RESEARCH ARTICLE

# From cookbook experiments to inquiry based primary science: influence of inquiry based lessons on interest and conceptual understanding

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**Abstract**

Inquiry based science education – if carried out effectively - can be a very efficient way to facilitate conceptual understanding both of important scientific ideas and how science works. Additionally it can promote positive attitudes towards science and learning science. For this study we evaluated a series of inquiry-based lessons on the role of plants as oxygen producers on its impact on i) students' attitudes towards independent investigation, ii) conceptual understanding and ii) understanding of characteristics of scientific experiments. The evaluation shows clearly that the conducted inquiry- based lessons raised students' interest for student-centered investigation and facilitated the understanding of content. Students' understanding developed from describing the scientific phenomenon using everyday language to explaining the scientific phenomenon using scientific vocabulary and making links to the conducted experiments to support their explanations. Additionally students' understanding of characteristics of scientific investigations (fair testing) was improved.

## 1. Introduction

Inquiry is a central term in the rhetoric of present science education reforms in Europe. One unifying goal of these reforms is the promotion of positive attitudes towards science and learning science. The importance of this promotion is emphasized by the mounting evidence of a decline in young peoples' interest in science studies and careers. Positive contacts with science at primary level are believed to have a long-lasting impact on students' interest in science whereas negative experiences at school, due to uninteresting content or poor teaching, are said to be very detrimental to future choices (OECD, 2006). Motivating students to study science is a worthy aim , however we believe that the primary goal of science education must not be to produce the next generation of scientists, but to offer an education that develops students' basic understanding both of the major ideas of science and of how science works (Osborne & Dillon, 2009). To achieve this goal we need to refocus science teaching on meaningful learning and conceptual understanding of scientific ideas rather than teaching and learning isolated fragments of theoretical knowledge. We do believe that inquiry-based science education, if carried out effectively, is a very efficient way to facilitate conceptual understanding. Learning with understanding is different from remembering facts such as the names of the planets in the solar system, which particular objects float or sink or the photosynthesis equation (Harlen et al., 2012). This is not to say that facts are not important, but rather that alone they are insufficient for developing understanding. The important thing is for students to understand why things do or don't float, why plants can't grow in the dark and what evidence supports these concepts. A review of 138 studies focused on the outcome of inquiry-based science education has shown that if students get the opportunity to engage in active thinking and are subsequently asked to draw conclusions from data they are more likely to understand the inherent scientific content. In addition institutions that foster engagement with science phenomena and put emphasis on student responsibility for learning are more likely to support students' understanding (Minner et al., 2010). These findings are consistent with constructivist learning theories — active construction of knowledge is necessary for understanding.

Besides the potential that is attributed to inquiry-centred teaching and learning by educational policy makers (Rocard et al., 2007) and curriculum developers, inquiry-centred teaching is still the exception in Austrian primary school classrooms. Children in primary school have a natural curiosity for science and can easily be motivated for conducting experiments (Bertsch et al., 2011; Fridrich et al., 2012). However, many of their teachers feel uncomfortable with science subjects and lack the confidence for conducting inquiry-based activities in the classroom (Bertsch, 2014). To cope with their low confidence they use different strategies such as i) teaching as little of the subject as possible, ii) emphasizing expository teaching and underplaying questioning and discussion and iii) avoiding all but the simplest practical work that could go 'wrong' (Harlen, 1999). Additionally, if inquiry is conducted in Austrian primary classrooms, lessons often focus on the hands-on aspects of inquiry only. Children are allowed to experiment and manipulate. However, these lessons often fail to capture important characteristics of inquiry and do not necessarily have a positive impact on students' content learning and retention. Inquiry in our understanding bears little resemblance to the cookbook experiments found in many science classrooms or to the very simple forms of inquiry found in many Austrian textbooks (Greinstetter, 2011), because the minds-on aspects of inquiry – predicting, planning experimenting, drawing evidence based conclusions on the basis of own observations, debating with peers and forming coherent arguments - are missing.

To address the lack of effective inquiry at primary level, more than 40 inquiry-based lessons on plant related topics were developed in the context of the EU funded project plant science garden which was coordinated by the second author. For this paper a series of 5 lessons on the role of plants as oxygen producers were designed and evaluated. In these lessons the young learners are asked to work in teams to make predictions and to design investigations to test their predictions. On the basis of these experiments students were expected to come up with their own conclusions taking their observations into consideration and constructing arguments to convince their peers. Reflecting on their own investigations and discussing historic experiments students gained insights into the processes and the nature of scientific inquiry. Teaching materials including lesson plans, worksheets for students and useful background information for teachers can be found on www.plantscafe.net.

