The analysis of conceptual understanding and selected inquiry skills of students within non-formal education activities in the science Centre

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Abstract. Science centers have been established in an effort to promote science and technology in society, among children and young people. They are basically institutions that have prepared a series of scientific experiments, observations, games and similar attractions working on a selected phenomenon. A surprising effect, unexpected behaviors or inexplicable phenomena that are supposed to raise curiosity and desire to discover in a visitor are offered to them as a rule. Visitors of science centers are often groups of school children on a school excursion. From a teachers’ point of view it would surely be welcome if besides motivation the excursion had an educational aspect and if it could be possible to use it to complement subject matter or to develop selected skills, which schools do not have appropriate conditions for. For support of such ideas we established Inquiry science laboratory within the science center SteelPARK in Košice, where groups of school students can participate on two different inquiry activities prepared for each mostly one month period. Activities are guided by a lecturer, a pre-service physics teacher, in parallel for 5 groups of 3-4 students. Our laboratory teaching centers around key problems, pre-selected for each inquiry activity. Total time for one activity is 60 minutes. Conceptual test questions are discussed during the first part of the activity as a tool for the student’s involvement into the problem and also as a source of motivation. Activities are on the level of guided inquiry, which we specified through examples of ESTABLISH project units. After the activity, formative assessment tools are used for self-evaluation of selected development skills. In the paper we present the results of the conceptual tests and rubrics, basically created within the SAILS project, for skills mapping across the sample of more than 600 students discussed and analyzed on the basis of one exemplary activity. After two years of experience with more than 4500 participants from lower and upper secondary schools, the level of selected inquiry skills across 15 different inquiry activities is presented. All of our worksheets as well as findings from non-formal educational activities are recommended for use by teachers in school practice.

1. Introduction
Informal learning and popularization events in science centers are used all over the world to increase the interest of youth and to lay the foundation of a positive stance on science in society. Science centers have a long tradition in many metropolitan cities, exploratory and entertainment – learning parks, such as Cité des Sciences et de l’industrie in Paris, Universum in Göteborg, Science Museum in London, CSOPA in Budapest, etc. Attendees learn about the laws of nature, of The Earth and The Universe, through interactive experiments and games. The interest of youths in their surroundings is am-
plified through the use of entertaining experiments; they discover the fantastic world of physics and other natural science disciplines through unforgettable experiences. Nowadays, when real life experience are being more and more supplemented by computer simulation, students can try by hands, how real experiments works. Each of the science centers is specific in some way; it presents its own story and approach to its visitors. The same is true about the new science centre SteelPARK Košice (www.steelpark.sk), the creation of which we took active part in. The visitors can find out about the history of steel – from its mining, refining and its final products. More than 50 interactive exhibits present the know-how and creativity of several scientific disciplines connected with the manufacture and use of products of metallurgy.

After two years of service, we have found that a large portion of visitors consists of school students. There was a natural request, from the teachers, when planning repeat visits to the center, to utilize the motivational function of the science center to strengthen the educational impact, mainly in the area of developing specific research capabilities of students of primary and secondary schools. Because of this we started the Inquiry science lab in October of 2014.

**Inquiry science lab in the science center**

Inquiry science lab (ISL) has been created for students of primary and secondary schools and their teachers, so that they can acquire their own experience with inquiry based education, through the use of non-formal learning. The activities are, from the view of classical education, untraditional measurements, and observations connected with the discovery of new findings and mainly acquiring inquiry skills. The students work in three or four person teams, under the guidance of a lecturer and using worksheets. The teacher is in the role of and observer, observing the progress of IBSE (Inquiry Based Science Education), which is on the level of guided inquiry (SAILS project). The activity in the ISL takes 60 minutes, and 2 different activities are run in tandem, in order to be able to include all the students of an entire class.

![Fig. 1. Inquiry science lab in SteelPARK](image)

The learning activities, worksheets, methods and tools of evaluation are available to the teachers and can use them later in their education in schools. ISL is also used to support the practical education of pre-service teachers of interdisciplinary study in combination with physics. Through lecturing they are preparing for their future career in teaching. They acquire important experience with inquiry based activities, they are thought to put them into practice, take part in the collection of data, and are informed on the results of didactic surveys.

