

# THE TOPIC OF BUOYANCY AS RESEARCH BOX FOR PUPILS

Volkmar Putz<sup>1</sup>, Renate Grof<sup>2</sup>, Ingrid Hantschk<sup>1</sup>

<sup>1</sup>PH Wien, Grenzackerstraße 18, Wien (AUSTRIA)

<sup>2</sup>NMS GÜSSING, Schulstraße 9, Güssing (AUSTRIA)

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## Abstract

*This paper focuses on the research based development and arrangement of a so-called interactive research box on the topic of buoyancy and evaluates if pupils can be lead to inquiry-based learning by physical experiments. A “research box” is an interactive exhibit comprising the implementation and evaluation of experiments, where visitors (here mostly pupils from 9-12 years) are not only encouraged to activity but also to reflection. The development is done with regard to design and suitability as learning environment. Evaluation of the exhibit is done by participant observation of pupils. Thereby a prolonged cognitive engagement with the physical content of the exhibit becomes apparent.*

**Keywords:** Innovation, exhibit design, learning environment.

## INTRODUCTION

The *Research Workshop (Forscherwerkstatt)* at the University College of Teacher Education Vienna (PH Wien) allows pupils in primary (and to a limited extent also secondary) school an autonomous, playful conduct of experiments and research and thereby conveys a first impression and basic insight in physics, chemistry, mechanics and technics. The concept of the *Research Workshop* is an activity-oriented, interactive acquisition of knowledge, allowing a deeper learning process. Based on an elaborated didactical concept encouraging self-activity of pupils, the *Research Workshop* consists mainly of so-called “research boxes”. Each box contains the required materials, a sheet with research questions, and an optional guide for the performance of the experiments. Pupils are asked to formulate their answers to the research questions on a “research pass”, where they are also prompted to think about further questions. Thereby, the *Research Workshop* is a typical place for inquiry-based, hands-on learning, where pupils perform research in order to generate scientific knowledge which, of course, is not new to science itself but new to them.

Mc Lean defines as “exhibits” interactive objects of exposition “... in which visitors can conduct activities, gather evidence, select options, form conclusions, test skills, provide input, and actually alter a situation based on input” [10]. In this sense a new element for the *Research Workshop* was to be developed. The chosen subject was buoyancy in water and air. A first encounter with the topic, away from textbooks, should be created for pupils allowing them to feel and truly grasp the scientific content of the subject with the help of an interactive research box.

The development process was accompanied by evaluations. The results supported the design process, especially regarding the guiding research questions for the pupils. Our own research questions during the process were:

1. How must a research box be designed in order to be accessible for pupils of different age and knowledge and to enable inquiry-based learning?
2. To what extent is it possible for visitors to use the research box as learning environment for experiments? How much guidance is necessary by a teacher or trainer to enable pupils to implement the experiment instructions?

## THEORETICAL CONSIDERATIONS

The aim of our considerations was to create an exhibit comprising PAR-interactive principles. These are defined as follows (cf. [2]):

- P for “physical”: a direct interaction between visitor and exhibit takes place, no computer or other medium is interposed.
- A for “adjustable”: the interactive part is not only a knob to push once, but can truly be adjusted by visitors (or adjust itself to the visitors).
- R for “relevant”: Working with the exhibit directly supports exploration of the phenomenon.