To get a clearer idea of how inquiry was implemented in the lessons we want to share the following description of one of these five lessons with you. In the previous lessons students elaborated the composition of air, found out that exhaled air differs from fresh air and discussed Priestley's historic experiment that led to the discovery of plants as oxygen producers. The aim of this lesson is that students find out that plants need carbon dioxide and light to produce oxygen.

Groups of four children are gathered round their tables. Three sprouts of a water plant (Elodea sp.), three test tubes and three bottles of different types of water (mineral water, distilled water and tap water – they differ in the amount of $CO_2$) are offered on each table. The children can use the equipment to conduct a series of tests to find out that plants need carbon dioxide to produce oxygen. By observing and counting oxygen bubbles produced by the water sprouts they observe the dependence between $CO_2$ content of the water and the $O_2$ production rate of the plant. Distilled water does not contain any carbon dioxide, thus no oxygen was produced. Another question is: 'do the plants need light to produce oxygen?'
The teacher, Mrs. Maier, hands out a concept cartoon (Naylor & Keogh, 1999) on the role of light for the oxygen production of plants and asks the children, who they think is right.

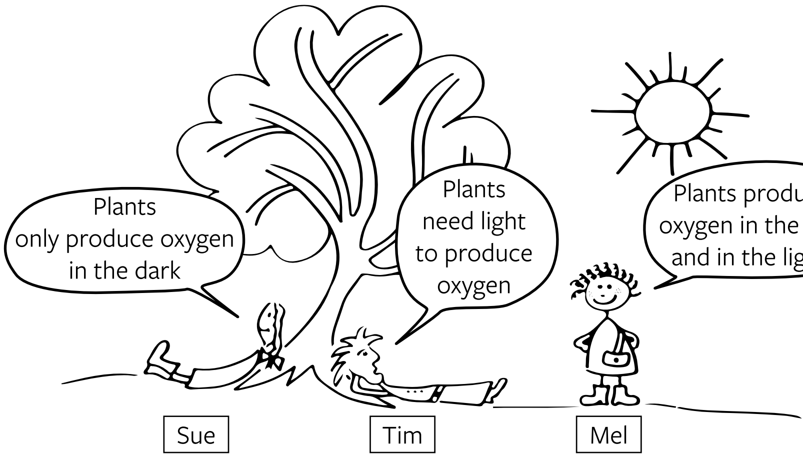


**Figure 2:** Concept cartoon on the role of sunlight for oxygen production

Most of the children think that Mel is right and that plants produce oxygen during day and night, because otherwise 'we could not breathe during the night and would die'. Two children, Rose and Jonathan, say that they think Tim is right and plants need light to produce oxygen. The children start enthusiastically to test their ideas. One group darkens the room and observes what happens in the test tube. Another group uses shoe boxes, which teacher brought to the classroom. Another group uses the overhead projector as a light source.
They are taking measurements of the number of oxygen bubbles using stopwatches and are recording them on their activity sheets. Some groups generate drawings of their experimental design.

**Figure 3:** Oxygen production in the light...

**Figure 4:** ... and in the dark

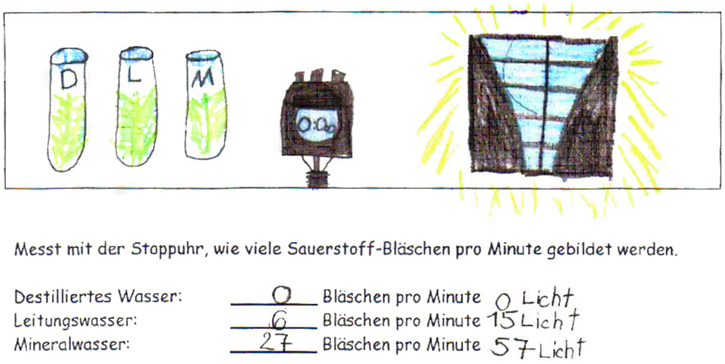


**Figure 5:** Experimental design and results

As far as we can see, the teacher has only had a brief conversation with the class at the start of the activity, when she introduced the concept cartoon. Most of the groups continue to test their ideas changing the experimental design. Some pupils walk around the classroom and observe others doing their experiments. Then they go back to their group report on what they saw and copy good ideas. One group has difficulties setting up a new experiment. In this group Mrs. Maier helps them by asking questions, not by providing answers.

