

Impact of Experiments on 13-year-old Pupils' Understanding of Selected Science Concepts

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The purpose of this study was to establish what impact experimental work has on the understanding of scientific concepts, what pupils remember about the experiments they carried out and how they are able to formulate and understand the experiment plan. A sample of 386 pupils aged 13+ participated in the research, of which 162 in the experimental group conducted 5 experimental science activities. Instruments used with all pupils in this study include: pre-test, knowledge test, delayed knowledge test and questionnaire, while 39 of the pupils also took part in semi-structured interviews. The results show that 35.8 % of pupils in the experimental group failed to write down at least one experiment they remembered from science classes, and none of remaining 64.2 % of pupils that wrote down at least one experiment correctly described it. In addition, the results of the interviews show that only 2 pupils remembered the experiments from 5 experimental science activities three months after the experimenting without interviewer's help, and only 5 pupils were able to adequately name and describe those experiments and interpret the experiments' findings. Although they were unable to describe the experiments, the students in the experimental group scored higher on the test and the delayed test than the pupils in the control group with a statistically significant difference. The results of the survey also show that pupils believe experiments to be the most popular part of science classes.

Keywords: experiment, primary school, problem tasks, science concepts, understanding

INTRODUCTION

An important part of personal general knowledge is science knowledge. Research shows that students enjoy experimental work during science lessons (Prokop, Prokop, Tunnicliffe, 2007; Prokop, Tuncer, Chudá, 2007; Braund, Driver, 2005), when the subject matter is not too complex and difficult. To prevent this from happening, in theory teachers should introduce science through experience with focused practical and experimental work (Abrahams & Millar, 2008) with frequent reflection on understanding (Herbert & Burt, 2003), doubt (Grooves & Pugh, 2002, Kalman, 2002)

and argumentation (Sampson & Clark, 2008). Experiments should aim to encourage pupils to develop manipulative skills, accurate observations and careful data recording, acquire information to interpret and to comprehend concepts and phenomena. The aim is also to develop abilities to plan experiments (Welzel et al., 1998).

Simpler experimental tasks provide firm ground for challenging questions, while more difficult ones usually bring confusion and strongly influence the experimentation enthusiasm, especially in an unguided instructional environment (Kirschner, Sweller & Clark, 2006). Research shows that pupils learn less when they themselves have to do more demanding and difficult experiments (Johnstone & Al-Shuailli, 2001). Pupils are not encouraged to think about what evidence is provided by their measurements, what the obtained data represent and what else could be concluded by broadening the experiment range (Klassen, 2009). In the

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State of the literature

- Students are interested in experimental work, when the subject matter is not too complex.
- Science should be introduced through experimental and practical work with students' reflection on their understanding, and argumentation.
- Experiments should encourage students to develop manipulative skills, be able to accurately observe and carefully record data, acquire information, interpret findings and plan experiments.

Contribution of this paper to the literature

- The study analysis the impact of experimental work on the understanding of selected scientific concepts and define what students remember from specific experiments.
- From the qualitative and quantitative analyses we can conclude that only conducting an experiment it is not enough to understand the concepts behind the experiment and they are also not able to remember the experiment at all.
- Students adequately describe and explain the experiments after some period of time only if they really understand the underlying science concepts. Students' experimental descriptions can be used to identify specific misconceptions.

review of the pupils' version of Millikan's oil drop experiment, Klassen (2009) identifies three essential aspects, which could be generalised to most pupil oriented science experiments; (1) exposing the difficulty in obtaining experimental results if the scientific method behind the experiment is strictly followed, (2) dealing with the difficult nature of the science behind the experiment, and (3) establishing the experiment outcome.

Through practical work, the pupils' knowledge and understanding of science is likely to be increased (Wellington, 2005), but it is important to distinguish between "knowledge", "knowledge how" and "knowledge why". Engaging in practical activities improves pupils' knowledge of what happens and how it happens, but not also why it happens. Understanding why is not the pupils' "discovery" behind the experiment, but self-reflecting on the experimental work already done.

What the pupils perceive as important to learn from a regular laboratory exercise is affected by the teacher's objectives (Högström, Ottander & Benckert, 2010). In this single case, the research results point to the

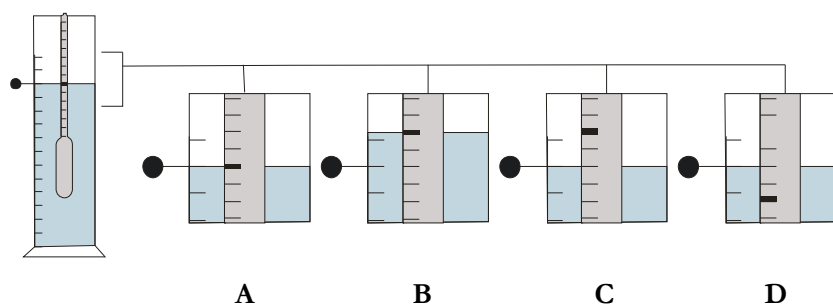
importance of teacher involvement to help pupils understand what to look for, how to do it and why. Poorly structured and overcomplicated tasks and lab work decrease the pedagogical value of the experiment and students' interest in it (Osborne, Simon & Collins, 2003). Instead of focusing on the outcomes of the task or experiment, pupils usually spend more time on dealing with instructions and preparation, which greatly affects the time needed to complete it. Learning experiences for pupils to plan their own experiments should be provided in laboratory exercises designed especially for such purposes (Högström, Ottander & Benckert, 2010) with well defined constants and variables to make sense of the data.

