". The participants' responses were also classified according to the levels of performance of the participants' experimental design. The results reveal deficiencies in content knowledge and scientific reasoning among the prospective science teachers tested. Those test participants who listed a greater number of essential environmental factors such as air, temperature, and water, tended to plan their experiments with a greater variety of variables and include experimental control in their experiment design. The majority of the students tested also neglected to frame a hypothesis regarding which variables ultimately influence cress germination. Interestingly enough, the type of test the science education students completed had an impact on the formulation of a hypothesis: Prospective science teachers who completed the open-response test were more likely to frame a hypothesis than those answering the guided response test. Most of the prospective science teachers also failed to write down their expected results. Finally, more than half of the students neglected to adopt the control-of-variable strategy and most confounded the variable "light".

Key words: Experimentation – prospective science teachers – scientific inquiry – scientific reasoning

Wissenschaftliches Problemlösen von Lehramtsstudierenden der naturwissenschaftlichen Fächer beim Planen eines biologischen Experiments

Zusammenfassung: In dieser Studie wurde untersucht, wie zukünftige Lehrer der Naturwissenschaften Experimente zur Keimung planen. 233 Studierende von drei deutschen Universitäten im 1. bis 12. Semester wurden in einem schriftlichen Test befragt, welche Materialien unbedingt notwendig seien, damit Kressesamen (*Lepidium sativum*) keimen. Zwei verschiedene Aufgabenformate wurden eingesetzt, solche, die Materialvorschläge enthielten (guided response), und solche ohne (open-ended response). Die Hypothese war, dass guided response-Tests zum eher rezeptartigen Planen in Form von konfirmatorischen Experimenten ohne experimentelle Kontrolle (control-of-variable-strategy) führen würden. Die Antworten der Probanden wurden einem Kategoriensystem zugeordnet. Dabei wurden zwei Prozessvariablen „Hypothesen generieren" und „Untersuchungen planen" in Übereinstimmung mit dem Strukturmodell zum Wissenschaftlichen Denken von Mayer (2007) überprüft. Eine dritte Prozessvariable „Nennen eines erwarteten Ergebnisses" wurde zusätzlich aufgenommen. Die Antworten der Befragten wurden darüber hinaus nach ihrem experimentellen Design verschiedenen Levels zugeordnet. Die Ergebnisse zeigen, dass die untersuchten Studierenden Defizite im Fachwissen zur Kressekeimung sowie beim Wissenschaftlichen Denken aufweisen. Diejenigen Teilnehmer, die eine größere Anzahl von Faktoren wie z. B. Luft, Temperatur und Wasser berücksichtigten, planten ihre Experimente mit einer größeren Vielfalt an Variablen und entwarfen ein Kontrollexperiment bei ihrem experimentellen Design. Die Mehrzahl jedoch formulierte keine Hypothese, welche Faktoren zur Kressekeimung unbedingt notwendig seien. Interessanterweise hatte das Aufgabenformat, das die Probanden bearbeiteten, einen Einfluss auf das Generieren einer Hypothese: Teilnehmer, die Tests ohne Materialvorschläge ausfüllten, stellten häufiger eine Hypothese auf als diejenigen mit Tests inklusive Materialvorschlägen. Die meisten Befragten dokumentierten kein erwartetes Ergebnis. Mehr als die Hälfte der Probanden veränderte gleichzeitig mehrere Variablen, die Variable „Licht" wurde am häufigsten konfundiert.

Schlagwörter: Erkenntnisgewinnung – Experimentieren – Lehramtsstudierende der Naturwissenschaften – Wissenschaftliches Problemlösen

1. Introduction

This study focuses on the assessment of prospective science teachers' problem solving strategies (Hammann, 2007). Experimentation is an essential element of science instruction in schools and can be seen as an integral skill in the problem-solving process (Grube, Möller & Mayer, 2007; Mayer, 2007). Science as a problem-solving endeavour requires both an understanding of valid concepts, laws, and theories as well as of scientific procedural design regarding data interpretation and analysis (Roberts, 2004). Scientific inquiry when seen as a structural model is a problem-solving strategy encompassing three central and interrelated dimensions (practical skills, scientific reasoning, and epistemological beliefs) (Mayer, 2007; see Fig. 1). Scientific experimentation in school, however, frequently tends to resemble more a "cookbook" (in the sense of confirmation inquiry) comprising simply of "hands-on" activities rather than inquiry-based, "mind-on" activities (Hammann & Mayer, 2012). In their research synthesis (1984 to 2002), Minner, Levy and Century (2010) established that inquiry instruction emphasizing students' own active thinking in the course of scientific investigation are more likely to increase students' understanding of science concepts.

