

# Guided Inquiry learning: How much support is most effective for children's learning?

*Gericht ondekkend Leren: Op zoek naar effectieve ondersteuning*

Master thesis of  
Elisa Kopitzki, BSc  
0163295  
Psychology  
University of Twente

Faculty of Educational Science & Technology

Department of Instructional Technology

Supervised by  
Dr A. H. Gijlers  
Dr. H. van der Meij

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## Abstract

When asked to predict whether an object will sink or float primary school students often focus on volume or mass but not on the relation between the two. In the present study we evaluated the effect of support aimed at students' structuring of experimental data and reflection on the experimental outcomes in a hands-on inquiry learning setting. Sixty-four German fourth grade students were randomly assigned to one of three conditions which varied in the amount of support aimed at assisting students' structuring of experimental data and reflection on experimental outcomes. All students completed a pre- and post-test and the four weeks retention-test. Results indicate that students in all conditions benefit from the inquiry learning setting. The two experimental groups had outperformed the control condition group. It can be concluded that students benefit of support in form of structure and prompts during inquiry learning, but that the question style (open or closed questions) to test these concepts is crucial. It appears that, in line with former research, pre- and more scientifically sounded concepts remain side-by-side, and when forced to choose one explanation students may prefer the stick to their naïve pre-conception.

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## **FLOATING AND SINKING - CONCEPTUAL CHANGE IN SCIENCE EDUCATION**

Children think about scientific phenomena but not always from a scientific point of view. Children's everyday experiences and interactions with physical phenomena invite them to construct their own (naïve) explanations even before they start school. Unfortunately, many of these explanations are partially or entirely inadequate from a scientific viewpoint. Children's incorrect or incomplete understandings of a scientific phenomenon are called, dependent on the researcher, pre-conceptions (Simons, 1999), naïve theories (Brewer, 1999) or misconceptions (Chi, 2005).

In their everyday life children observe that some objects float in a swimming pool or puddle while others sink. Their explanations of why some objects float when immersed into water, while others sink are often incomplete or incorrect according to modern science. Smith (Smith, Carey, & Wiser, 1985; Smith, Maclin, Grosslight, & Davis, 1997) and Möller (1999) conducted interviews with elementary and secondary school students. These interviews showed that children's explanations typically focused on one dimension only: They refer either to the mass of an object ("things that are light will float"), to its volume ("large things will sink"), or to its form ("things with holes will sink"). These incomplete explanations of floating and sinking originate from students experiences with various objects in water but are not utterly in line with scientific explanations based on the concepts of mass, volume and density. The children do not consider the relationship between object and surrounding fluid.

Biddulph and Osborne (1984) report on the explanations children provided to explain why some things floated and others sank. Students provided explanations for individual materials and did not realise, that there could be a general explanation. The explanations offered, whether multiple or single, could be described as partial explanations. They focussed on specific aspects such as lightness or heaviness and failed to take into account other aspects (such as volume) needed to formulate a general rule that would explain all cases (Biddulph & Osborne, 1984). Students thus often hold conceptions that hold true in some situations but not in others. The idea that heavier objects will sink when immersed in water holds for objects that are made out of materials that are denser than water.

Generally, it can be concluded that with respect to floating and sinking incomplete pre-conceptions are very common. The process of restructuring student's pre-conceptions in order to build more complete and scientifically accepted conceptions is framed as conceptual change (Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001). Students' pre-conceptions are quite resistant to change through instruction. Pre-conceptions have been conceived of as

fragmented, loosely connected pieces of knowledge (diSessa, 1988) or as a coherent pattern of notions that form consistent explanatory systems within domains (Vosniadou & Brewer, 1992) or even across domains (Chi, 2005).

Conceptual change is regarded a gradual process (Chi, 1997; Vosniadou, 2001). Vosniadou (1994) argues that student's concepts are embedded in larger theoretical structures constraining them. Conceptual change thus involves the restructuring of underlying concepts, which can take place in various ways. For instance, an understanding of the concept of density requires the simultaneous consideration of the two dimensions of mass and volume. A concept that young children often lack is mass as a continuous and measurable characteristic of the material world (Smith et al., 1985). It is therefore difficult for them to grasp the concept of density as a whole and all its related consequences.

When students are confronted with experiences, information, or instruction that is inconsistent with their existing conception of a phenomena they will gradually assimilate the new information in their existing explanatory framework. While the shift from the misconception to a more coherent pre-conception to the finally scientifically grounded concept occurs, the different concepts remain side by side (Zimmermann, 2007). Dependent on the (learning) situation one of the pre-conceptions is chosen as a basis for an explanation of the phenomenon at hand. The comparison of mass and volume thus require the simultaneous consideration and integration of concepts. At least an intuitional idea of this notion is the first step toward a revise of the pre-conception.

Although, according to Smith et al. (1985), especially young children have a tendency to adopt an undifferentiated conception of mass and density. Kohn (1993) showed in his study that even between pre-schoolers and adults are considerable parallels with regard to their inadequate strategies for judging an object's floating or sinking.

The issues of density and buoyancy force are often presented first in secondary school, based on the argument that students need to be mature enough to be able to grasp the abstract aspects of the involved formulas such as proportions. Nonetheless, there is indication that concept improvement may be reached when early curricula explicitly address these concepts.

In this line Ilonca Hardy et al. (2006) argues

If, however, children were also introduced to the explanations for the behavior of different materials in water, thus receiving the opportunity to revise misconceptions early on, there is good reason to expect that they will be able to profit more from the formulas of density and buoyancy force treated in secondary school.

Unfortunately most often contemporary curricula in elementary school only introduce a material based pre-concept, e. g. that solid objects of the same material behave the same way when immersed in water. But even this relative simple pre-concept of continuity of characteristics is easily neglected as students are asked to explain why things float or sink (Biddulph & Osborne, 1984). Thus how can instruction promote conceptual change?