Learning through practical work and experience is very important in science lessons. Research on the effect of using live animals in the classroom on pupils' perception of the animals showed that, in comparison to other approaches, pupils get a better attitude and long-lasting knowledge about the living organisms (Tomažič, 2009), they experiment without the teacher's intervention (Tomkins & Tunnicliffe, 2001) and also invent and unify their own terminology while reporting on the experiment. In general, pupils are intrinsically motivated towards learning, but not also for explaining abstract experimental observations (Jurišević, et al. 2008). It is interesting that in this research pupils' motivation for observing chemical phenomena is almost as high as their motivation for learning biology and mathematics. Pupils show interest in more concrete content, while abstract content gives rise to anxiety.

Purpose of Research, and Research Questions

To increase the pupils' perception of the usefulness of the knowledge of science concepts, a set of problem based experiments was introduced that encourage practical skills, experiment observations, data recording and information gathering. The introduction to experimental work, preparation of instruments for conducting the experimental work and first observations was teacher guided, while all later observations, data recording and information gathering were structured as group guided activities. The experiments were designed to be simple to do and the observations easy to interpret. The concepts behind the experiments were known to the pupils at least at the declarative level of understanding.

Pupils in the experimental group had to prepare, make and use the simple instruments (see appendix) for a longer period of time and also define the observed relative and absolute changes they could see on the measuring instrument, write down the data and transform the data to a graph.



The correct answer is __, because _____

Figure 1. The first task of the test.

The aim of the research was to establish the impact of experimental work on the understanding of selected scientific concepts: temperature, density, air-pressure and precipitation. The research questions were: (1) what details pupils remember from the experiment they observed or carried out, if the concepts behind the experiment are known, and (2) how detailed pupils' descriptions and explanations of the experiments are after a period of time.

METHOD

Participants

Overall, 386 seventh grade pupils participated in the research in the school year 2006/2007. On average, the pupils were 13 years old and were from 14 different schools. Among those students there were 162 (85 boys, 77 girls) students from 7 experimental schools and 224 (107 boys, 117 girls) from 7 schools in the control group. The sample represented a population with mixed socioeconomic status. Seven experimental schools were selected to represent various demographic backgrounds, but were matched with the schools from the control group. Average test score on the pre-test was 14.8 (46.0% success, min = 0, max = 31) with average difficulty index at 0.43 and discriminative index of 0.4 ($p < 0.01$). The experimental and the control group showed no statistically significant differences (exp: $M = 15.1$, $SD = 5.0$; cont: $M = 14.6$, $SD = 5.2$; $t(384) = 0.953$, $p = 0.341$). Finally, 39 pupils from the experimental group were interviewed.

Instruments

The pre-test

Before engaging in experimental activities, all pupils took a pre-test, structured as a paper-pencil test with sixteen questions, of which one had additional sub-questions. Among ten multiple choice questions three were questions with one correct answer and seven questions with more correct answers, of which two

asked for additional argumentation of the answer. The test results were analysed using statistical software. Objectivity was satisfied in all phases: (1) during the testing, (2) evaluating the results, and (3) during the interpretation of the results. Testing was executed with the help of teachers and principals of the schools. All pupils had enough time to finish the test. Cronbach- α coefficient was 0.705. A relatively low value of the coefficient was expected, since most of the tasks on the pre-test demanded understanding. Content validity was confirmed by four university scientists. Correlation between the test score and finally graded science subject in school was measured with Pearson's correlation coefficient, which showed a strong positive correlation ($P = 0.513$; $p < 0.01$).

The knowledge test

The knowledge test was structured as a paper-pencil test with twelve questions, of which six had additional sub-questions. Two sets of questions were yes/no questions. Four tasks were multiple choice questions with one or more correct answers, of which two asked for additional argumentation of the answer. The knowledge test was administered twice, the first time right after the experimental activities (test) and the second time three months later (delayed test). The items, both in the test and in the delayed test, were the same. After the delayed testing, pupils also filled in the questionnaire and some of them were then invited for an interview. The test results were analysed using statistical software. Interviews were transcribed and qualitatively analysed.

As during the pre-test, objectivity was satisfied in the same way. The Cronbach- α coefficient of the test was 0.851 and of the delayed test 0.861. Content validity was confirmed by four university scientists. Correlation between the test score and finally graded science subject in school was measured with Pearson's correlation coefficient, which showed strong positive correlation for both the test ($P = 0.531$; $p < 0.01$) and the delayed test ($P = 0.536$; $p < 0.01$).