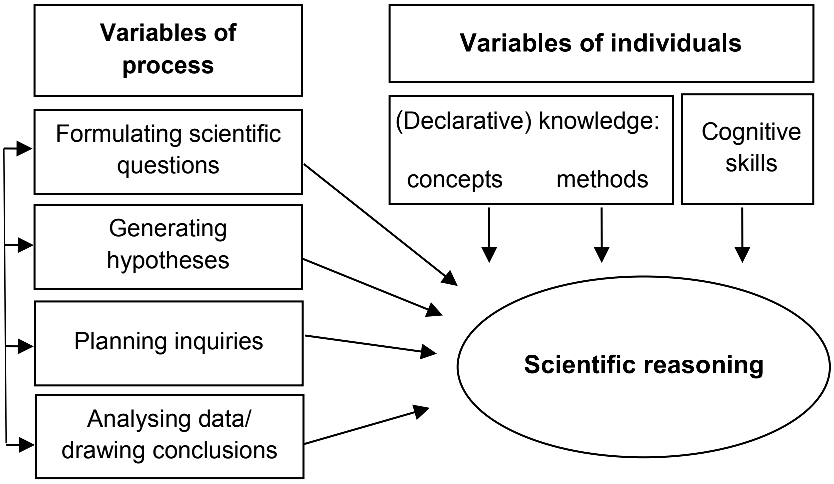

Figure 1: Model of scientific reasoning (according to Mayer, 2007)

Hence, we sought to assess the capabilities of prospective science teachers to plan a scientific experiment with a high degree of student involvement in the inquiry process. Teaching strategies that actively engage students require open inquiry situations (i. e. circumstances in which students must derive the inquiry question themselves), followed then by guided inquiry. The task we set our test participants was thus equivalent to a guided inquiry of the problem presented to them. In addition to this (hypothetical) task, the science education students were asked to design an experiment including all necessary aspects; thus, due to the high level of cognitive competence and scientific reasoning required to successfully complete such a task, we created an open-inquiry setting.

2. Theoretical framework

Inquiry competence is described as a problem-solving process (Kuhn & Pease, 2008). This study focuses only on one aspect of the problem-solving process, namely, on scientific reasoning. In his structural model of scientific reasoning, Mayer (2007) identified four skills involved in this process: “formulating scientific questions”, “generating hypotheses”, “planning of scientific investigations” and “interpreting data”. In order to engage in scientific inquiry efficiently, prospective science teachers need to bear different aspects in mind. For example, they have to consider the necessary variables for generating a hypothesis. Furthermore, they must take the need for replication and the control of confounding variables into account while planning the experiment. These process variables combine with individual variables, such as declarative knowledge and cognitive skills, to form scientific reasoning. Pedagogical content knowledge (PCK) is a domain of teacher knowledge (in addition to pedagogical knowledge and content knowledge) that is vital for teaching a specific subject as well as any particular topic (cf. Shulman, 1986, 1987). Käpylä, Heikkinen and Asunta (2009) established that good content knowledge (CK) has a positive influence on prospective teachers' pedagogical content knowledge (PCK), and thus, on effective teaching. Content 'experts' (in this case, biology education students training for secondary school level) were able to recognize students' conceptual difficulties more easily than content 'novices' did (biology education students training for primary school level). PCK is relevant to create cognitive activation in classrooms and to support learning processes (Ball, Lubienski & Mewborn, 2001; Baumert et al., 2010). Several articles on professionell knowledge exist, whereas most science publications emphasize knowledge of students' understanding, and knowledge of instructional strategies and representations for teaching as central elements of PCK (survey in Park & Oliver, 2008). Some components of PCK, as e. g. students' misconceptions, seem to require a deeper content knowledge than others (Borowski, Fischer, Olszewski, Reinhold & Riese, 2010; Gramzow, Riese & Reinhold, 2013). However, better content knowledge seems to have no significant effect on the prospective science teachers' knowledge of experiments and demonstrations suitable for teaching. Content experts were not much better in generating topic specific teaching methods than the content novices were. This confirms that PCK must be taught, at least in part, explicitly; that PCK does not automatically develop out of either content knowledge or general pedagogical knowledge (Käpylä et al., 2009; Schmelzing, Wüsten, Sandmann & Neuhaus, 2010).