## **INQUIRY LEARNING AND CONCEPTUAL CHANGE**

What form of instruction stimulates students to consider more than one dimension to be crucial for floating or sinking of objects?

According to the work of Posner, Strike, Hewson and Gertzog (1982), an essential condition of conceptual change is for students to become dissatisfied with the conceptions they have, thus experiencing the need for new explanatory mechanisms. Central to this notion is cognitive conflict as a motor of conceptual change. For instance, in order to challenge the pre-conception that all floating objects are light, children can be confronted with a comparative light object that sinks (Hardy, Jonen, Müller and Stern, 2006). Hardy et al. (2006) argues that these kinds of confrontations are crucial for challenging plausible but inappropriate explanations, and as a consequence, students may start to consider new ideas.

The mere confrontation with a situation that challenges student's naïve ideas is not enough to foster conceptual change (Limón, 2001). The adoption of appropriate scientifically accepted explanations is a constructive process requiring the active cognitive engagement of students (Zimmermann, 2007). Instructional approaches that offer students opportunities to discover new principles and stimulate them to engage in sense making activities and to formulate explanations, are more likely to promote conceptual change (Bransford, Brown, & Cocking, 1999). In a typical inquiry learning environment, students are confronted with tasks and materials that encourage activities such as experimentation, exploration and generation of hypotheses and explanations. The students are active agents in their own knowledge acquisition process and this allows them to explore and make sense of the material and physical resources in a way that is adjusted to their individual level of prior knowledge and capabilities. Several studies suggest that students working in an inquiry learning setting achieve a higher degree of conceptual understanding than students in environments of direct instruction (Christianson & Fisher, 1999; Staub & Stern, 2002).

However, many open questions remain as to how inquiry learning can be effectively realized at schools. Klahr and Nigam (2004) challenge the presumed superiority of inquiry learning when teaching young children basic scientific investigation procedures (Klahr & Nigam, 2004). Further Mayer (2004) points out that the translation of principles of inquiry learning into learning environments has largely followed the simple formula "inquiry = hands-on activity". In an open-ended and thus highly self-directed inquiry learning setting, students may not reflect on the relevant concepts, and may perform below expectation. If the inquiry task or setting is too complex and too much freedom is given to the students with respect to directing their own learning, students may be enthusiastic and actively involved; but may not discover scientific principles intended, because they do not integrate their sense making activities into a conceptual framework (Kirschner, Sweller, and Clark, 2006). Thus one of the problems might be that students are simply overburdened with the freedom and complexity of unguided inquiry learning settings (De Jong, Van Joolingen, 1998). The observation that students need support during inquiry learning activities leads us to the next paragraph.

## **INSTRUCTIONAL SUPPORT IN INQUIRY LEARNING ENVIRONMENTS**

During unguided inquiry learning activities students may typically experience difficulties. Support in the form of instruction of assignments may help students overcome these problems (de Jong, 2006; de Jong & van Joolingen, 1998). But what are the dimensions relevant to instructional support within inquiry learning environments? De Jong and Van Joolingen (1998) provide an overview of the difficulties students experience with inquiry learning up and listed a number of possible solutions.

De Jong and Njoo (1992) make a distinction between regulative (processes that are necessary to control the inquiry learning process) and transformative processes (processes that directly yield knowledge). The two most central regulative processes; planning and monitoring (De Jong and Njoo, 1992) can be supported by structuring the inquiry process. The structure given has to be based upon the characteristics of the knowledge domain, and thereby additionally enhances the possibility that the student comes to valuable findings.

Beside the regulative processes, essential transformative processes such as designing experiments and interpreting experimental outcomes are of main interest. Providing structure can also be valuable with respect to transformative processes (De Jong, Van Joolingen, 1998). By structuring the experimentation process students can be stimulated to choose reasonable experiments and foster useful comparisons which are the basis for correct interpretations (De

Jong, Van Joolingen, 1998). Therefore to create a fruitful inquiry learning environment that facilitates learning a basic structure is inevitably needed.

Reiser (2004) stresses that *structuring* and *problematizing* are essential aspects when scaffolding inquiry based science tasks. Structuring works to reduce the complexity of a task, for example, by breaking the task down in little step-by-step assignments. Problematizing subject matter stimulates students to relate their work to a disciplinary framework or students' prior knowledge base, for example, by enhance elaborations or by prompting to discrepancies within the data gathered. Two key elements of scaffolding thus seem to be (1) the structuring of tasks to allow students to remain focused on important aspects and (2) the supporting students' reflection on their insights.

Inviting students to keep record of their on-going experiments on pre-structured worksheets is a facile structuring solution. A pre-structured worksheet might reduce the complexity of the inquiry learning task, and note taking makes it possible to free more memory capacity. This is important, since primary school students typically underestimate their memory limitations, when involved in an inquiry learning task and do not spontaneously keep notes (for a recent summary see Zimmermann, 2007).

Support on problematizing can enable the students to make important observations so that they are enabled to question their prior beliefs (Zimmermann 2007). Students often focus on observations that are in line with their initial beliefs (Quinn and Alessi, 1994) or provide explanations that do not question their initial beliefs. However, observing and explaining counter-evidence to their pre-conceptions is essential to promote conceptual change (Chinn & Malhotra, 2002) and secondly these direct experiences coupled with instructional conversations which incorporated discrepant events are essential to helping children change their view of sinking and floating objects (Butts, Hofman & Anderson, 1993). Further support can therefore be a question of making students conscious about contradicting information between their prior knowledge in form of pre-conceptions and the real world with its scientific explanations. By the use of verbal prompts students could be stimulated to think over those contradictions. Prompting students to evaluate and reflect on their experimental findings might therefore enhance their scientific understanding. Especially prompting for self-explanations promotes understanding (Chi, 1996). In the domain of floating and sinking this can be accomplished by e.g. confronting students who hold the conception that mass alone is crucial to buoyancy with two objects with different density, so that one object sinks and the other floats.