The test included two tasks with specific open-ended argumentation about the researched experiments and research questions. These two tasks are analysed in detail in this paper. It was expected that a pupil who understood the experiment would solve the questions correctly, whether or not he or she remembers it. Remembering the experiment is not necessary for also understanding its outcomes. From detailed analysis of the open ended argumentation, it is possible to link the argumentation with the actual experiment. Misconceptions by themselves show the impact of the experiment on the pupils' conceptions.

The first of the two questions on the test in this paper asked what would happen if we add one spoonful of salt in the measuring cylinder filled with water up to the 100 mL mark and then place the areometer into the cylinder. In the task there were drawn four possible answers, labelled A, B, C and D (Figure 1).

In the picture there is a measuring cylinder filled with water and an areometer placed in it. The four pictures A-D on the right of the cylinder represent the zoomed-in position of an areometer in the cylinder after the salt was added into water. There are two distinct marks on each zoomed-in drawing. The black circle shows the level of the liquid in the measuring cylinder, and the black line on the areometer shows the depth to which the areometer is sunk into the liquid. The pupils had to choose the presentation which shows the right position of the areometer in salty water.

Option A in Figure 1 shows no change in the position of the areometer and in the level of liquid (wrong answer, the density changed); option B shows the increase in volume of the salty solution (wrong answer, the volume did not change); option C shows raising of the position of the areometer (correct answer, the density of the salty solution is greater than the density of water); and option D shows that the areometer is sunk deeper in salty water (wrong answer, the density of water is greater than the density of the salty solution). To solve this task, the pupils had to understand that the volume of water did not change when the salt is dissolved in water, and that the density of the salty solution is greater than the density of water.

The second specific question on the test discussed in this paper was an open-ended problem, asking how the pupils would gather data to determine the monthly changes of air temperature and the volume of rainfall. To answer this question, the pupils could use the knowledge about the instruments they had made during the experimentation. To accept the answer as fully correct, they had to mention that it is necessary to measure the temperature at the same time of day and describe the way of measuring the volume of precipitate. They also had to mention the way they would present the gathered data of the measurements.

The questionnaire

The questionnaire was structured as a paper-pencil questionnaire with seven questions in two sections. The first section dealt with pupils' school grades, where the first two questions were about the grades of different subjects. The third question was about the highest and the lowest grade they ever got in science classes. The fourth question asked pupils if they prefer oral examinations or written examinations, prefer being evaluated during group work or being evaluated by making and presenting reports in school.

The second section of the questionnaire dealt with experiments and science in general. The first open-ended question in this section asked what kind of activities they would like to have more often during science classes. The next one asked them to rank on the five item scale if they want more science; here they picked an item: (a) more, (b) more, but only if ... (pupils could add open-ended argumentation), (c) it is enough already, (d) less, but only if ... (pupils could add open-ended argumentation), and (e) less. Items (b) and (d) were valid only if pupils also wrote down their reasons for more or less science. The last, seventh question, asked them to name a few experiments they remember from this year's science classes and describe them in a few words. The questionnaire was administered after the delayed testing.

The interviews

The interview was a semi-structured interview with questions in six parts. In the first part were questions about their general attitude towards science, about learning and science hobbies. The second part contained questions about science as a school subject, their attitude towards science, what they are doing during science classes and what they have to know to get good marks. Additional questions were about experiments, outdoor school work and homework. In the third part were questions about the interdisciplinary approach to teaching and their perception of how much work different school subjects demand. The fourth part included questions about the experiments that were used in the research. In the fifth part were questions about the experiments that were part of the research. Lastly, the sixth part was composed of final questions about their perception of their knowledge and what they would change in school and science lessons.

After the delayed testing, 39 pupils from all the schools were invited to an interview. Pupils were picked according to their perceived motivation during the experimentation. Pupils that seemed highly motivated, and those that seemed not motivated at all, were grouped in two separate groups of three. In the interview, they had to describe the selected experiments

and interpret their findings. During the semi-structured interview, the pupils were given additional help, if they did not by themselves recall the experiments and had not completely answered the questions. This was used to clarify the understanding of the experiments and misconceptions, as well as to encourage pupils to recall details about the experiments. It was expected that those pupils who do understand the suitable concepts related to the experiments would be able to reproduce the actual experiment without outside help. If pupils did not mention the researched experiments, it was planned to ask helping questions to aid their memory: (1) first ask if they liked the lesson when they made the instruments for measuring, (2) ask them to explain their answers, (3) ask them about the measuring tools they had made, focusing on the areometer and the precipitation gathering instrument, and (4) describing how they made the instruments. If they failed to remember after the four helping questions, it was presumed that they had not remembered the experiments.