As one child closes the curtain it is quite dark in the classroom now. But the plants are still producing oxygen bubbles. Children notice that the number of oxygen bubbles per minute is decreasing but the plant is still producing. Thus many children think that their prediction was right and that plants produce oxygen during day and night. Some children argue that 'in the night when we sleep we need less oxygen that's why the plants produce less oxygen'.

One student, Rose, however still believes that the plants need light to produce oxygen and argues that it still isn't dark enough in the classroom. Her group changes the experimental design and puts the test-tubes with the plants into a shoe box. There are even fewer bubbles now but there is still oxygen production. The children are discussing their observations. Rose is still convinced that plants need light to produce oxygen. She explains her ideas as following: 'The less light the less oxygen bubbles. We still can observe oxygen bubbles, because it is not completely dark. The problem is that we cannot see and count the bubbles, if it is completely dark'. Fifteen minutes before the end of the lesson the children stop experimenting. Mrs. Maier asks them if the groups have come to a conclusion. Most of the children, even Jonathan, who was convinced that plants need light to produce oxygen at the beginning of the activity, think that plants produce oxygen during the day and night, but that during the night less oxygen is produced. Only Rose's group says that Tim is right and they use the above mentioned argument for their conclusion.

Each child is asked to write their findings on their activity sheet. Many of the children jot down that plants produce oxygen during the day and night. Before the end of the lesson all test tubes with the water plants are put into shoe boxes. All the boxes are stored in a corner of the classroom and covered with a dark cloth.

The next morning, before the lesson starts, two children come to Mrs. Maier and say that they have changed their mind and that they now think that Tim is right. It seems that they thought about the experiment at home. Mrs. Maier starts the lesson with a repetition of what they did yesterday. Then she uncovers the test tubes and every group gets its tubes and observes what is happening. No bubbles are produced at all. Many of the children erase what they had written the day before and replace it with a new sentence like 'we have found out that plants do not produce oxygen when it is completely dark'. But this insight raises new questions! 'Why can we breathe during the night?' 'How can people breathe in the dessert, if there are no plants?'

Mrs. Maier uses these questions to discuss the function of the atmosphere and the role of the rain forests and seaweed as huge oxygen producers.

Was this a good science lesson? The children weren't told hard scientific facts. Records did not follow the commonly used structure of an experimental protocol using headings such as apparatus, method and results. At the end of the first day most children even had a wrong concept without being corrected. The activity sheets were a mess, because many children had to overwrite their conclusions from the day before.
And yet it felt like a good science lesson. The children could clearly talk about their ideas and test their ideas. They were very motivated and worked actively on their own. They discussed their ideas in small groups and used arguments to underpin their findings. Some even found plausible arguments for their wrong conclusion. Some of them were thinking about the problem at home and discussed their experiments with their parents. At the end of the next morning they had a clear answer and obviously made some conceptual progress.
After the lesson Mrs. Maier writes into her project diary: 'We discussed the experiment set up, because on the previous day many of the students still didn't understand that plants need light to produce oxygen. Through the experiment all of them seemed to be convinced that this is the case. At this point – it's the fifth day of the project – I notice that children make connections between the insights gained through the single experiments'.
Mrs. Maier is very pleased with the progress children make and how enthusiastic they are. Mrs. Maier herself lost her nervousness and feels comfortable with the situation of children exploring and investigating on their own. She is gaining the confidence to conduct inquiry centred lessons and shares her knowledge with her colleagues in school.
The lesson described was one of five inquiry-based lessons Mrs. Maier conducted with her class on the topic plant as oxygen producers. In the other lessons different methods were used but in all the lessons children were encouraged to do their own investigation. In all lessons the children were actively engaged in both thinking (minds-on) and doing (hands-on). At the end of the lessons not only the outcomes of the experiments but also the scientific investigation itself were discussed. We do believe that providing inquiry followed by a reflection on the outcomes and the methods applied to produce these outcomes is the most effective way for developing an understanding not only about the topic of the lesson but also about the processes and the nature of science. 'Teaching science and teaching about science is at its best by having students perform scientific investigations followed by reflection on these activities and the nature of the knowledge produced' (Abd-El-Khalick et al., 2004)

## 2. Objectives

The objectives of this study are to present

1. whether the inquiry-based teaching materials had an impact on primary school children's attitude towards independent student-centered investigation
2. how students' concepts concerning the composition of air and the role of plants as oxygen producer changed in course of the project and
3. how the students' knowledge about key characteristics of a scientific experiment (fair testing) developed in course of the project.