Under the considerations outlined above, it seems likely that inquiry learning environments can contribute to conceptual change or at least to the first step toward a revision of pre-conceptions.

Crucially, however, inquiry learning environments need to be designed in a way that supports students' cognitive activity apart from behavioural activity. In unguided inquiry learning setting students might easily perform experiments that confirm their initial ideas (Dunbar, 1993). Furthermore the mere confrontation with ideas that contradict students' initial incomplete understanding of floating and sinking is not enough to facilitate conceptual change (Limón, 2001). This phenomenon called confirmation bias is described by Dunbar (1993), that some students have a strong inclination to search for evidence that support their current hypothesis, even when they are confronted with inconsistent evidence.

As Reiser (2004) points out, it is a delicate task to provide an optimum level of support so that students can complete the learning task successfully and feel challenged enough to stay engaged in the learning process. Depending on students' skills, prior knowledge or intellectual ability a different amount of support is needed. Often stated is that the more students know beforehand about the task and/or the domain the more they learn from an inquiry learning session. The reason that students do not know which hypothesis to state, engage in unsystematic experimentation and cannot make a good interpretation of data might be insufficient prior knowledge (Glaser et al., 1992). In their detailed overview over about the difficulties in inquiry learning settings De Jong and Van Joolingen (1998) distinguish between good and bad students. They found that successful students use a more systematic planning and monitoring, whereas unsuccessful students work in a more unsystematic way (Lavoie & Good, 1988 in De Jong and Van Joolingen, 1998). Further findings are that good students make more notes during learning. Subjects with low prior knowledge have problems with proper goal setting and individuals with a low intellectual ability showed an inferior working method than individuals with a high intellectual ability (for an extended overview see De Jong and Van Joolingen, 1998).

In this project we investigate the amount of different instructional support needed to facilitate an inquiry learning setting with respect to the floating and sinking domain. More specifically we will address how structuring of the inquiry learning task and the use of problematizing prompts can help students to further develop their conceptual understanding of density.



## **THE CURRENT STUDY: EXPERIMENTAL VARIATION OF INSTRUCTIONAL SUPPORT IN THE DOMAIN “FLOATING & SINKING”**

This study wants to contribute to the question of how conceptual change with regard to floating and sinking may be effectively realized in science education at the elementary level. The main question that this study tries to answer is: What is the effect of structuring and problematizing students' experimentation behaviour and data interpretation on students' learning outcomes and processes. The study compares the learning outcomes of students who worked with three versions of the same inquiry learning environment. All three versions of the learning environment were designed to facilitate a high degree of hands-on experimentation with relevant material allowing the student to discover relationships between physical quantities and scientific principles by independent work sessions. The degree of support differed between conditions. Between the two experimental groups and the control group the instructional time, the experiment leader, and the material for experimentation were not varied. The so called control condition (cc) fulfils a minimum of scaffolds, namely the worksheet to keep notes about predictions and observations of each object immersed into water. In experimental condition 1 and 2 (e1 and e2) the work sheet is extended with the request to explain why the object actually sank or floated and an anticipated order to evoke comparisons (see figure 3 and 4) of interesting object pairs (mentioned above). Explicitly requesting students to predict, observe and explain their experiments is an instructional strategy to promote students conceptual change (White and Gunstone, 1992). Due to students' pre-conceptions, their observations often conflict with their predictions. By creating cognitive dissonance and surprise, predict-observe-explain helps students realize the limitations of their pre-conceptions and get ready to learn scientific theories (Yin, Tomita & Shavelson, 2008). Only in experimental condition 2 the teacher gets an active role by on the one hand prompting to contradicting self-explanations of the students and on the other hand confronting students with the interesting comparisons (Appendix A) mentioned above.

A repeated-measures design (pre-test, post-test, and four weeks follow-up measure) of pre-conceptions about of floating and sinking, with three groups based on an experimental variation of instructional support was conducted.

Based on the literature one would expect that the support provided in both experimental conditions results in more systematic evaluation of the data obtained in the experiment (De Jong and Van Joolingen, 1998 and Zimmermann, 2007), because the predefined structure

allows the students to make valuable comparisons between the floating and sinking behaviour of different objects. We expect that the pre-conceptions students held measured on the pre-test will reduce mostly and lastly in the e2 group, less in the e1 group and fewest to not at all in the cc group.

## **HYPOTHESES**

We compared the learning outcomes of students that engaged in three versions hands on inquiry learning environment on floating and sinking. The considerations in the introduction lead to following hypotheses.

First students who are supported by a worksheet that provides them with a predefined experimentation order will have higher knowledge gains than students who can decide the experimentation order on their own. The predefined structure allows students to make valuable comparisons between observations. Students who are allowed to determine the experimentation order on their own are probably less systematic which might hinder in the process of making valuable comparisons.

Second, students who receive additional support in the form of comparison prompts will gain more knowledge than their peers. Providing students with a predefined experimentation order allows them to make valuable comparisons, but does not necessarily mean that students will actually see the potential and make these comparisons. Prompting students to make certain comparisons might stimulate students to make comparisons along the dimensions mass and volume.

Third, we expect that the differences between conditions will last over a longer period.