Research design

Before the experimental part, pupils wrote a pre-test. The next part of the research, dealing with the research questions presented in this paper, started with a set of simple experiments. These involved activities with the purpose of making measuring instruments using common household objects: (1) a simple thermometer, (2) a simple pressure measuring instrument (manometer), (3) a simple density measuring instrument (areometer), and (4) planning a simple experiment for measuring precipitation and determining the effects on evaporation of water (For more detailed descriptions of the experiments see Appendix). Besides making the instruments, the pupils had to determine the relative changes that can be measured with the instrument made, and define the accuracy and usability of such an instrument. The fifth task (5) was to determine what kind of graph would best be used for long period measurement presentation of the data gathered with self-made measuring instruments.

Pupils of every class were randomly grouped in five groups (thermometer group, manometer group, areometer group, evaporation/precipitation group and graph group). Each group was given specific instructions on how to make one of the instruments mentioned, how to measure and define the results of measurement and how to compare these results with those obtained with the commercial measuring device. After the experimentation, each group reported their findings to the rest of the groups.

The test was administered one week after the experimentation. During testing, pupils could ask

clarifying questions. The test was timed at 45 minutes, but pupils were able to take longer, if needed.

The delayed test was scheduled for three months later, following the same procedure as the first take of the test. After the test, pupils were given the questionnaire, which took them on average ten minutes. Pupils did not ask for clarification on any question. During that time, groups of pupils were invited for an interview which would take place one week after the delayed testing. For the purpose of the research, schools also obtained final grades of all participating pupils. SPSS 18 was used for statistical analysis.

The results of the pre-test were used to determine pupils' knowledge about science in general and also about science concepts behind the experiments. The results of this test were used to find out pupils' understanding of the concepts and the misconceptions they might have. The results of this delayed test and the additional interviews would show how much they actually remembered about the experiments. Analysis of the answers would also show how permanent misconceptions are. With the comparison of results of both (first and delayed) tests, it would be also possible to establish the impact of the repetition of data gathering on pupils' knowledge.

RESULTS AND DISCUSSION

Comparing average scores and differences between the experimental and the control group shows that the intervention in experimental schools had an important impact on the test scores. Average test score on the test was 21.9 (44.0% success; $min=0$, $max=51$) with average difficulty index at 0.47 and discriminative index of 0.45 ($p < 0.01$). On the delayed test an average score was 21.6 (43.1%, success; $min=0$, $max=50$) with average difficulty index at 0.46 and discriminative index of 0.42 ($p < 0.01$). The experimental and the control group showed statistically significant differences (exp: $M=22.8$, $SD=6.8$; cont: $M=21.3$, $SD=5.8$; $t(384)=2.348$, $p=0.019$). Statistically significant differences were also measured on the delayed test (exp: $M=22.7$, $SD=6.9$; cont: $M=20.8$, $SD=5.9$; $t(384)=3.028$, $p=0.003$).

Understanding the concept of density

In response to the first question "what would happen if we add one spoonful of salt to the measuring cylinder filled with water up to the 100 mL mark and then place the areometer in the cylinder" 31.5 % of the pupils in the experimental and 22.3 % of the pupils in the control group answered correctly. There is a statistically significant difference between groups on the test ($\chi^2(1)=4.083$, $p=0.043$) and the delayed test ($\chi^2(1)=19.767$, $p=0,000$).

There were 22.8 % correctly explained argumentations in the experimental group and 12.0% in the control group with answers: “*salt dissolves in water and the density increases*”, “*solution is denser*” or “*the instrument rises*”. It seems that remembering the “argumentation” is easier than reading the state of the solution from a picture.

The wrong answers were arranged in three groups. In the first group (exp: 13.5% and cont: 18.7% answers) there are statements which are not wrong, but are not connected with the question. Statements such as: “*salt dissolves in water*”, “*the instrument displaces the water*” and “*it is easier to swim in salty water*” show that pupils remember changes observed at the experiment, but are not able to explain them.

In the second group (exp: 21.0 %, cont: 28.3 %) there are statements from pupils who do not understand the concept of density: “*Salt displaces water*”, “*salt is less dense than water*”, “*salt flows on water*”, “*salt is not heavier than water*”, “*salt is lighter than water*” and “*the higher the density, the lower the measuring meter*”. These pupils did not have a basic understanding of the concept of density, nor did following the experiment make any sense to them.

In the third group (exp: 16.7 %, cont: 16.4 %) are the answers related to other concepts, such as the statement in: “*salt sucks the water in and the surface of the water lowers*?”. The pupil was aware of the process of hygroscopicity, but did not correctly use his knowledge.

Some of the answers revealed misunderstandings that were not identified during the experimentation. Pupils counted the lines on the measuring cylinder in the picture, which was part of the question, and tried to provide numerical data. This was not possible, since the scale was not shown on the measuring cylinder in the picture. When dealing with concepts like density, attention should be devoted to the potential misunderstanding of concepts and conceptual change. In research on cognitive conflicts in scientific conceptual learning (Kang, Scharmann, Noh, 2004), at least half of the seventh graders were found to have an early-stage density concept even before they had formally learned it in school. When introducing the concept of density, teachers should emphasise the distinction between weight and density, because many pupils have problems in distinguishing one concept from the other (Kang, Scharmann, Noh, 2004). Similar is true for the concept of temperature and heat (Harrison, Grayson, Treagust, 1999).