During the 18 months of existence of ISL, 6383 visitors took part in 15 different activities. The annual attendance rises every year. In two academic years (2014/2015, 2015/2016) 15 activities were conducted, on which around 400 groups of students took part. Table 1 shows the number of students who took part in the individual activities.
Table 1. Activities of ISL in the academic years 2014/2015 and 2015/2016

| Activity                                         | Number of students | Together |
|--------------------------------------------------|--------------------|----------|
|                                                  | PS     | SS     |         |
| **Academic year 2014/2015**                     |        |        |         |
| 1. Can we measure the weight of air?            | 134    | 183    | 317     |
| 2. What can we learn from a laser range finder? | 156    | 357    | 513     |
| 3. Battle on an unstable basin                   | 210    | 26     | 236     |
| 4. Become a forensic scientist                   | 342    | 81     | 423     |
| 5. How do we breath?                            | 295    | 113    | 408     |
| 6. Fill it up with water and go                  | 298    | 151    | 449     |
| 7. How does a bat see motion?                    | 420    | 185    | 605     |
| **Total**                                        | 2951   |        |         |
| **Academic year 2015/2016**                     |        |        |         |
| 8. What does a scale show?                      | 410    | 102    | 512     |
| 9. How does a candle burn?                      | 410    | 102    | 512     |
| 10. YO-YO, child’s play full of physics          | 71     | 82     | 153     |
| 11. On the heels of a physics scale             | 220    | 71     | 291     |
| 12. Where do we get the air we breathe?         | 350    | 185    | 535     |
| 13. Known and unknown shadows                   | 387    | 163    | 550     |
| 14. Let us repair Galileo’s thermometer          | 406    | 101    | 507     |
| 15. How to take pictures of moving objects?     | 298    | 72     | 372     |
| **Total**                                        | 3432   |        |         |

2. The mapping of students’ conceptual understanding by use of pre-test

We have conducted a didactical research on the preconceptions of students, the development of specific inquiry capabilities and elements of scientific knowledge on a wide range of visitors within the individual activities. At the beginning of the activity, the attendants take an entry conceptual test on keywords connected with the activity, which is supposed to motivate active learning.

We would like to show the concepts researched in the activities by illustrating it on an example “YO-YO, child’s play full of physics”, which is concerned with the speed of the falling yo-yo. 149 students took part, choosing an answer from 5 different options.

Q1 The speed of a downward motion of a yo-yo:
   a) Uniformly increases.
   b) Stays constant.
   c) Firstly it stays constant, then it decreases with the final stop at the lowest position.
   d) Firstly it increases and then it decreases with the final stop at the lowest position.
   e) Uniformly decreases.

A staggering 65% of the students have the wrong idea about the yo-yos downward motion.

When the yo-yo reaches its lowest point, we feel a slight jolt. This is caused by the change in the direction of its speed. The students had to choose from 4 different options.

Q2 When the yoyo reaches the lowest position we can feel the slight force acting on our hand. The reason is:
   a) We do it ourselves in order to make yoyo to continue in an upward motion.
   b) The change in direction of rotation.
   c) Change in the direction of velocity (from descending to rising motion).
   d) The string that is not ideally smooth and the energy losses.

86% of students of secondary and 96% of primary schools failed to answer correctly.
Q3 At the lowest position, the rotational motion of a yo-yo:
   a) Stops and then it starts in the same direction.
   b) Stops and then it starts in the opposite direction.
   c) Does not stop, it continues in the same direction.
   d) Does not stop, it continues in the opposite direction.

Q4 After reaching the lowest point, the yo-yo can move up because:
   a) We tug upward with a string by a hand and this way we supply energy to motion (Without tug-
      ging the yo-yo would not move upwards).
   b) The yo-yo has kinetic energy that can be changed into potential energy.
   c) The string works as a spring that is stretched.

When comparing the answers of primary and secondary school students, we have concluded, that
there are no relevant differences in conceptual understanding of the given theme (see Fig. 2).

![Conceptual understanding of yo-yo motion at lower and upper secondary school pupils]

**Fig. 2.** Correct answers of students of PS and SS on individual questions on the pre-test

In the activity “How does a candle burn?” which 512 students took part in, we mapped the students
predictions about the temperature of the flame.