## **METHOD**

### **Participants**

A total of 64 fourth graders of seven intact classrooms from four elementary schools in a provincial town with 55.000 citizens in North-West Germany participated in this study. Students, who incompletely filled in parts of the test, missed the retention-test or which parents were not willing to make the ability rating of their child available, were omitted from the original sample of

75 students. Of the remaining participants were 32 boys and 32 girls. The students from all classes and all schools were randomly assigned to one of three conditions and we finally counted 21 students in the control and e2 condition and 22 in the e1 condition. The age of the participants ranged from a minimum of 9 years and 9 month to a maximum of 11 years and 8 month, whereas the average was 10 years and 4.46 month (SD= 5,227 month).

### Experimental Task

The experimental task was based on a series of experiments conducted by Kohn (1993) and Kloos, Fisher & van Orden (2010). Following a predict-observe-explain approach (White and Gunstone, 1992 and Yin et al, 2008) students were asked to inspect the presented cubes and to predict whether the cubes would float or sink when immersed in water, subsequently students were allowed to immerse the cube into water and observe whether the cube sank or swam. After each trial students were asked to explain what they observed. Students were free to make comparisons between different cubes.

### Materials

Floating and sinking cubes. The objects for the inquiry learning session were eight self-made wooden cubes. The cubes were of four different volumes and filled with lead and wood putty until the desired specifications presented in table 1 were obtained. The lead and wood putty was distributed carefully so that the mass was equally distributed over the entire cube. Cubes were painted black so that it was difficult for students to make conclusions about the material.

block	volume (size)	mass (weight)	density (water=1,0)	
A	large	1240g	$\rho > 1$	sinks
H	large	760g	$\rho < 1$	floats
C	large	620g	$\rho < 1$	floats
B	medium	620g	$\rho > 1$	sinks
E	medium	370g	$\rho < 1$	floats
F	small < F < medium	190g	$\rho < 1$	floats
D	small	190g	$\rho > 1$	sinks
G	small	10g	$\rho < 1$	floats

Table 1. overview block set

The worksheets used in all three groups were based on a input and predict-observe-explain schema (White and Gunstone, 1992).

block	weight (in g)	size (small, medium, large)	I guess, that it will		I see, that it	
			float	sink	floats	sinks

Figure 2. Worksheet control-condition (translated from German into English)

Whereby the worksheet for the control condition contained a predict and observe column, the sheets for both the experimental conditions contained a predict, observe, and additional a explain column and forced the student to pick the blocks in a fixed pre-determined order. The blocks were arranged in a way that the ones with one dimension in common succeed each other (see Appendix A for those valuable comparisons). The worksheet is designed as a table, in a clearly arranged manner.

block	weight (in g)	size (small, medium, large)	I guess, that it will		I see, that it		explanation?
			float	sink	floats	sinks	
E							
B							
C							
F							
D							
A							
H							

Figure 3. Worksheet experiment-condition 1 and 2 (translated from German into English)

For the E2 condition prompt cards were designed that stimulated students to compare the floating and sinking behavior of specific cubes.

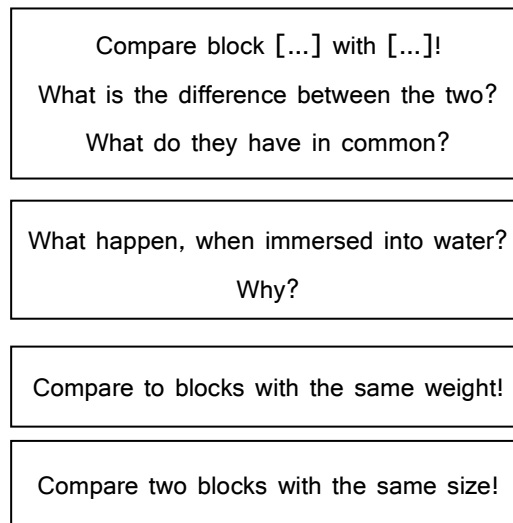


Figure 4. Comparison question and prompts cards used in e2 (translated from German into English)

## Test

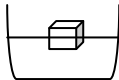
The prior ability was measured by the school marks in math, science and German by the class teacher. As a measure for general ability we use the school recommendation by the class teacher for secondary school (Germany has a three-tier school system after 4<sup>th</sup> grade).

All participants completed the same knowledge test three times: a pretest, a posttest, and a four week retention test. The pre-test, the post-test needs approximately 15 minutes each, whereas the 4 weeks retention test needs 5-10 minutes (no think-aloud). The posttest was used as an indicator of immediate effects and the retention test was administered to investigate long-term effects of the interventions.

Our test was inspired by the pre-conception-test by Yin, Tomita & Shavelson (2008). In order to identify incomplete conceptions of density and the direction of those concepts, we selected test-items regarding to volume, mass and continuity of characteristics. With other words, we used the items to check if the students argue in line with one of the dimensions (mass or volume) mentioned earlier as a common pre-conception or have more mature conceptions such as that the neither mass, nor volume alone is a good predictor of floating or sinking of an object.

The test consisted of four parts; were A focused on the dimension mass, B focused on the dimension volume, C focussed on the continuity of characteristics and D was an open (essay) question.

**Subtest A**



This block is swimming.

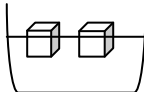
1a) If a second block, made of the same material, is 10 times bigger, would it float or sink? The second block would:   A) float  
  B) sink  
  C) I can't say, because \_\_\_\_\_

1b) If a second block, made of the same material, is 10 times smaller, would it float or sink? The second block would:   A) float  
  B) sink  
  C) I can't say, because \_\_\_\_\_

3) As soon I know the size of a block, I know if it will float or sink.  
Is this sentence right or wrong? \_\_\_\_\_

Figure 5. Example of subtest A (translated from German to English)

**Subtest C**



Block A and B are swimming.