Also, a surprisingly high number (exp: 19.7%, cont: 21.1%) of them read the height of the liquid in the measuring cylinder and not the position of the instrument. Those pupils simply stated that “*adding salt does not raise nor lower the amount of liquid*”.

In response to the first question in the delayed test, 34.6% pupils in the experimental group and 15.2% in the control group answered correctly in comparison to

the same question on the test (31.5 %, 22.3 %), and 24.8 % in the experimental and 11.9 % in the control group (22.8 %, 12.0 %) also correctly explained the answer.

Understanding of the temperature/precipitation experiment

The second specific question on the test was an open-ended problem, asking how the pupils would gather data to determine the monthly changes of air-temperature and volume of precipitation.

Among all pupils only one fifth (exp: 20.3 %, cont: 20.0 %) correctly answered the question, while the majority of pupils (41.2 % in the experimental and 43.3 % in the control group) did not even try to answer the question. There is no statistically significant difference between groups on the test ($\chi^2(1) = 0.727$, $p = 0,394$) and the delayed test ($\chi^2(1) = 3,048$, $p = 0,081$).

The pupils had to measure the temperature and the volume of precipitate and follow the results for a longer period of time. Pupils usually skip open ended questions or simply write down a few terms, which is, in most cases, insufficient to find out if the pupils understand the question. It is also possible that pupils did not strictly follow or did not understand the text of the task. Among researchers, there is considerable agreement that pupils just do not solve open ended tasks and that the accuracy of the answers is low (Boddy et al., 2003; Ibabe & Sporer, 2004, Klahr & Li, 2005).

For the answer to be accepted as complete, pupils had to: (1) define the change in the volume of the precipitate in the container; (2) measure the temperature of the air; (3) write down the data in the table or present data in the climograph. In most cases pupils described the gathering of rainwater correctly, but forgot to mention the temperature. Whether this could be attributed to not reading the test carefully enough, or just forgetting to write it down, was partially answered during the interviews (the temperature seems “*easy to measure*” and “*easy to understand*”). Among the interesting answers, there were some solutions using other sources of information. One pupil wrote that he would “*gather data from newspapers and transform the data to a climograph*”, seven of the pupils would use the “*internet*” or other “*written sources*”, while two pupils wrote that “*each pupil would observe the weather and write down the results and then would report the findings to other pupils*”. These pupils simply repeated the instructions given to them on how to do an experiment. Those pupils that did not understand the task (13.5 %) wrote: “*I would wait to gather one kilogram of rainfall*”, “*I’d measure temperature and rainfall for one day*”, “*I’d measure temperature and humidity*”, or simply “*would draw the climograph*”, not mentioning from where data would be obtained.

Analysis of the delayed test showed that even fewer pupils (exp: 17.9%, cont: 17.6%) answered the second

question correctly, and around the same percentage of pupils (exp: 44.5%, cont: 46.7%) did not even try to answer this question, in comparison to the first test.

Detailed students' explanations about the tasks

After the delayed testing, pupils were asked to fill in the questionnaire to name a few experiments they could remember from science classes and describe them in a few words.

Pupils wrote down 10 physics, 27 chemistry, 3 technical experiments and 9 different biological activities, of which only 4 of them were actual experiments. It is interesting that some of the experiments are not - as was later found during the interviews - comprehended as a real experiment by the pupils. They see such experiments (e.g. precipitation measuring experiment) as some kind of "biological group activities". According to the pupils' perception, biology by itself does "not have" experiments as chemistry and physics do. Biological experiments are "activities" that deal with biological material. Pupils put forward experiencing live animals as the most important aspect of biology, and are fascinated by the life itself in connection with the outdoors. Among the listed experiments, they mentioned evaporation of water and making of measuring instruments (areometer, thermometer and manometer), but did not refer to using them or making measurements. None of the pupils mentioned measuring the volume of the rainfall.

Answers to the questions in the questionnaire showed that 30.8 % of all the pupils want more science classes and 14.2 % want more experiments and outdoor activities. It is safe to say that these pupils primarily connect science with biology. Almost half (45%) of the pupils want more, while only 0.9 % want less science classes. All the others (54.1 %) believe there is already enough science.

It was expected that pupils would recall the experiments after a period of four months. In the interviews it was found that only two pupils (among 39 selected from the experimental group) recalled those experiments without help. Most of the pupils remembered the actual classroom setting, but were not able to name the experiments, nor describe any of those experiments. Some found the tasks interesting, others not.

In response to the question: "Do you recall any experiments you did this year during the science classes?" pupils named many different experiments, but no one explicitly mentioned the making of the instruments. Among the mentioned ones were mostly physical and chemical experiments similar to those from the science textbook. Replying to the additional question: "Do you recall tasks where you had to make instruments?", some (5) of the pupils mentioned the thermometer, which was one

of the measuring instruments. Other supporting questions did not reveal any additional details about the experiments. In the following section, some of the answers are written. The letter Q represents the researcher's question, and the letter U followed by the number indicates answers from different pupils.