As a standard professional mode of reasoning and practice, experimentation provides learners with essential insights into scientific methods (Hammann, Phan, Ehmer & Grimm, 2008) – and improves their scientific literacy. Current specifications of standards for teacher qualification in Germany also clearly state that teachers must be acquainted with basic scientific methods and theory and have knowledge of and skills in hypothesis-guided experimentation (GFD, 2005; KMK, 2004). Comparable to the standards set by the National Research Council (DfES & QCA, 1999) and found in the National Curriculum for England and for the USA (NRC, 1996), the Conference of Cultural Ministers (KMK) in Germany hence determined in 2008 that teachers must be able to plan and carry out experiments in order to use scientific inquiry in their instruction.

3. Research design

Our research question was strongly influenced by the current discussion in Germany about teaching standards and the necessary level of competencies prospective science teachers should develop in teacher education programs (KMK, 2008; Tepner et al., 2012). More specifically, we asked, to what degree are prospective science teachers able to plan a scientific experiment with a high level of student involvement in the inquiry process.

The task presented to the test participants was to explain in detail possible ways of conducting a specific biological experiment. Two different types of tests were utilized in the survey, one group of education students was given a paper-and-pencil test with guided responses in the form of a list of possible materials to be used; the other group was given a test with open-ended responses. The open-response test was worded as inquiry instruction that emphasizing students' own active thinking as should be offered in school instruction. Since a study investigating the effects of open and guided-response inquiries (with and without material proposals) on the participants' scientific reasoning has yet to be published, the impact of two types of tests was of central interest for our study. Our hypothesis was that guided response tests would lead to plan confirmatory experiments without control-of-variable-strategy.

Our study focused on the individual inquiry skills of education students in regard to two of the scientific reasoning variables mentioned above, "generating hypotheses" and "planning inquiries" pertaining to biological experimental design. Since the research question for the task was provided in the paper and pencil tests, and the task encompassed a purely hypothetical experiment, the variables "formulating scientific questions" and "interpreting data" in Mayer's structural model of scientific reasoning were not relevant for our study. We broke the factor "planning inquiries" down into three essential aspects: "factor varied", "control-of-variable-strategy" (no confounded variables), and "planning a control experiment". We also examined the factor "giving an expected result", because this was expected to give us insight on the participants' CK. We hypothesized that skills in these five areas (generating a hypothesis, varying a factor, applying the control-of-variable-strategy, planning a control experiment, and giving an expected result) increases with the number of semesters studied. Furthermore, we assumed that the subjects studied by the education students would be relevant to their performance in the test. Science education students with a double major in two fields of natural science should do better than students majoring in one natural science and a social science should; this would be characterized by a more frequent generating of hypotheses, planning control experiments and stating expected results.

4. Sample and research procedure

Germination of garden cress (*Lepidium sativum*) was chosen as the experiment example. This is an easy, practical experiment with clearly identifiable factors of influence and is often used in schools. The assignment was to design one or several experiments, which would allow the identification of factors necessary to start the process of the germination of cress seeds. For germination of garden cress the factors water, temperature and air (oxygen) are absolutely necessary.

Water leads to imbibition and the breaking of the seed coat. Oxygen is essential for the metabolism to reduce reserves to set free energy for germination. Temperature starts the germination process and serves as indicator that there is the right warmth in the habitat (Bewley, 2013). For taking the right factors into account, content knowledge about plant germination – in contrast to plant growth (which includes in addition light and substrate/soil) – is necessary. Planning correct experiments requires knowledge about scientific reasoning and hypothesis-guided experimentation.

The sample comprised 233 prospective science teachers. The sample included both undergraduate and graduate education students studying in their first to their twelfth semester at three German universities. In the overall sample 69.1 % of the participants were studying to become elementary school teachers, 22.3 % were studying to teach in secondary schools, and 8.6 % were studying to become teachers at special schools for the handicapped and children with learning problems. The age ranged from "younger than 25 years" (73.8 %) to 40-44 years (0.4 %), 25-29 years (19.4 %), 30-34 years (3.8 %), 35-39 years (2.5 %). 35 % of the participants had chosen biology as an intensive course (Leistungskurs) in school. More than 80 % judged their attitude towards biology in school positive, while only 6.8 % of them disliked it. The survey was completed in spring of 2007.