1a) If both blocks are glued together tightly, would they float or sink?  
They would:             A) float  
  B) sink  
  C) I can't say, because \_\_\_\_\_

1b) If block A is cut in the middle, would this block (which is precisely the half of block A) float or sink? This block would:   A) float  
  B) sink  
  C) I can't say, because \_\_\_\_\_

3) As soon I know if blocks float or sink, I also know if the blocks will float or sink when they are glued together or cut into the half.  
Is this sentence right or wrong? \_\_\_\_\_

Figure 6. Example of subtest C (translated from German to English)

We extended Yin et. al.'s (2008) test with an open question about the reasons why things float or sink (see figure 7). The open question format allowed students to give a more creative and fully self-created answer. No forced choice and answer directions are given, to elicit possible hidden knowledge.

<p><b>Subtest D</b></p> <p>What is in your opinion the reason, why things float or sink? Write down your ideas and how do you get them.</p> <hr/> <hr/>
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Figure 7. Example of subtest D (translated from German to English)

For the different question types a matching point schema was implemented to score the test. The student could receive one point for the items 1a, 1b, 2a, 2b and two points for the third item of each subtest A, B and C. The scores in the subtests A – C are indicators of the pre-conception in the measured dimension the students held, whereas the subtest D indicates general knowledge about the phenomenon.

Due to the different and more open question type a coding scheme was developed for subtest D. One point was awarded for phrases like „size/volume alone is not important“, “weight alone is not important“, “it floats, because it contains (more) air“, “it sinks, because it contains (more) metal/stone“. Two points could be earned for phrases like “the material is important” and three points are given for mature explanations like “the proportion of size and weight is important“. Immature pre-concepts, like “heavier things sink and lighter things float” or explanations, based on individual experiences such as, “I once got a sheet of paper which folded sank, whereas the same sheet not folded floated, because of its bigger surface”, were neglected and students received nor points nor discounts.

A second coder rated the 15% of the three multiple-choice sub-tests and the open-question subtest. Cohen's Kappa on the tests and open questions reached 0.98 which can be considered excellent.

### General procedure

The students participated in the experiment during regular school time. Participation was therefore obligatory. The experiment was carried out in a separate room, were individual work without disruption was possible. The experiment last per student one school hour i.e. 45 min.

The students worked individually on the task and were told not to communicate with other students about the content and their findings. The experiment set included for each student a chair and a table with a water basin on it, 8 cubes with different density, a balance with 10 gram accuracy, the “tangram” game, the experiment worksheet (see figure 2 and 3) and a pencil.

The experiment leader briefly introduced herself and the study to the children. She asked a few small talk questions to help the student feel comfortable. The session started with the introduction of the think aloud procedure followed by a short think-aloud training with the puzzle game “tangram”. After the experiment leader gave some motivational tips to stimulate students to think aloud, the microphone was turned on.

The experiment leader shortly introduced the domain and asked the students to start with the pre-test. She explained that she wants to know what the student already knows about why an object floats or not.

After completing the pre-test the participants started with the floating and sinking task. The experiment leader explained to the students that they can use the 8 cubes (A-H) to experiment and test their own ideas about floating and sinking. She demonstrated the procedure, stressing that the students have to write down their expectation and weigh the cube before dropping it into the water. She asked them to write down the mass and the volume of the cube. Afterwards they wrote down whether the cube floated or sank on the worksheet (see figure 2 and 3 for the different worksheets). The experiment leader showed each step of this process exactly to make sure that the participants know what to do. All participants were told that they have to use each cube at least one time and that they were free to use each cube more than one time. If students had at least used each cube one time they were free to stop experimenting when they felt ready.

After students completed the floating and sinking task they received the post-test. The inquiry learning session needs approximately 15 minutes. The retention test was administered to the whole class 4 weeks after the first session of each school. Each student has to make the test individually and silently, time needed ranged from 5 to 10 minutes.

#### **Procedure in the different controlled conditions**

The procedure of the cc group did not differ from the general procedure.

The e1 group received the extended worksheet (*structure*) and the experiment leader explained that they have to choose the blocks in the order of the sheet. They were told that they have to write down an explanation why the particular blocks sank at least after two blocks.



The e2 group received additionally to the e1 procedure prompts and assignments (*structure + problematizing* via prompts). The prompts were written on cards (see figure 4) and read out loud by the experiment leader and subsequently lay down on the table so that the student can have a look at it later on. These assignments had the purpose to dispose the student's attention to certain experimental data, which accordingly could initiate rethinking of pre-conceptions.

After every two blocks which resemble a valuable comparison pair (see Appendix A) the student received the prompting questions formulated as assignments: "Compare block [...] with [...]! What is the difference between the two? What do they have in common?". If the student eventually neglected the explanation part the experiment leader used the prompt for further explanation "What happen, when immersed into water? Why?".

Further prompts were used when a student argues just according to the volume of an object, the comparison assignment would comprise two blocks of the same volume, but with different densities (one denser than water, the other with a lower density than water), for example: "Compare two blocks with the same size!". If, then the students argues the mass is crucial, a comparison assignment was chosen, that let the student compare two blocks with the same mass, but different densities (again one with a lower and the other with a higher density than water) for example: "Compare two blocks with the same weight!".

Beside these assignments the student in the e2 group were prompted on eventually contradicting explanations. Once a student wrote an incoherent explanation, for example that a block sank "because it is heavy", and then later on as a heavier one floats provide the explanation that "the weight does not matter", the experiment leader told the student that his or her explanation is contradicting and further ask him or her to decide on a general explanation or one of the two.

## **RESULTS**

In the following section, we first present the results on the tests. We explored the differences between the conditions based on the scores of the preconception-subtests A, B and C (multiple-choice) and the knowledge subtest D (open question). Subsequently to this quantitative approach, we will show excerpts from the think-aloud protocols of the students to present a more qualitative analyses of the results.