## 3. Methods

The teaching materials were tested in four primary school classes with 84 students (43 boys and 41 girls) age 9 to 11 years. The students' investigations in class were supervised by their teachers after they attended training on inquiry-based science education using the developed material. The lessons were observed and filmed. To monitor attitudinal change we used a questionnaire consisting of a 4 point Likert scale. The scale drew on a set of items from the study of Pell and Jarvis (2001) and the questionnaire was administered before and after the project. To test attitudinal change the data was analyzed using the non-parametric test according to Wilcoxon (Bortz, 2003).

Gender bias of attitudes towards science in general and science experiments in particular were tested using the Mann-Whitney U-test (Bortz, 2003). The data was analyzed using the software SPSS. To facilitate reading we chose to present means and standard deviations instead of the mean ranks that are the basis of the Wilcoxon test. To test students' knowledge about characteristics of a scientific experiment this questionnaire included three questions focusing on different aspects of a scientific experiment: using a control group, changing only one single factor in each experiment and the need of measurability. These questions were adapted from the TIMSS 2007 study. To monitor conceptual understanding we interviewed 20 groups of four to five students each (n= 84) before the first lesson and one week after the last lesson and asked them about their concepts of air. The focus was put on the difference between exhaled and fresh air and the role of plants as oxygen producers. Student discussions were recorded, transcribed and analyzed following a grounded theory approach (Glaser & Strauss, 1967) using the software Atlas.ti.
Additionally the teachers were asked to use project-diaries and to write down their observations after every lesson and we interviewed them a few days after the last lesson. These notes and interviews were also analyzed using the grounded theory approach.

## 4. Results and Discussion

### 4.1. Influence of inquiry based science lessons on attitudes towards independent student-centered investigation

The 4th grade primary school students in our sample have very positive attitudes towards school science in general, even though it is not considered as being an easy subject (Table 1). Our results suggest that students enter secondary school with a highly positive attitude towards science. A review of literature on attitudes towards science supports these findings. A clear feature of international research is the decline in attitudes towards school science from age 11 upwards (Osborne et al., 2003). The absence of any gender difference in our sample (Table 1) does not support the view that science is a male subject at this level of education (Jones, 2000).

**Table 1:** Interest in school science (1= I strongly agree, 4= I strongly disagree)

| | Girls | | | Boys | | |
|---|---|---|---|---|---|---|
| | N | Mean | STD | N | Mean | STD |
| I like learning science | 41 | 1,49 | 0,64 | 43 | 1,47 | 0,67 |
| Science is boring | 41 | 3,56 | 0,77 | 43 | 3,65 | 0,78 |
| Science is easy | 41 | 2,22 | 0,88 | 43 | 2,07 | 0,91 |

Our results show that students especially like the co-operative practical hands-on aspects of science (Table 2). In the pretest there is no significant difference in attitudes towards 'watching the teacher doing experiments' and 'doing experiments on your own'. However, the pretest suggests that children are not so keen on finding out how an experiment works on their own. They prefer 'Teacher is telling you how an experiment works' to 'Finding out how an experiment works on my own'. These findings are in line with other studies (Pell & Jarvis, 2001).

**Table 2:** Interest in school science (1= I strongly agree, 4= I strongly disagree); ** Statistically significant difference between same items pre- und posttest, Wilcoxon signed rank test, α=0.05

| | | Pretest | | Posttest | |
|---|---|---|---|---|---|
| | N | Mean | STD | Mean | STD |
| 1) Working with worksheets | 84 | 1,76 | 0,75 | 1,77 | 0,70 |
| 2) Watching the teacher do an experiment | 84 | 1,19 | 0,55 | 1,48** | 0,74 |
| 3) Doing experiments on your own | 84 | 1,08 | 0,39 | 1,06 | 0,24 |
| 4) Teacher telling you how an experiment works | 84 | 1,32 | 0,64 | 1,63** | 0,76 |
| 5) Finding out how an experiment works on my own | 84 | 1,62 | 0,87 | 1,24** | 0,62 |
| 6) Working with friends | 84 | 1,31 | 0,56 | 1,37 | 0,69 |
| 7) Working alone | 84 | 2,26 | 0,99 | 2,40 | 1,13 |
| 8) Making excursions | 84 | 1,08 | 0,35 | 1,00 | 0,00 |