In connection with these aspects there are many properties to be fulfilled by a good and well-functioning interactive exhibit. Part of these are practical aspects: The exhibit should be robust, safe and require little maintenance; defective or missing parts should be easily replaceable with small expenditure of money. Actually, the crucial demands are of pedagogical and didactical nature: Of course, an exhibit has to be applicable for the mental and (not to be underestimated!) physical skills of the target group, in this case pupils from 9-12 years [7]. It is also evident that it must not be too lengthy and tedious, in order not to scare potential visitors away. Therefore it is essential to keep the intellectual effort small enough at the first contact with the exhibit. This can be done by eschewal of sophisticated technical vocabulary, which would need memorization, avoidance of too many quantitative connections or complex lines of thought [1]. Our research box is planned in a way that it can be done by one single pupil or by up to six pupils together, without fear of disturbance or damage [5], [14]. Norman suggests the design to be self-explanatory in a sense that it appeals to the habits of the visitors (he speaks of “affordance”): “Plates are for pushing. Knobs are for turning. Slots are for inserting things into ... the user knows what to do just by looking.” [12]. Yet interactivity must not become a self purpose distracting visitors from the point: The interactive parts of any exhibit should not be an irritation for visitors, but must be clearly connected with the scientific content of the exhibit.

An important aspect is to keep the attention of the visitors focused long enough to understand the scientific content of the exhibit, i.e. having them not only “play” but also understand. Visitors must be challenged and incited. This can be done by splitting the activities in several sub-steps, where each offers sufficient motivation (cf. [1]). Csikszentmihalyi und Hermanson describe this as visitors being in a “flow state”, which can be achieved if the individual challenges of the exhibit are well adapted for the level of the visitors (cf. [7]). For the flow state of children, who are our target group, characteristics are:

- the child feels itself able to cope with the task (challenge and solution expertise are in balance)
- the child focuses on a defined, close action field
- activities are followed by clear responses
- acting and awareness coalesce (the child forgets the surroundings)
- the child loses itself in the activity
- sense of time is changed (past and future do not exist)
- the activity is rewarding (no external compliments needed).

Perry and Tisdal specify and extend this general definition of a “flow state” by the concept of “active prolonged engagement” (APE) (cf. [14]): The interactivity of the exhibit should be not only a possibility for activity and undertaking but must also offer room and opportunities for deeper cognitive experience. “Hands-on” and activity alone are not enough (this would mean the visitors just playing). Stimulation of scientific reflection must be an integral part of the exhibit (cf. [9]). The immediate or subsequent reflection can be supported by affective learning (cf. [6]). This can be done e.g. by using an emotional topic for the transfer of scientific content (cf. [13], [11]).

Not to neglect are the long term effects of a good and joyful exhibit, apart from learning new scientific facts right away: acquisition of a positive attitude towards science and memorability if the visitors (even having not fully grasped the scientific aspects of the exhibit) are confronted with the same subject later in their lives, which is usually the case with pupils.

## METHODS

The development of the exhibit was done based on the above considerations. A front end analysis was performed to set the topic and contents of the research box: The wishes of the *Research Workshop's* leading team had to be taken into account, avoiding duplication or imitation of existing exhibits. Also the target group had to be specified, the decision was made for pupils of age 9-12. Therefore, the box is intended to be used by primary *and* secondary school children.

After a first design, a formative evaluation has been performed in order to examine if the intended aspects of a PAR-exhibit were sufficiently implemented. 8 groups of 4 pupils each, with various age and sex, were subject to a qualitative participant observation (cf. [4]). Important for the selection of pupils was that they had *not* learned about buoyancy in their science classes before in order to detect more clearly a possible increase of knowledge with respect to the topic via activity-oriented, interactive learning.

Collection of data was carried out anonymised. The "participant observation" is a certain methodical process which has to be distinguished from observation of daily life by stronger focus on a certain objective and more control (cf. [3]). Perceptions of the observer are written down and connected with the results of the investigation. The main reason for this choice of methods is given by the procedures in the *Research Workshop* itself: One or more teachers are always present, not only to take care of the pupils but also to arouse their interest for certain topics, to trigger their preoccupation with a box, and (if necessary) to give support. Therefore the presence and participation of a teacher is quite normal for the pupils and this guarantees not only a closer but also a more unobtrusive and less irritating way of observance than could be achieved by external observers, video cameras or written questionnaires.

There were four categories of observation: preparation before the experiment, setup of the experiment, conduct of the experiment, consolidation of insights. From the results of the observations conclusions were drawn regarding adaptations of the research box for regular use. This will be discussed in the next section.