Half of the test participants (*n* = 120) were given paper-and-pencil tests which explained the task and named the following possible materials: garden cress seeds, jam jars, cotton wool, potting soil, shoe boxes, refrigerator, tins with cover, water, lamps, magnets, Bunsen burners, glass wool, stones and fertilizer. The only essential factors named were water, air, and temperature. The other half of the participants (*n* = 113) were given a paper-and-pencil test which simply explained the task without any materials listed (Fig. 2).

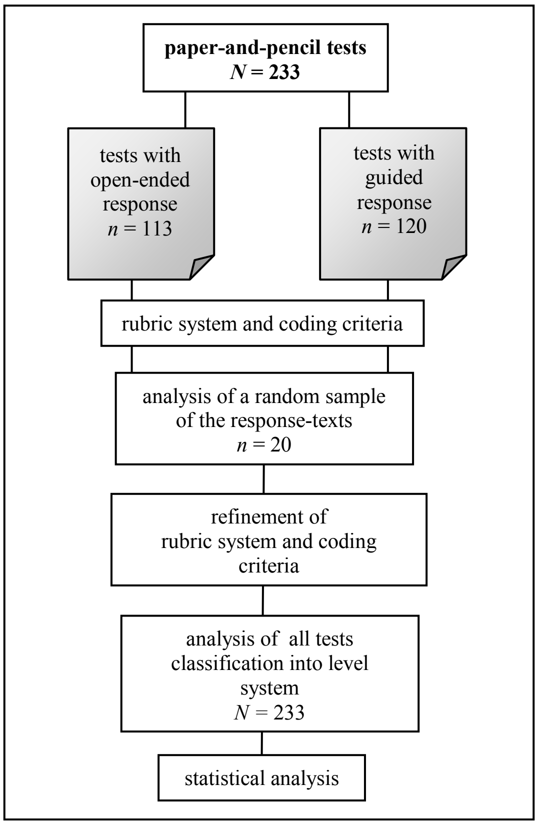

Figure 2: Research procedure

The science education students had had varying opportunities to practice experimental design during their studies concerning behavioural, ecological and biochemical research questions. University coursework focuses on planning classroom instruction, including conducting experiments, for children in grades three to six.

The paper-and-pencil tests were handed out during a regular university didactic course. In the introductory explanation, all survey participants were informed of the study's scientific setting and their anonymity assured. The participants were asked to participate in an in-class test with a single research question. The wording of the test is mentioned in box 1.

Observation: Sowed cress seeds germinate after some days.

Question: What brings these cress seeds to germination?

- Design one or several experiments, which are suitable to decide which conditions are absolutely necessary for the germination of cress seeds.
- Describe the experiment precisely, so others can follow your instructions accordingly. Sketch a drawing if necessary.

Box 1: Research question of the paper-and-pencil test

5. Data analysis

Prior to the evaluation of the data, examples from the sample were recorded as a rubric reflecting correct and incorrect responses for the assessors. In order to test the rubric system and coding criteria, two raters independently interpreted a random sample of the response-texts ($n = 20$). Thus, an inter-rater agreement was determined. Consistency across the raters was very good (Cohen's kappa $\kappa = 0.897$, $p < .001$) (Landis & Koch, 1977). After rubric refinement all paper-and-pencil tests were examined. We evaluated the following: formulation of a hypothesis, predictor, and manipulation of relevant variables with appropriate control. Categories were labelled "yes" or "no". The skill in planning two-factor experiments depended on: (1) recognizing the need for an experimental control; (2) taking into account all the test variables that need to be investigated; (3) differentiating between variables to be tested and those that need to be controlled; (4) designing the experiment without confounding variables (Hammann et al., 2008). Following these authors, the participants' answers were classified into four levels (Tab. 1 and Tab. 2). Furthermore, the frequency of the variable "naming an expected result" was categorized as "no", "yes", and "yes, but wrong".

Table 1: Coding guide for planning skills in the task

Level	Determination of level
0	- Description of a single experiment with no experimental control - Expected results are described
1	- Experiments with only one manipulation - Several variables named, but effects confounded
2	- Correct experiments with varied variables (control-of-variable-strategy)
3	- Correct experiments with varied variables (control-of-variable-strategy) - Experimental control applied to all test factors

Table 2: Coding guide for identifying a level as indicated by Hammann et al. (2008): 0 = does not occur in the science education student's response, √ = occurs in the response

	Variable varied	Control-of-variable strategy	Experimental control
Level 0	0	0	0
Level 1	√	0	0
	0	√	0
	0	0	√
Level 2	√	√	0
	√	0	√
	0	√	√
Level 3	√	√	√

The following box 2 gives an example for a correct design, classified into level 3.