After conducting the inquiry-centred lessons we observed a significant change in the attitudes towards item 2, 4 and 5 (Table 2). Using the non-parametric test after Wilcoxon we noticed that positive attitudes towards 'watching the teacher doing an experiment' and 'teacher telling you how an experiment works' decreased significantly, whereas students' interest towards 'finding out how an experiment works on your own' increased significantly. Looking closer at item 3 and 5 we get a sub-scale 'student-centred investigation' that can be used as a measure for individual investigative science. Focusing on item 2 and 4 we can create a sub-scale 'teacher-centred investigation', pointing towards a measure of instructed investigation.

The use of the developed inquiry-centred materials - where students were asked to formulate questions, make predictions and design investigations to test their predictions on their own - led to a decrease of interest in teacher-centred investigations. At the same time the students gained the confidence to find out how experiments work on their own and a significant increase of interest for individual investigations was observed. There is no gender difference identifiable concerning interest in individual investigation.

This was noticed by one of the teachers as well. She wrote in her project-diary:

> I noticed that on the first day it was almost impossible for them to draw conclusions from what they have seen. They asked me what they should write down. This changed dramatically over the course of the project. And this is the main achievement for me: I observe and I think about what that means! There was a development from 'I observe then I ask the teacher what I have to write down' to 'I observe then I try to write down my own conclusions'. This improvement is the best thing of this approach.

### 4.2 Development of students' concepts of air composition and plants as oxygen producer

For many science education researchers the constructivist view of learning has proved to be a powerful model for describing how conceptual change in learners can be promoted (Gerstenmaier & Mandl, 1995; Duit & Treagust, 2003; Duit, 2009). The central point of this approach is that learners can only make sense of new situations in terms of their existing knowledge. Learning is therefore an active process in which learners construct understanding by linking new ideas with their existing knowledge (Reinmann-Rothmeier & Mandl, 2001). Transferred into everyday language the constructivist approach is closely linked to the notion of 'starting where the child is' (Naylor & Keogh, 1999). Learning in science from a constructivist view therefore includes the following criteria:

- Students' own concepts develop to scientifically accepted concepts
- Describing scientific phenomena develops to explaining scientific phenomena
- Use of everyday language develops to the correct use of scientific vocabulary

To identify the pre-instructional concepts the students were interviewed in groups of 4-5. For the interview we used a nylon bag, exhaled into this bag and asked the students if there is a difference between the air inside the bag and outside the bag. The discussion was then focused on possible differences and the connection of plants and air.

Most of the students knew that there is a difference between fresh and exhaled air, however only a few could describe the difference correctly. Some children had alternative explanations for exhaled air like the air is dirty or used.

**Interviewer:** What happens if I continue breathing in and out the bag?

**Child 1:** You will pass out.

**Child 2:** There is no air in the bag.

**Child 3:** There is air but it is not good for your body.

**Interviewer:** What does it mean, not good for the body? What is the difference to the air in this room?

**Child 1:** The air is not clean. It is used.

**Child 2:** And it is dirty.

These kinds of explanations were coded as 'alternative explanations'. In twenty interviews this code was used eleven times. Other children had a clearer understanding about the difference between fresh air and exhaled air, even if they had problems with the correct wording.

**Interviewer:** What happens if I continue breathing like that?

**Child 1:** There will be no oxygen. Carbondiotisi or so will be produced.

**Interviewer:** Carbon-dioxide?

**Child:** I breathe in oxygen and I breathe out this diotisie – oh man forgot it again. And when you use a bag you only inhale what you have exhaled before and pass out.

**Child 2:** The trees do it the other way round. They take in carbon-dioxide and spread oxygen.

In this interview the codes 'oxygen' and 'carbon-dioxide' were used. In the twenty interviews before the inquiry centered lessons the code 'oxygen' was used twelve times, the code 'carbon-dioxide' five times. All interviewed groups knew that trees improve the air quality; some said trees make the air fresh while others said that trees produce oxygen.