## RESULTS

### Design Decisions

The research box comprises instructions and material for four experiments (Fig. 1), which can easily be done by pupils with the exception of Experiment 4 where a candle is used and which thereby has to be done under supervision of a teacher.



**Fig. 1 The contents of the research box "buoyancy"**

To ensure that pupils do not only play arbitrarily but also strive to gain knowledge, for any experiment a handout and a sheet with "questions for the researcher" are included. The latter have to be answered in

written form in teamwork and/or alone. From pupils' perspective "research" and "discovery" do not mean the creation of knowledge and discovery of facts beyond well-known physics (although this still seems to happen every now and then...), but beyond the pupil's own knowledge. But it is precisely this "baby modeling" of science which makes school children acquainted with the methods and skills necessary for doing science later in their lives. Moreover, this way of knowledge acquisition is quite sustainable and lasting [8]. Ideally, pupils will never forget what they have learnt by their own research.

The four experiments are as follows:

**Experiment 1:** Three litres of water have to be measured and put into a pot. Pupils shall try which objects swim (styrofoam, cork) or sink (paperclip, Plasticine®) in the water. The intention is to find out that mass and size are crucial, but also shape. The latter is guaranteed by the request to make Plasticine® swim, where pupils may come up with the idea to form a boat. Further questions invite pupils to consider why this happens and how much additional mass can be transported by this boat.

As an example, we give the researcher's questions for Experiment 1 (translated from German):

- (1) What happens to the different objects, which ones swim/sink?
- (2) How do size and mass of a body influence the behaviour with respect to swimming or sinking? Make a protocol and compare with your colleagues.
- (3) (Use 4 pieces of Plasticine®): How can you make Plasticine® swim?
- (4) What happens if further weight is put onto the swimming Plasticine®?
- (5) Can you add infinitely weight? How much load can be maximum supported?

**Experiment 2:** An ordinary balloon is filled with not too much water, knotted, and attached to a not too short rubber band (Fig. 2). Then the balloon is immersed into the water pot (presumably the same as before). The reduction of the balloon's weight and the rubber band's length shall be noticed and buoyancy consciously felt by the pupils.



**Fig. 2 Experiment 2 "balloon filled with water in water" (German captions omitted)**

**Experiment 3:** Pupils should find out that warm air is lighter than cold air. Soap bubbles are created using breathing air (with bubbles at first going up, then sinking down) and hot air from a hair dryer (with bubbles going up faster and not sinking down). Thus, the very first principle of the hot-air balloon is made known.

**Experiment 4:** This is preferably only for older children (12 years up). A small paper bag (open underside) is balanced on a self-constructed balance with the help of a clothes-peg (Fig. 3).



**Fig. 3 Experiment 3 "candle beneath paper bag" (German captions omitted)**

When the air is heated by the candle the air within the bag expands, cold air discharges partially. The remaining hot air is lighter than the surrounding and cold air and the balance goes up. Again, further basic principles of the hot-air balloon are introduced.

## DISCUSSION

For carrying out the four experiments of the research box, the intended time span was 45 minutes. This is close to the actual average time which was observed during evaluation.

At Experiment 1, preparation before the experiment was done as intended by 6 out of 8 groups. The setup of the experiment was done by 4 groups following the instructions. 1 group did it without instruction. 3 groups had problems in measuring the correct amount of water. In the instruction it says "put 3 litres of water in the smaller box" and a measuring cup of half a litre was included. For younger children it was not possible to measure 3 litres out of this, since the concept of "half" was not clear as a precise quantity and much time was wasted with this rather trivial step. Therefore, the smaller measuring cup was replaced by a larger one of 1 litre.