Hypothesis: Cress seeds need water to germinate.

Cress seeds are given on top of cotton wool into two jars. One jar is watered a little every day the other one is kept dry.

Observation: Only the wet seeds germinate.

Hypothesis: Cress seeds need heat to germinate.

Into two jars cotton wool and cress seeds are given. One jar is put into the refrigerator the other one is kept in the room in a shoebox (to keep it without light as well). Both are watered a little every day.

Observation: Only the seeds kept at room temperature germinate.

Hypothesis: Cress seeds need air to germinate.

Cress seeds are given on top of cotton wool into two jars, both are watered. One jar is put into a locked plastic bag and the air is sucked off. The other jar is kept open.

Observation: Only the seeds kept with air germinate.

Control experiment: In this experiment none of the three factors is excluded. Cress seeds are put on top of cotton wool. The jar is kept at room temperature and watered regularly.

Observation: The cress seeds germinate.

Box 2: Example for a correct design, classified into level 3

The data were analysed using the software programs Excel and SPSS. Statistical tests were applied following Kähler (2004). The distribution of data was checked (test for normality, Kolmogorov-Smirnov test). Chi-square tests (χ^2) were applied to analyse, whether two categorical variables were associated. When one of these categorical variables had more than two categories, the coefficients Phi (φ) respectively *Cramer V* describe the strength of statistical connection. Since not all tests were evaluable in regard to the different analyses, the sample size sometimes varies in the following analysis.

6. Results

6.1 Differences between inquiry with guided and open-ended response

Significantly more participants completing the open-ended response test generated a hypothesis (nearly 50 %; $n = 113$) ($\varphi = -.2$; $p = .005$) and contemplated a control experiment (about 60 %; $n = 113$) ($\varphi = -.1$; $p = .042$) (Tab. 3). Only about one third of the prospective science teachers completing the guided response test ($n = 120$) framed a hypothesis and about 40 % of this group considered a control experiment.

Table 3: Proportion of test participants [%] with guided response (test material proposals given, $n = 120$) and open-ended response ($n = 113$) considering variables of process necessary for scientific reasoning ($N = 233$)

Test material proposals given	**Providing hypothesis [%]**	**Factor varied [%]**	**Not confounded [%]**	**Control experiment [%]**	**Naming an expected result [%]**
Yes	30.8	92.5	72.5	44.2	9.9
No	49.1	93.8	76.8	57.1	9.5
Statistics	$\varphi = -.2$ $p = .005$	$\varphi = -.03$ n. s.	$\varphi = -.05$ n. s.	$\varphi = -.13$ $p = .042$	$\varphi = -.01$ n. s.

There were no statistical differences that could be discerned between these two test groups concerning the frequencies of “naming an expected result”, “varying factors”, and “adopting the control-of-variable-strategy” (Tab. 3); consequently, the findings regarding these process variables are described for the entire sample below. In spite of that many science education students working with the guided response test formulated biological incorrect “expected results” (52.2 %, $n = 12$ of 23), this is significantly more than students filling out the open-response tests (13.6 %; $n = 3$ of 22) ($\varphi = -.4$; $p = .006$). With one exception, this mistake in “expected results” concerned the effect of “light” (8 stated “light”, 4 “sun”, 2 “lamp”). Three of these students noted light and fertilizer as essential factors in order for cress seeds to germinate; one student recorded only fertilizer. These assumptions had furthermore an influence on the further factors considered: The students took different variables into account for their answers (Tab. 4). The variables that were most often considered were “water” (guided-response test 94.2 %; open-response test 100 %, $N = 233$) and light (guided-response test 94.2 %; open-response test 93.9 %, $N = 233$). The variables that were manipulated most often (with or without control) were light (83.3 %, *n* = 194) and water (74.7 %, *n* = 173). Some factors given in the guided-response test such as cotton wool and temperature were chosen nearly twice as often as others. The factor "fertilizer" was considered nearly ten times more often in the "guided-response" test than in the "open-response" test. Most prospective science teachers adopted the control of variable strategy, only 26.7 % (*n* = 66) of the test persons became confused about the effect of at least one variable. On average, the science education students confounded 0.7 variables (*SD* = 1.32), there was no significant difference between guided-response test and more open-response test students ($\chi^2 = .56$, n. s.).