### Pre-test

No a priori differences between the conditions on the pre-test scores were found (subtest A:  $F(2, 64) = .210$   $p = .082$ ; subtest B:  $F(2, 64) = .431$ ,  $p = .651$ ; subtest C:  $F(2, 64) = .381$ ,  $p = .685$ ; subtest D:  $F(2, 64) = .000$ ,  $p = 1$ ).

### Post-test and retention test

Repeated measures ANOVA's with students' scores on respectively the pre-test, post-test and retention test version on sub-tests: A, B, C and D as within variable and the condition as between variable (means and standard deviations are presented in table 8, 9 and 10).

Condition	N	Mean scores of pre-tests			
		subtest A	subtest B	subtest C	subtest D
cc	21	3,50 (1,41)	2,27 (0,99)	3,27 (1,39)	0,45 (0,74)
e1	22	3,55 (1,54)	2,32 (0,89)	3,45 (1,50)	0,64 (1,30)
e2	21	3,77 (1,58)	2,55 (1,22)	3,05 (1,76)	0,55 (0,96)

Table 8. Means and standard deviations of the pre-test scores (standard deviation between brackets)

Condition	N	Mean scores of post-tests			
		subtest A	subtest B	subtest C	subtest D
cc	21	4,85 (1,23)	2,70 (1,03)	3,00 (1,12)	0,60 (0,82)
e1	22	4,77 (1,19)	2,73 (1,16)	3,27 (1,67)	1,77 (1,38)
e2	21	4,52 (1,08)	3,33 (1,02)	2,95 (1,48)	1,90 (1,26)

Table 9. Means and standard deviations of the post-test scores (standard deviation between brackets)

Condition	N	Mean scores of retention-tests			
		subtest A	subtest B	subtest C	subtest D
cc	21	4,19 (1,50)	2,33 (1,32)	3,29 (1,71)	0,57 (0,98)
e1	22	4,55 (1,41)	2,82 (1,18)	3,55 (1,71)	1,41 (1,33)
e2	21	4,00 (1,23)	3,19 (1,29)	3,14 (1,53)	1,81 (1,17)

Table 10. means and standard deviations retention-test

The test revealed a main learning effect from pre to post-test and a minimal and not significant decline from post to retention test. No significant differences between conditions were found for subtest A, B and C. A significant difference between conditions was found for the scores on subtest D. A Bonferroni corrected comparison of the means indicated that students in the e1 and e2 condition outperformed their peers in the control condition. All post-test measures (subtests: A, B, C and D) were analysed by one-way ANOVAs with condition as factor. The subtest A, B and C revealed no significant results on the post-test scores.

Analysis of post-test scores showed a significant effect of condition on the open question (subtest D),  $F(2, 64) = 8.146, p = .001$ .

A post-hoc Bonferroni comparison of the scores on subtest D revealed that participants in the e1 and e2 condition outperformed participants in the control condition ( $p = .05$ ).

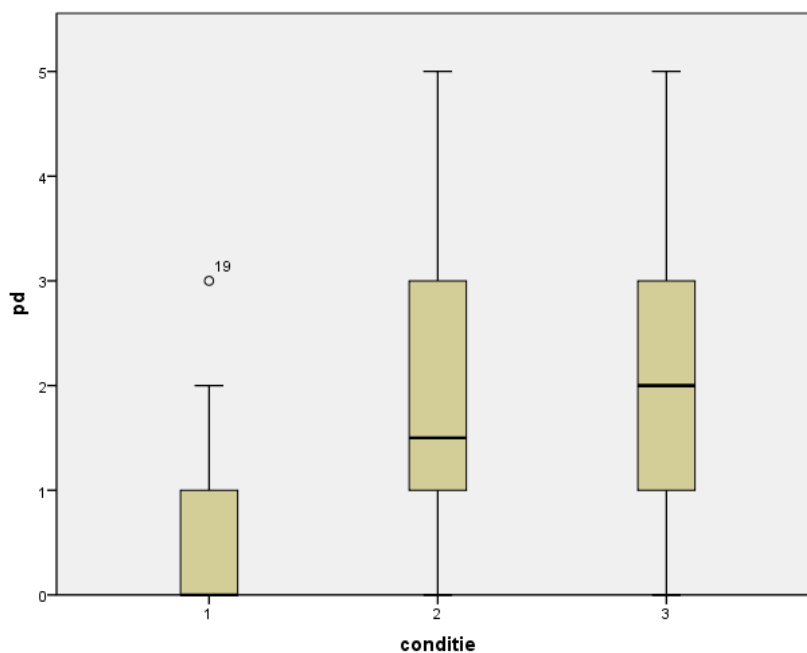


Figure 11. Scores of post-test sub-test D (pd) distributed over the control condition (1), the experiment condition 1 (2) and the experiment condition 2 (3)

## Retention-test

Pairwise-comparison using Bonferroni post-hoc test administered on the 4 week retention sub-test D scores indicated that the students in the e2 group, but not the students in the e1 group, outperformed the students in the control condition  $F(2, 64) = 5,475$   $p = .006$ .

## Interaction-effects

Furthermore is an interaction effect found between the conditions and the math-ability and science-ability. A MANOVA was administered and showed values of  $F(2, 64) = 3.366$ ,  $p = .024$  for the retention sub-test D for math-ability\*condition. Interaction effect size for the retention sub-test D and science-ability\*condition was  $F(2, 64) = 4.873$ ,  $p = .004$ .