Q Imagine a candle flame. Think first and then answer:
   a. What is the flame temperature?
      Write down the temperature and describe how you have decided about this value.
   b. Is the candle flame temperature equal all over of the flame?
      Explain your answer.

69% of the students got the answer wrong, it was less than 300°C), and the factors influencing the
time of burn, whereas only 24% of the students answered satisfactorily.

At the beginning of the activity “Can we measure air?” we gave 144 students a question without an
exact answer.

Q How much air weights in a room with the volume of 100m$^3$?
   13% of those who took part said that air weighed nothing, 39% gave a very low number, mostly in
   grams, 44% did not answer at all (Fig. 3). Only 4% wrote the correct relationship for calculating the
   weight of air, which was not given because of the absence of knowledge of the air density.
Fig. 3. Students preconceptions about the weight of air in a room

Guided inquiry with the help of worksheets
The introductory motivation on the given theme in the form of a pre-test and the evaluation of correct answers directly precedes the activities in the worksheet. The students act in accordance with the manual, with pre-defined steps. They acquire the skills of scientific work by way of observation, evaluation, measurements, collecting and evaluating data (Wenning 2007). They have an opportunity to write down their predictions on the worksheet, to plan their experiment, argue and make conclusions (Van den Berg 2013). The worksheets are scanned and stored in pdf, after the activity, for future reference. By analysis the worksheets and also by observing the work of the students during the activity, we can see reasonable reserves of the students in the following capabilities of scientific work:
- problems with writing own prediction, remarks, comments (not given by teacher),
- to argue,
- to plan an experiment,
- work as a team, discuss topics, personal responsibility for team work,
- reading with understanding.

Personal feedback and self-evaluation
At the end of the activity the students, by means of a self-evaluating sheet, evaluate the degree of their own abilities (through rubrics with three grades), which were developed. They also assess what they have learned, what they found most interesting, what they still do not understand. Through the use of self-evaluation rubrics we focus on the formative evaluation of the students work.

During the activity “What can we learn from a laser range finder?” (Ochoa et al. 2014), the students researched the refractive index of water, based on the fraction of the length of the aquarium measured above and below the level of the water. They recorded their measurements in a table. After completing the activity the students evaluated four capabilities developed, through rubrics with three grades (complete the activity with strong support, with support, independently) (Hattie & Timperley 2007).

Table 2. Self-evaluation rubrics, filled out by students after the activity

| Selected skills | With strong support % | With support % | Independently % |
|-----------------|-----------------------|----------------|-----------------|
| use a laser range finder | 2 | 13 | 85 |
| save data into a table | 4 | 16 | 80 |
| determine refractive index of liquid | 5 | 35 | 60 |
| explain meanings of refractive index | 12 | 50 | 38 |
With activities with manual focus, we can achieve satisfactory results in the development of skills. The amount of development of skills drops with activities which are more intellectually challenging. It will be important to strengthen the activity from the point of understanding and the ability to explain the meaning of the refractory index.

507 students took part in the “Let us repair Galileo’s thermometer”. It seems at first glance as an easy explanation for the principles of a thermometer through the use of Archimedes’ law. In reconstructing the thermometer, the original liquid is replaced with water, which has a higher density. The students are faced with a problem, to use their current knowledge in solving a new challenge. Guided inquiry teaches the students about the importance of acquiring new experimental data and of its evaluation. We have observed, during the activity, some persisting problems with:

- making conclusions with help of own data,
- using knowledge for solving a new problem.

We intend to share the acquired results with teachers, to show them the importance of practical understanding of Archimedes’ law and the missing skills of applying their knowledge to new problems.

3. Conclusions and recommendations
Guided inquiry activities are well accepted by students because they are always looking for new information. There are no relevant differences in the conceptual understanding of selected concepts between primary and secondary school levels – secondary schools have to focus stronger on it. In some skills, the level of upper secondary school students is lower than lower secondary one. It is our opinion that this is caused by the fact that secondary school education is dominated by a theoretical form of knowledge being educated and by the methods of interpretation of teachers. Our challenge toward the teachers is: Next, let’s try activities from Inquiry science lab with your students at your school!

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