Q1: *How did you like the lessons when you had to make instruments?*

U1: *Those tasks were not interesting.*

U2: *There was more work for us and we were not so interested as usually.*

U3: *I remember, yes. They were good, interesting, because we learned how to make them from simple materials.*

U4: *I liked it, because we found out something new, like how we really measure things. You don't have to listen hard and you see more.*

U5: *Those tasks were not hard, yet were not easy. It was something in between.*

U6: *I really do not remember those tasks.*

The pupils who positively described as interesting the experiments of making measuring instruments, were merely fascinated by the way it was done and not by the science behind the experiments. Using simple materials was interesting for them, but that is all.

During the interviews one pupil mentioned the density:

Q1: *So, what is density?*

U1: *Well, density is ..., well, for example, when you have two matters, now, one of them can be more compact or thin in comparison to water, right? And if it is more compact it sinks, if it is thinner it floats, right? And if you put a lot of salt in the water, then the water runs slower, right?*

During the experimental group work, the density task included also comparing the density of water with the density of salty water and density of oil. The pupil's explanation was based on his own experience from outside the school.

Measuring the volume of precipitation was found to be very unpopular among pupils, due to involving more work than usual. Pupils were also asked during the interviews how much science homework they get, and how difficult it is. None of the pupils found the homework to be hard and none complained about the quota, especially since there was always more homework from other subjects, like maths and both foreign and mother language lessons than from science. Science homework concerning making the climograph was described by the pupils as "hard".

Q1: *What about the climograph task?*

U1: *I didn't like it, because we had to take measurements every day.*

U2: *I always did my homework!*

U3: *It was a lot of work and I did not fully understand what I had to do.*

U4: *Those tasks were the hardest, since we had to make graphs or something like that.*

If some of the pupils did gain an understanding of some precipitation experiment details, this must be connected to the long-term activity that forced pupils to do the tasks step-by-step for a longer period of time. At some schools, teachers do a lot of experiments and encourage pupils to also try out experiments at home. Most experiments were carried out in schools where the teacher had a lab assistant and at schools where science was scheduled for two-hour joint classes. Pupils described homework as important at schools where the teacher always checked the results of the homework at the beginning of the class. Drilling for the details about the rainfall experiment revealed another interesting find. Three pupils reinvented the task:

Q1: *How would you measure the change in the amount of rainfall?*

U2: *With the container, with the mensural vessel. I'd place it outside when the rain fell and then take data, notes and sum up the values at the end of the year.*

U3: *For example, 15 L of water falls on one square metre.*

Q1: *But how often would you take a look in the container to check how much water fell?*

U1: *Every day.*

U2: *The day that rain fell and the second day.*

U3: *The second day the water would already have evaporated.*

Q1: *Aha, what would you have to do then, to prevent that from happening?*

U1: *Write down the amount and then carry on with the measurements.*

Q1: *Could you make some adjustments to prevent water from evaporating in the first place?*

U3: *Yes, we could cover the container.*

Q1: *Then, how would the water get into the container?*

U2: *When the rain started, we would uncover the container.*

Exactly the same experimental procedure, as the pupil described it, was used during the group experimenting in schools, with the difference being in the defined surface of the container. The surface, in the original experiment in school, was defined as being much smaller than one square metre, and the cover to minimise the evaporation was proposed with a small hole.

Pupils that posed those answers did not recall the task of measuring the density of the liquids and volume of rainfall, as was found during the interviews, but they very well remembered the live organisms they saw in school. All groups of pupils during the interview named the majority of animals they had worked with during the science classes. They recalled how many times they had outdoor lessons and science tour days, and even remembered what the teachers had promised them, but never actually did. One group of pupils was especially critical during the interview:

U2: *Our teacher likes to say how they, when she was in school, went to see caves four times, and likes to tell stories about what happened on that trip, but we do not even go outside.*

U3: *Yes, all those cave animals she mentions - we will never go and see them.*

There is a strong connection between Klassen's (2009) findings that, during classes, pupils are not encouraged to think about the proofs, evidence, measurements and acquired experimental data. They are also not trained to quickly accomplish tasks by frequent repetitions of simple subtasks (like periodically gathering bits of data to make a graph or some other kind of data presentation), nor are they encouraged to argue about their findings (Kuhn, 2010). Repetitions demystify data gathering and also make data a less emphasised part of the experiment. Experiments can be effective in increasing manipulative skills, but much less effective in using scientific ideas and reflecting upon the collected data (Abrahams, Millar, 2008). This shows the importance of focusing on aspects like interpretation or presentation of data. What is important, and what is not so in this case, is the pupils' own perception. The fact is that teachers usually do not emphasise the importance of correct data gathering, nor do they make experimental tasks that would emphasize data on their own. If teachers evaluated all stages of experimenting equally and finally demanded the open argumentation, the impact would undoubtedly be higher.