## Qualitative Analyses of the think aloud protocols

In the following paragraphs we present excerpts from students' think aloud protocols during the inquiry session and the post-test to provide examples of reactions to the scaffolds in the e1 and e2 condition. Our analyses focus on the student's approach to the different question styles, on the one hand closed questions and on the other hand open questions, and the argumentation while answering the different test items. All excerpts are translated from German into English.

### Excerpt 1

Participant nr.29, e1

During experiment task while thinking about the explanation why C float and A sink

1 Okay, I would say, that A sank, because it is of a material which is really heavy and that's the reason why it sank (explanation)

---

2 I guess that C will float on the water, because it is lighter, probably like E... But it is of a different material, like A, I can feel it immediately, but I guess that it will float (prediction)

---

3 C floats, because it is lighter than A and A consists more of such a stone material, I don't know it precisely, kind of a hard material and C is more like light, I would say, that C floats, because...  
I can't explain it... But definitely a different material than A, but there has to be another explanation... (explanation)

---

4 *What about the material? (experiment leader)*

---

5 C floats, [starts writing] because A is much heavier, that's a kind of stone-material, I guess, and C is not hollow inside, but something different in it, C consists of a different material than A, probably a lighter one (explanation)

The first excerpt is taken from the think aloud protocol during the experimentation task. The participant nr.29 was in the e1 condition, but made already relatively useful comparisons on her own. She also used a more mature argumentation, with the content or material of the cubes as the main point, not only size or volume. Further she said that she can *feel* the different densities of the cubes, but she is not able to name it.

All in all, it was a more structured and sophisticated experiment session, with already good pre-concepts which yield probably as basis for a lot considerable explanations of floating and sinking.

### Excerpt 2

Participant nr.29, e1

During closed question of the post-test subtest A

test item	think-aloud
1a	Sinks, because it is as big as B or D, for example (wrong answer)
1b	Swims, because it has a light weight, too. But I can't tell it precisely, because it just drawn on the paper, but I guess, that it is as light as E (right answer)
2a	Sinks, because it is bigger and therefore heavier than the little one, which already sank (right)
2b	Swims, because it is first of all smaller, I mean very small and if it already sank while the experiment and that one was also small, but that one sank... I don't know it exactly, but... I guess yes, because it is so small it swims. (wrong)

This excerpt is a good example for a single case argumentation while the multiple choice questions had to be answered. The participant did not search for a general rule, but only makes random comparisons to the actual cubes from the experiment.

In the next excerpts we percept the argumentation of the same student much more objective and universally valid.

### Excerpt 3

Participant nr.29

During open question of the post-test subtest D

1 she said	In my opinion, makes the material and the size the difference.
2 she wrote	It is not always the size or the weight alone, why a block floats or sinks. But crucial is both, the weight and the size. I learned that in the experiments, but I already had an idea about that.

This obvious swift in argumentation occurred relatively often throughout the experiment. As we can read in her essay answer, participant 29 had a relatively mature concept of floating and sinking, but still had difficulties to answer the multiple choice format. Although she is not (yet) able to verbalise that the *proportion* of both parameter is crucial, she described in her open essay answer exactly this phenomenon.

#### Excerpt 4

Participant nr.63, e2

During experiment task while answering the comparisons assignments of the experiment leader

1	Experiment Leader (EL)	What's the reason why things float or sink?
2	Student	Crucial is the size and the weight.
3	EL	Can you explain it?
4	Student (St)	Things with more weight sink and things with less weight swim.
5	EL	Look, this one sinks with 200g weight and that one also 200g weight floats. What's the difference between them, what do they have in common?
6	St	The difference between them is the size and they have the weight in common.
7	EL	Can you think of a reason why the one floats, while the other sinks.
8	St	Maybe cause, no, big things not always float, that's not the reason... Maybe because of the weight?
9	EL	They both weigh the same.
10	St	Weight can't be the reason.
11	EL	What would happen if both were the same size?
12	St	Than still they would have different weight.
13	EL	What does that mean?
14	St	Doesn't matter how big or little, no, if this one had the same size? Good question...
15	EL	Hold this one for a while (she holds B and E, same volume-different mass)
16	St	They are different in weight, what could be the reason? Maybe they made of the same material, but different amount of it.
17	EL	So, what the reason why some things float or sink?
18	St	The material.

In this example you can follow the reactions on the comparison questions asked by the EL. You can observe that single dimension pre-concept arguments are automatically excluded by the sort

of the questions the experiment leader asked. Nevertheless, the student needed a respectively amount of time and effort to assume in the correct direction. The excerpt is a part of 6 minutes and between the lines were a lot of “thinking time” of the student.

Whereas participant 63 reacted exemplary to the comparison questions assigned during the inquiry task, she had the same difficulties while answering the closed questions. Although she fell back into the single dimension pre-concept during closed question, in the essay question she was finally able to write down her former in the inquiry task developed more mature concept (here: that the “amount of material” is crucial).

This frequently observed at the first sign contrary argumentation is shown in the next two excerpts.

#### Excerpt 5

Participant nr.38, e1

During closed question of post-test subtest B

test item	think-aloud
1a	Sinks! Ten times heavier! That`s obvious! (wrong answer)
1b	The other swims already and this one is even lighter! (right answer)
2a	Sinks! It`s even heavier! (right answer)
2b	Swims, oh wait, it`s lighter so it sinks. (wrong answer)
3	Because the weight is crucial, most of the times. (wrong answer)

#### Excerpt 6

Participant nr.38, e1

During open question of post-test subtest D

student wrote and said	First the weight, than the size. Big and Light swims; Little and Heavy sinks. The other way round light and little swim and heavy and big things sink and in the middle the weight is crucial.
------------------------	--

Again the student is responsive of the interrelationship between the two dimension volume and mass and it seems that he is even aware of the fact that a definite density is crucial (“in the middle”). But as you see in excerpt 5 he argues solely on the dimension of mass (in his words weight).