Table 4: Proportion of test participants [%] with guided response and open-ended response considering different factors for germination of cress seed (*N* = 233)

Factors considered	**Proportion of science education students [%]** **guided response**	 **open-ended response**
Water	94.2	100.0
Light	94.2	93.9
Soil	85.8	76.3
Cotton wool	75.8	39.5
Temperature	65.0	38.6
Fertilizer	37.5	3.5
Air	19.2	22.8

6.2 How do process variables influence each other?

To analyse the impact of a single process variable on the other process variables of scientific reasoning the sample was analysed as a whole. 50 % of those who planned a control experiment also generated a hypothesis and 64 % documented an expected result (Fig. 3). 45 % of those who had formulated a hypothesis and 31 % of those who had not formulated any hypothesis planned correct experiments with varied variables (control-of-variable-strategy) and experimental control applied to all test factors. Thus, they reached level 3 (Tab. 5). Generally, participants who considered a greater numbers of essential variables in their experiment, such as air, temperature, and water, reached the higher performance levels (*Cramer-V* = .15; *p* = .058).

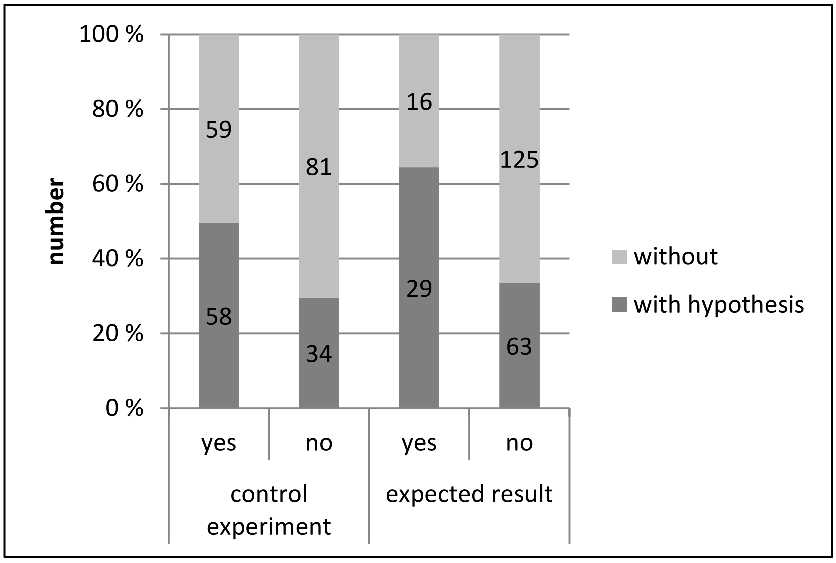

Figure 3: Correlation between "generating a hypothesis" and the proportion of participants [%] "planning a control experiment" and "giving an expected result" (*n* in bars, *N* = 233)

Table 5: Proportion of participants [%] reaching a particular level (as indicated by Hammann et al., 2008, see Tab. 2) correlated with hypothesis generated, the planning of a control experiment and/or an expected result given (*N* = 233)

	Level			
	0	**1**	**2**	**3**
Hypothesis				
Yes	0 %	16.3 %	39.1 %	44.6 %
No	0.7 %	20.9 %	47.5 %	30.9 %

6.3 Does the combination of the fields of studies influence the students' achievement?

Students studying two natural science subjects did not achieve better results than students combining a social science major with a natural science major, or without any natural science discipline at all. None of the correlations to "formulating a hypothesis", "varying a factor", "applying the control-of-variable-strategy", "planning a control experiment", and "giving an expected result" were significant (χ^2, n. s.) (Tab. 6). There was no correlation between providing a hypothesis and the participants' major field of study: Those majoring in social science framed a hypothesis just as often as those majoring in a natural science (biology, chemistry, physics or mathematics) ($\chi^2 = .81$; $p = .640$).