Emphasizing learning through experience with practical and experimental work should be designed in such a way that every step of the pupils' researching and experimenting is suitably credited or assessed (Hammann et al, 2008). Observation and data recording can have an important impact on developing understanding. Since understanding the scientific phenomena also reduces the learning of plain facts and makes instruction more interesting (Prokop, Prokop, Tunnicliffe, 2007), this would also suggest the importance of making an extended effort to increase internal motivation for science.

CONCLUSION

The aim of the research was to establish the impact of experimental work on the understanding of selected scientific concepts and find out what pupils remember from experiments.

The pupils in the experimental and the control group were compared by knowledge using the pre-test and they showed no important statistical differences before the intervention in the classroom. Pupils in the control group learned about the same concepts.

The difference in instruction between the experimental and the control group was in experimental tasks where pupils in the experimental group prepared, made and used simple measuring instruments, defined the observed measurements, gathered data and transformed the final data to graphs. Finally, students of

both groups solved the test after the intervention and again the same test three months later.

Comparing the results of testing and delayed testing shows that there was a statistically important overall impact between groups. Students in the experimental group scored higher on both tests and retained more knowledge comparing the first and the second take of the test.

Since some questions on the test and delayed test asked about the concepts that were part of the experimental activities, carried out by the pupils in the experimental group, it was presumed that these questions would also remind pupils about the experiments. That, as the data showed, was not the case. Only two pupils mentioned the experiments during the interviews without the interviewer's help. Those that did recall experiments with or without help described the tasks only superficially and focused more on solving the task during the experimentation and less on the meaning of the measured value.

During experimental work there is a lot of stress on the knowledge of "how", at least in gathering data, but as it shows, there is much less emphasis on "why" something happens. Pupils can reach conclusions about what and how it happens, but to explain "why" something happens, they usually just do not have enough knowledge. An important part of the development of understanding is reflecting on the experiment and thinking about the meaning of the gathered data. Understanding "how", helps to understand "why".

Research has shown that doing an experiment is not enough to remember it. They also need to repeat it and need to think extensively about the data and its presentation. It has been found, during the intervention in the classroom, that pupils did make adequate observations about the experiments and did come to correct conclusions about the experiment, but it seems that they did not connect the conclusions of the experiment with the science concepts behind it. It is also possible that each group of pupils had their own "leading scientist" among them during experimenting, which helped the group with the reasoning.

On the basis of the results obtained with this small sample of pupils, it can be concluded that: (1) pupils do not remember experiments, but the experiments do help students to understand scientific concepts; those that understood the experiment's outcome in the first place preserved the understanding, which showed in the delayed test. It is also evident that (2) pupils adequately describe and explain the experiments after some period of time only if they really understand the underlying science concepts. If they do, then they can "reinvent" the experiment. Although the research has shown that very few pupils remembered concrete details about experiments and were unable to interpret the findings,

they still believe experiments to be the most interesting part of natural science lessons.

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Appendix

In order to make the instrument, pupils were given only common objects used every day. The teacher gave them oral instructions and also showed the steps for putting separate parts of the equipment together. Pupils were also given written instructions, which were the same as the teacher's oral presentation. For instance, to make the areometer, they had to turn the plastic dropper upside down, then cut the narrow stem of the dropper, fill the dropper with sand and then weld the dropper's hole with modelling clay. After placing it in the water, they had to calibrate the instrument in water (Figure 2a); then they had to make a mark on the dropper, with the permanent colour marker, to show how deep it sank in the water. If not enough sand was filled into the dropper, the areometer would not stand in upright position, or if it was filled with too much sand, it would sink too deep. When this simple areometer was made, they had to test it and take measurements of density in salty water and in oil, relative to the density of water. The measurements were also made with a commercial device to compare the results.

The same principles were applied to the thermometer and manometer (Figure 2b and 2c).

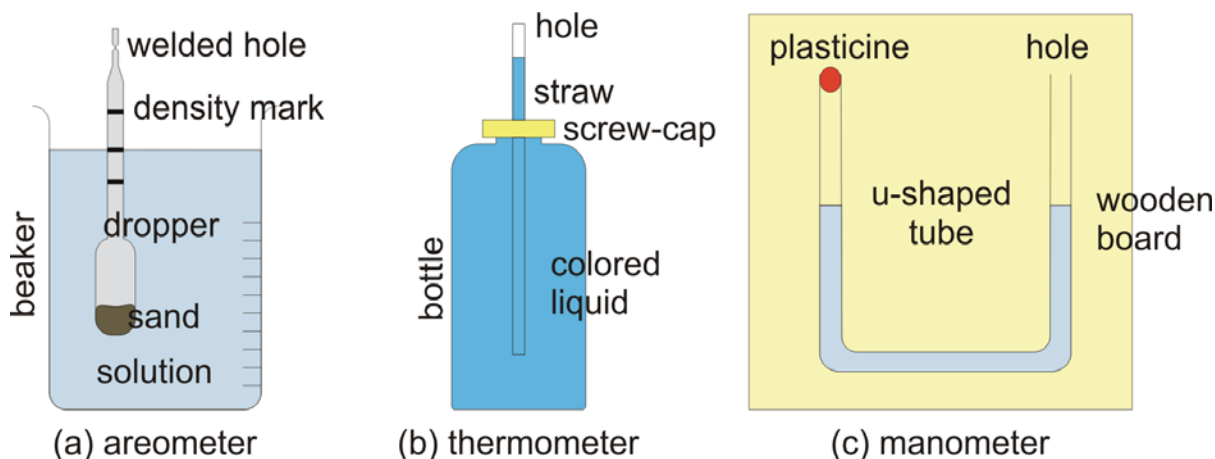


Figure 2. (a) areometer, (b) thermometer and (c) manometer made of a common object.