## Synopsis

The presented excerpts of the different question styles reveal that students sometimes verbalized and reported mature concepts and physically sound explanations for floating and sinking, while still argue in line with their former pre-conceptions. Thus both conceptions remain side by side.

While the open question style creates a setting where students feel free to describe in detail, what they a priori knew and/or learned during the inquiry session, the closed question yielded an answer style where students mostly relied on their pre-conceptions. These pre-conceptions as mentioned above are based on single case or single dimension explanations, but were in the past as a rule of thumb precisely enough.

We did not only observe this in the control and e1 condition, in which the students received no support of the experiment leader, but also, and that is an important finding, after the comparison assignments and prompting on pre-conception (excerpt 4) in the e2 condition. That shows that in a forced choice environment students tend to argumentations which are not in line with their just made learning progress. In other words a well guided inquiry environment can be the basis of a conceptual shift, but alone is not enough to strengthen this progress irreversible.

## CONCLUSION AND DISCUSSION

The aim of the present study was to investigate the effect of support aimed at students' structuring of experimental data and reflection on the experimental outcomes in a hands-on inquiry learning setting. We compared the learning outcomes of students who worked on a hands-on inquiry learning task on the domain of floating and sinking in one of the following conditions:

- (1) The control condition (cc) fulfils a minimum of those scaffolds, namely the worksheet to keep notes about predictions and observations of each object immersed into water.
- (2) In experimental condition 1 and 2 (e1 and e2) the work sheet is extended with the request to explain why the object actually sank or floated and an anticipated order to evoke comparisons.



(3) Finally experiment condition 2 the experiment leader prompted to contradicting self-explanations of the students and confronted students with the interesting comparisons mentioned above.

It was hypothesised that, first students who are supported by a worksheet that provides them with a predefined experimentation order will have higher knowledge gains than students who can decide the experimentation order on their own. Students who are allowed to determine the experimentation order on their own are probably less systematic which might hinder in the process of making valuable comparisons.

Second, students who receive additional support in the form of comparison prompts will gain more knowledge than their peers. Prompting students to make certain comparisons might stimulate students to make comparisons along the dimensions mass and volume.

Third, we expect that the differences between conditions will last over a longer period.

Our hypotheses were only partially confirmed by the experimental outcomes. No significant differences between conditions were found for students overall scores on sub-tests A, B and C. We do found differences between conditions for subtest D.

Inspections of students think-aloud files suggest that these differences may be due to characteristics of question style. In contrast to sub-test D, which ask the open question “why do objects float or sink”, the sub-tests A, B and C force a decision, if an object actually sink or not. The think aloud files suggests that some of the participants thought of a single object situation and not of a general rule that holds for several situations/objects. Subtest D in contrast asks for a general rule and thus the students are triggered to think about a more coherent concept. Furthermore, we found that some students considered more scientifically accepted explanations that referred to their recent experiences during the hands-on inquiry learning task, but when forced to choice they opted for their initial explanation (naïve conception). The option to answer “I can’t say, because ...” was available, and was the right answer alternative in a number of cases. Unfortunately, students often seemed to associate the phrase “I can’t say, because ...” with being not able to find the correct answer. Furthermore, students might have avoided this specific answer alternative because of the need to explain their decisions, which ask for deeper considerations and additional time and effort.

The question why the closed questions sub-tests revealed no learning effects, whereas the open question sub-test clearly does, could be answered with the fact mentioned above in the introduction, that immature pre-conception remain side by side with the new scientifically

sounded concepts (Zimmermann, 2007). Only when students use their newly acquired more scientifically accepted conceptions, rethink them, are stimulated to use these conceptions in new situations and relate them to other conception. When students feel forced to choose one explanation they may prefer to stick to their initial conception. On the open answer question students could use as many words as they want to explain floating and sinking. Thus the different question style elicit different concepts, which are used as the basis for the answer and if asked explanation.

Students in the e1 and e2 condition outperformed students in the control condition at the post-test (subtest D); students in the e2 condition outperformed students in the cc and e1 condition at the 4 weeks retention test (subtest D).

Our research findings implement practical relevance for the design of support during inquiry learning settings. Namely that, structuring the inquiry task yields a short term learning gain, but for a longer lasting learning gain problematizing in form of prompts seem essential. We are careful to believe that one inquiry learning session causes conceptual change; but we acknowledge that this could be the first step toward it, especially if well supported.

In our particular study we analysed the effect of the support on structuring and problematizing (Reiser, 2004) during inquiry learning sessions and not what impact question style had. Therefore our analyses only provided limited insights into the reasons why students choose for their initial or their newly acquired conceptions. We suggest that prospect research could focus more on question style in regard to conceptual change or at least knowledge gain in an inquiry learning session. Future research could provide valuable information for the development of tests for inquiry learning environments for the classroom as well for scientifically investigations.

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Elisa Kopitzki

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## Appendix A

### *Valuable comparisons:*

*C : B, same weight, unsimilar volume (smaller sinks) or*

*F : D same weight, unsimilar volume (smaller sinks)*

*A : H, same volume, unsimilar weight (heavier sinks) or*

*B : E, same volume, unsimilar weight (heavier sinks) or*

*D : G, same volume, unsimilar weight (heavier sinks)*

*A : E/F/G, unsimilar weight, unsimilar volume (bigger & heavier sinks)*

*D : H/C/E, unsimilar weight,  $\neq$  volume (smaller & lighter sinks)*

### *Comparison question and prompts used in e2*

*Compare block [...]! What is the difference between the two, what do they have in common?*

*What happend, when immersed into water? Why?*

*Compare to blocks with the same weight!*

*Compare two blocks with the same size!*