After the project the same interviews were carried out with the same groups of students. In twenty out of twenty interviews 'oxygen' and 'carbon-dioxide' were mentioned, 19 times 'nitrogen' was mentioned. There were no 'alternative explanations' and 18 groups could tell the interviewers the composition (21% oxygen, 78% nitrogen, 1% carbon dioxide and inert gas) of fresh and exhaled air in percentage as discussed in the lessons.

**Table 3:** Frequency of used codes; pre-interviews and post-interviews (n=20)

| | N | Oxygen | Carbon-dioxide | Nitrogen | Alternative explanation | Composition of inhaled/exhaled air |
|---|---|---|---|---|---|---|
| Interviews before instruction | 20 | 12 | 5 | 0 | 11 | 0 |
| Interviews after instruction | 20 | 20 | 20 | 19 | 0 | 18 |

Before the inquiry centred lessons the students knew that there is a difference between fresh and exhaled air; however the majority could not explain the difference. They used alterative explanations like 'bad air' or 'used air'. In the course of the project the students learned to explain the difference using adequate scientific vocabulary.

**Interviewer:** What kind of air is in the bag?

**Child 1:** Exhalation-air.

**Interviewer:** What is in this air?

**Child 1:** Carbon-dioxide, Oxygen, Nitrogen.

**Interviewer:** Great – do you know the distribution?

**Child 2:** Yes. 16 parts Oxygen, 78 parts Nitrogen, 6 parts carbon-dioxide.

**Child 1:** And in the air we inhale are 21 parts oxygen and only 1 part carbon-dioxide.

**Child 2:** Because the plants take in the carbon-dioxide and produce oxygen. The have tiny holes in their leaves – stomata.

**Interviewer:** That sounds different to the last interview.

**Child 2:** Yeah - that was silly.

The last sentence shows that the children are well aware of their progress. Their concepts developed to scientifically accepted concepts and they were able to use scientific vocabulary correctly. Even better they could easily match the experiments they conducted to their understanding of air and the role of plants as oxygen producer. They could explain how to prove that there is a difference between fresh and exhaled air, how to prove that plants produce oxygen and what they need to do so.

### 4.3 Development of students' knowledge about key-characteristics of a scientific experiment

The ongoing discussions revolving around the concept of scientific literacy stress the importance of developing images of science that are consistent with current scientific practices. Students should develop an understanding of what science is, what science is not, how science works, what science can and cannot do, and how science contributes to culture (Schwartz et al., 2004; Hmelo-Silver et al., 2007; Lederman 2008). During teacher training on the materials we discussed the importance of not only talking about the outcomes of single experiments with students, but also about the process of the experiment itself (Sadler et al 2010). What are key-characteristics of a scientific experiment? How does a scientific investigation differ from just experimenting by trial and error? We also talked about key-characteristics of fair testing like working with a control group, modifying one variable only whilst not changing others in one experiment and trying to collect measurable data. During lessons children had the possibility to experiment, to manipulate and to measure. It was up to the teacher supervising classroom activities to explicitly reflect on these methods of data collection. In our observations we noticed that it is easier for teachers to run a discussion on outcomes of the experiments than on the process itself. Only two out of four teachers we observed explicitly discussed the processes of scientific investigations with their students. In the interviews with the teachers this observation was confirmed. When asked about the aims of the single lessons teachers mentioned mostly topic related aims (e.g. students should know the difference between fresh and exhaled air, students should know that plants need light to produce oxygen). Process related aims (i.e. students should know that in a scientific experiment control groups are used) were hardly mentioned, although it was discussed during teacher training. The concept of the nature of science is a very new one to Austrian primary school teachers and it is neither mentioned in the curriculum nor in pre-service teacher training. Maybe this explains the problems our teachers have when it comes to making the nature of science or scientific investigations explicit. However a recent study by Capps and Crawford (2013) revealed that even though reforms in science education have advocated the implementation of inquiry based instructions and teaching about the Nature of Science in the US since 1989 even well qualified and highly motivated teachers have limited experience with scientific inquiry and hold naive conceptions of the nature of science. The authors therefore emphasize the 'the need for rigorous and continuous professional development to support teachers in learning about inquiry and NOS and how to enact reform based instruction in classrooms' (Capps and Crawford 2013, p.497). Nevertheless we noticed a strong increase of correct answers concerning the three questions on the characteristics of a scientific experiment. In the posttest 60% of the students could answer the question on the use of a control group correctly (33% in the pretest). 53% of the children answered the question on the need of measurable data correctly (31% in the pretest) and 80% answered the question correctly on the need for changing only one factor at a time whilst keeping the others constant (55% in the pretest).