To make the thermometer, they had to take an empty 200 mL glass bottle, make a 5 mm hole in the middle of the bottle's screw cap, push the straw through the hole and tighten it with modelling clay. Then they had to fill the bottle with water and place the screw-cap on the bottle and screw it down, pushing out all the bubbles. By pushing the straw into the bottle, they raised the water column in the straw just a centimetre above the screw-cap. Making a mark on the straw after the column settled, defined the room temperature. When heated, the water column in the straw rises.

To make the manometer, they had to take a 50 cm soft transparent plastic tube, tighten it on the wooden board in U shape and then pour water through the hole on one side of the tube. Water had to reach the straight part of the tube. Pupils had to fill the hole on the left side of the tube with modelling clay. The height of the column on the left side was defined as the current air pressure.

The precipitation/evaporation activity was set outdoors. Pupils had to find a way to measure the amount of rainfall. They were given an empty 500 mL beaker which they placed somewhere outside the school. They were guided by questioning to confirm that the gathered water would evaporate if they left it unattended for a longer period of time, especially if it is left in the sun. They concluded that water would evaporate slower if they closed the opening of the beaker and only left a small hole. They also concluded that they must place a funnel into the beaker (Figure 3; right picture).

They had to place the apparatus outside and were given instructions to carry out measurements for one month at approximately the same hour of the day. They had to write down the measurements of rainfall and temperature on the prepared spreadsheet hanging on the classroom wall. The goal was to make a special graph called a climograph. They learn about this type of graph during the geography classes at the beginning of the seventh grade, where they focus on different ratios of temperature/precipitation at different places around the world.

An apparatus for gathering rainfall precipitate and an example of the climograph are shown below (Figure 3, left graph).

After making the instruments for measuring relative values of temperature, density, pressure and evaporation/precipitation and answering the questions from the pupil's work sheet, each group reported on: (1) which instrument they had researched, (2) what materials they were given, (3) how they made the instrument, (4) what results they got, and (5) how to prepare an experiment to use the instruments and corresponding commercial instruments for a period of one month. At five schools, all groups made all measuring instruments, at two schools each group made only one, but all groups made the precipitation experiment and measuring of temperature.

During each group's presentation in front of the classroom, other groups asked questions to clarify the experiments of each group. At the end of all presentations all groups were given instructions to carry on taking measurements with the instruments they had made. For a comparison measurements were also made with the commercial instrument. On each day in school (Monday to Friday), assigned pupils had to come to the science classroom and read the measurements of temperature, pressure and precipitation at approximately the same time of the day and write them down on the prepared spreadsheet on the classroom wall. During the regular science classes, the teacher checked if they had correctly filled in the measurements on the spreadsheet.

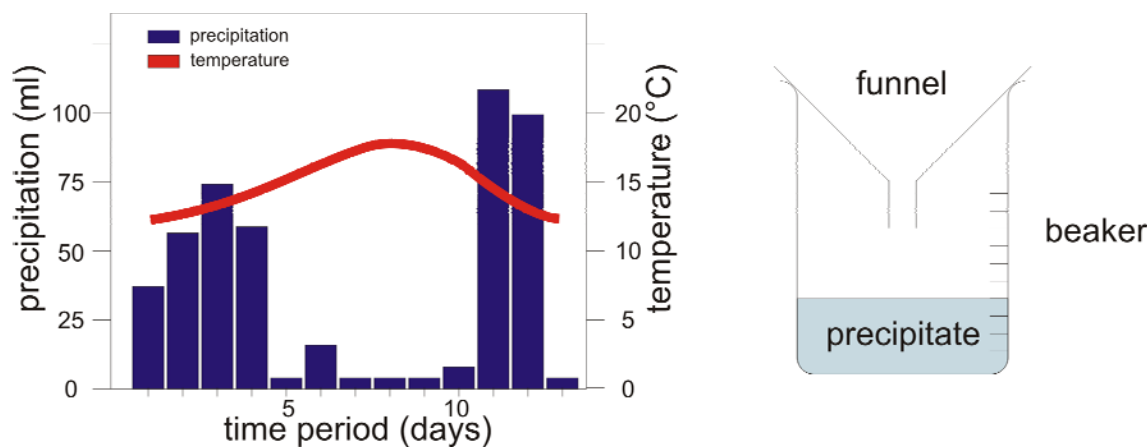


Figure 3: climograph (left) and an apparatus to measure the amount of rainfall (right).