Table 6: Proportion of test participants [%] divided into two groups (two science majors in the natural sciences and/or mathematics versus all other subject combinations) and the adoption of process variables ($N = 233$)

Students with	**Providing hypothesis [%]**	**Factor varied [%]**	**Not confounded [%]**	**Control experiment [%]**	**Naming an expected result [%]**
two natural science majors	39.0	15.9	54.9	75.6	10.98
one natural science major	40.7	21.4	48.97	72.4	13.1

Whether the education students framed a hypothesis or not, was also not dependent on number of study semesters they had completed. Although graduate students generally provided hypotheses more often than undergraduate students did, the difference between groups was not significant (χ^2 = .34, n. s.). Participants farther along in their studies (fifth semester or higher) confounded on the average only half as many variables in comparison to their younger fellow students (first through fourth semester) (*Cramer-V* = .04, n. s.).

7. Discussion

Prospective science teachers show deficiencies in the process variable “generating hypotheses“ in connection with “planning experiments“. The hypothetical experiments were often planned arbitrarily and the effects of variables confounded. Giving some participants a possible direction of choice in planning the experiments by providing a list of likely materials to use actually had a negative impact on the students’ capability to draft an experiment emphasizing inquiry instruction, confirming our hypothesis that guided response test lead to plan experiments more recipe-like in the form of confirmatory experiments without control of variable strategy. Moreover, the science education students completing the guided-response test tended to note a biological incorrect “expected result” significantly more often than the students completing “open-response” tests did. This could be because these students were uncertain in their content knowledge. Although the “naming an expected result” was not asked for in the task, we included it in our analysis concerning content knowledge. In retrospect, we consider that this variable (naming an expected result) should be included in tasks in conjunction with further research.

Sadeh and Zion (2009) investigated the development of dynamic inquiry performances within an open inquiry setting comparing it to guided inquiry setting.

They found that open inquiry students used significantly higher levels in "changing during inquiry" and "procedural understanding" while there were no significant differences in the criteria "learning as a process" and "affective points of view". As in dynamic inquiry learning aspects of change, intellectual flexibility, and critical thinking is emphasized, the authors assume that within the context of inquiry learning, it will contribute to the development of higher order thinking skills.

As noted above, those participants who framed hypotheses had broader hypothetical experimentation skills, e. g. more of them included a control experiment in their plan and documented an expected result. Ben-David and Zohar (2009) examined the instructional effects of meta-strategic knowledge (MSK, "thinking behind the thinking") regarding the development of two scientific strategies of thinking, such as "Define Research Questions" (DRQ) and "Formulate Research Hypotheses" (FRH). Students' responses to the request to frame a research hypothesis presented by a fictional story were analysed using a coding scheme in which three levels were given. In our research, the framing of a hypotheses was not included in the coding scheme for levels but was correlated to the level scored. Other more or less similar performance models or levels – e. g. with regard to research questions or hypotheses in this field of research – can be identified (Ben-David & Zohar, 2009). Allowing for four different cognitive processes ((1) generating questions, (2) posing preliminary hypotheses, (3) designing and conducting the research study, (4) explaining results; with 3 and 4 considered special sub-processes), we organized them in a matrix containing four levels of complexity. A more specified matrix for evaluating complexity of reasoning during scientific inquiry was published by Dolan and Grady (2010). In their matrix categorizing the complexity of students' reasoning, within the cognitive process "designing and conducting the research study" they included "selecting dependent and independent variables" and "considering experimental controls" as subprocesses. Dolan and Grady base their research on the principle that teaching by inquiry is an appropriate way to encourage people (in their case, students) to reason scientifically. Their study centres on the real practice of best case scenarios in classrooms, exploring the reasoning behaviours of individuals in complex, social, and situated environments.

As mentioned above, we found that chosen fields of studies had no influence on the performance of the students. The proportion of students providing a hypothesis does increase in correspondence with the number of semesters the students have studied; however, this trend was not statistically verifiable. There were neither correlations to be found between the investigated process variables and the science education students' major, their chosen combination of fields of study, nor with the type of school targeted, in which they would later teach. These results imply that knowledge of correct scientific procedures has not been conveyed – at school or at the university – adequately. Loughran (2007) emphasizes that subject matter knowledge and teaching knowledge when combined highlight the skills and expertise of specialist subject teachers. Our findings show that good CK had a positive influence on planning a scientifically correct biological experiment. CK was indicated in the data by the correct selection of essential variables; students who chose a greater number of essential variables were categorized in the higher levels. Hof and Mayer (2009) also discerned a positive correlation between CK and process variables of scientific reasoning of students working on photosynthesis. Roberts' (2004) content-based demands of the problem-solving model for the natural sciences, a modification of the model proposed by Gott, Duggan and Johnson (1999), differentiates between substantive understanding and procedural understanding. Substantive understanding is fed by facts, i. e. in our study, the biological knowledge of seed germination. Procedural knowledge develops from basic skills – in our case, the scientific knowledge how to correctly plan an experiment. The mental processing responsible for putting the ideas together in the head may vary depending on the problem's context. This model coincides with the model published by Mayer (2007, Fig. 1): Scientific reasoning requires biological knowledge combined with individual variables and scientific knowledge, which is incorporated in the variable of process.