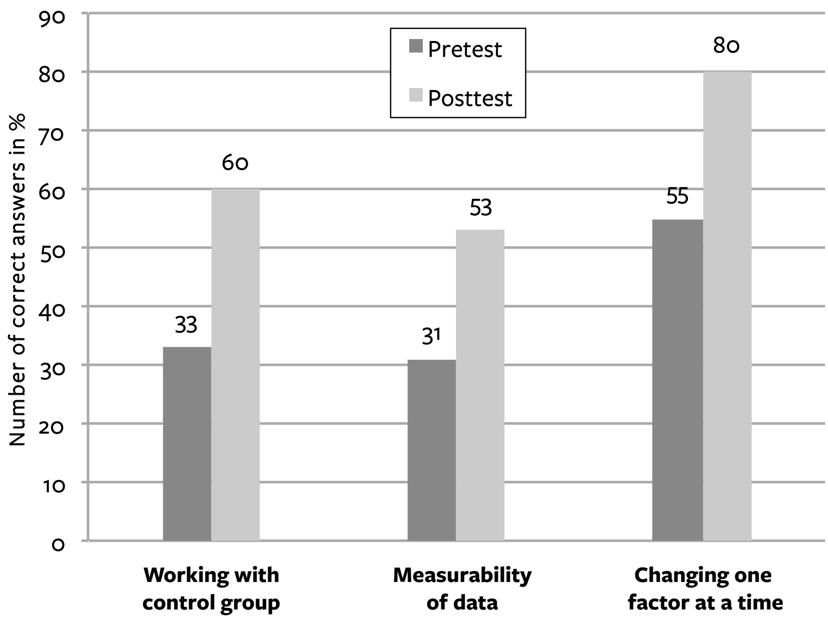


**Figure 1:** Number of correct answers on questions concerning key-characteristics of a scientific experiment in % (n=84 student, pretest and posttest)

This increase can be explained by the two observations that i) students had to develop their own investigations in small groups. In the groups we often saw single students that had a clear idea about fair testing and discussed this ideas with their peers and ii) two out of four teachers testing the materials explicitly discussed the nature of scientific investigations and experiments with their students. There is still room for improvement (e.g. 'only' 60% knew about the need to use a control group after the lessons). Our results show that doing inquiry-based science has the potential to change students' ideas about the nature of scientific investigation. Our data supports the idea that inquiry based science teaching is at its best by combining inquiry-based sequences with a reflection about both the outcomes and the processes of the investigations. To achieve this kind of science teaching teachers themselves must be aware of how science works and what the characteristics of scientific investigations are. This can only be facilitated if the nature of science is made explicit in the pre-service and in-service training of primary science teachers (Sadler et al. 2009).

## 5. Conclusion

We do believe that inquiry-based science education – if carried out effectively - is an efficient way to facilitate conceptual understanding of both important scientific ideas and how science works. Carried out effectively means that it bears little resemblance to cookbook experiments found in many Austrian textbooks but combines hand-on aspects, where children are allowed to experiment and manipulate with minds-on aspects, where children have the possibility to predict, plan experiments, draw evidence-based conclusions on the basis of their observations, debate with peers, and form coherent arguments. The evaluation of five inquiry-based lessons on the role of plants as oxygen producers shows clearly that inquiry-based lessons hold the potential to raise students' interest for student-centred investigations and facilitates the learning and retention of content. Students' understanding developed from describing the scientific phenomenon using everyday language to explaining the scientific phenomenon using scientific vocabulary and making links to experiments to support their explanations. Additionally students' understanding of characteristics of scientific investigations was improved. We consider science teaching to be at its best when students have the possibility to perform scientific investigations followed by joint reflection on the outcomes of these activities, as well as on the process of investigation itself and the nature of the knowledge produced. However, science education researchers and teacher trainers have to be very explicit about the fact that inquiry is more than doing experiments. If the hands-on aspects do not trigger active thinking and the drawing of evidence based conclusions opportunities that lead to enhanced conceptual understanding are missed.

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