7.1 Transferability of the results

The purpose of this study was to analyse prospective science teachers' competence in scientific reasoning by means of an open-response paper-and-pencil test. Differences in the participants' performance can be interpreted as an indication of different skills necessary for planning experiments. Only approximately one third of the participants were able to plan a biological experiment correctly, 84 prospective science teachers were rated at level 3. Owing to the research methodology used in this study, we cannot say how this affects real classroom practice. Our findings indicate that prospective science teachers with an inaccurate and inadequate knowledge could possibly transfer their own misconception(s) on to their students, and hence add to pupils' conceptual difficulties (Even, 1993; Hashweh, 1987; Ruiz-Primo, Li, Tsai, & Schneider, 2010). Participants completing the guided-response test performed worse than participants given the open-response test: Including material proposals in the paper-and-pencil test had a moderately negative effect on the students' performance, e. g. the prospective science teachers confounded the effects of variables on the cress germination more often and noted an expected result less often. The fact that the variables "fertilizer" and "light" were listed by the majority of the participants of the guided-response test implies that these students were not able to distinguish between plant germination and plant growth. This seems to indicate a lack of domain knowledge. How content knowledge and domain-independent strategies interact; thus, this remains an open question in research concerning of scientific reasoning (cf. Sodian & Bullock, 2008).

Providing only a limited choice of useful materials in a test could help to investigate the influence of guided response on planning strategies and concepts. However, since a paper-and-pencil test only asks for hypothetical knowledge, concepts of experimentation are actually not implemented. Data from paper-and-pencil tests correlate only partly with practical work (Roberts & Gott, 2004). Further research could shed light on the effect of hypothetical learning, content knowledge and scientific reasoning on practical skills by means of concrete experimentation.

7.2 Implications for teacher education

In inquiry activities, students demonstrate autonomy by making choices and self-regulation, which may enhance their motivation (Polman, 2000). As a result, experimentation can be a mean to foster students' inquiry skills and their understanding of scientific concepts and processes. Teacher thinking has been the focus of research on components of effective teaching (Lederman & Niess, 2001). PCK, as discussed by Shulman (1987), represents the blending of content and pedagogy into the understanding of how particular topics, problems or issues are organized, depicted, adapted to the various interests and abilities of learners, and presented for instruction. Park, Jang, Chen and Jung (2011) conclude from their research that PCK is integral to effective science teaching and science teachers should possess PCK to facilitate student learning. The "control of variables" thinking strategy (Zohar & Ben-David, 2008; Zohar & Peled, 2008) reveal considerable effects on explicit instruction of students' meta-strategic knowledge in laboratory settings and authentic classroom situations. A crucial point in teaching meta-strategic knowledge is the students' concrete experience, in which they use a thinking strategy rather than addressing a task solely in an abstract way. In these cognitive activating (classroom) situations PCK is central (Ball et al., 2001). In the course of their individual learning through experimentation, prospective science teachers should be encouraged continuously to include meta-cognitive control and regulation.

Nevertheless, beyond the general outlook of the teaching and learning concepts in the natural sciences, the discussion concerning the relevance and universality of scientific reasoning or scientific inquiry is still an ongoing process of differences. Dean and Kuhn (2007) show that direct instructions are advantageous to discovery learning, however this advantage was not preserved six months after instruction. At that time, students who had experienced discovery rather than guided learning outperformed all other groups. The authors therefore conclude that discovery learning is the most desired type of learning for achieving long-term and transferable effects.

In the course of our study, we have established that prospective science teachers need training in meta-cognitive skills that would enable them to challenge their own experimental approach and to draw logical conclusions from it. A main focus of their studies should be placed on the "control-of-variables strategy"

(DiSessa, 2008; Kuhn, Iordanou, Pease & Wirkala, 2008; Kuhn, Pease & Wirkala, 2009; Sodian & Bullock, 2008). Since framing a hypothesis has profound influence on the correct planning of an experiment, we recommend explicitly schooling in hypotheses-guided experimentation.

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