The conduct of Experiment 1 was performed as intended by 5 groups, 2 groups did it their own way, 1 group not at all. Consolidation of insights was done groupwise by 2 groups, individually in 3 groups and not at all by 3 groups. Only one group did not find out what was intended by the researcher's question "How can you make the Plasticine® swim?", i.e. to form a boat. They found another creative solution, placing the Plasticine® onto a piece of styrofoam. Consequently, the question has been reformulated to make clear that no additional tools are allowed to be used.

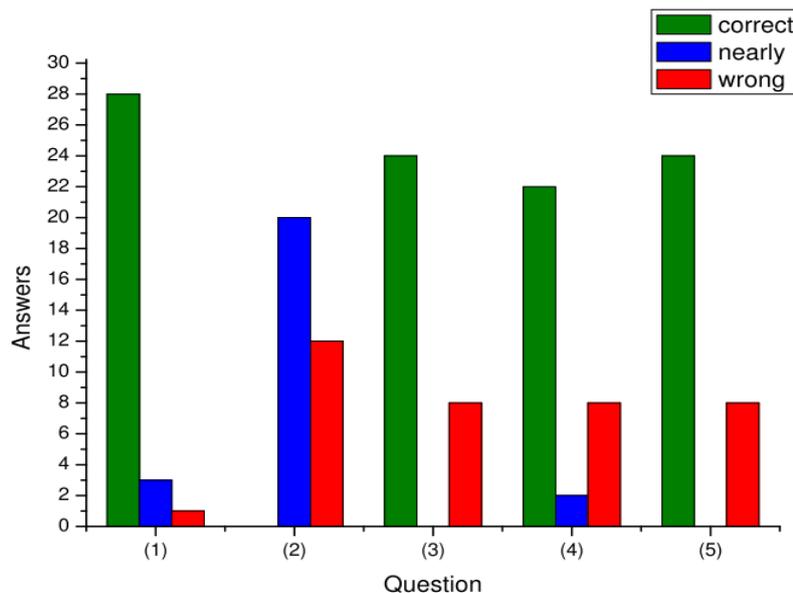
Similar observations hold for Experiments 2 to 4. Additionally, at Experiment 2 knotting a balloon and attaching the rubber band seemed to be difficult for the children. Therefore a further instruction sheet about "how to knot a balloon" with pictures was included. At Experiment 3 the researcher's question "What happens with the soap bubbles?" repeatedly led to answers like "they are faster" or "they burst". This problem was overcome by a reformulation of the question aiming more on what should be found out: "Do the bubbles go up or down with time?" At Experiment 4 two groups had troubles to calibrate the balance. Three groups were not able to affix the paper bag at the balance. Pictures were included to avoid these problems (Fig. 3).

For the observation of the pupils' increase of knowledge, the written answers to the "researcher's questions" were examined. Whereas nearly all school children answered correctly or nearly correctly the questions "What happens...?" or "What do you see?", questions comprising "Why...?" and "What...if...?" caused more problems, especially with Experiment 3, where the questions were originally formulated in an ambiguous way. But even with the trickier questions at least 2/3 of the pupils were able to give (nearly) correct answers. E.g. with the second question of Experiment 1, where the influence of size and mass of a body should be investigated, not a single person could give a fully correct answer, but 20 pupils answered nearly correctly. This shows that the developed research box is appropriate for increasing the knowledge of the pupils and can be utilized for teaching.

As an example, the results of the 5 researcher's questions for Experiment 1 as written above are given. Out of 32 children, the questions (1) – (5) were answered (Fig. 4)

- (1) correctly by 28, nearly correctly by 3, wrongly or not at all by 1
- (2) correctly by 0, nearly correctly by 20, wrongly or not at all by 12
- (3) correctly by 24, nearly correctly by 0, wrongly or not at all by 8
- (4) correctly by 22, nearly correctly by 2, wrongly or not at all by 8
- (5) correctly by 24, nearly correctly by 0, wrongly or not at all by 8.

Again, similar results hold for Experiments 2 to 4.



**Fig. 4** Answers to the researcher's questions of Experiment 1

A special aspect of the box, guaranteeing prolonged learning success, is the observation that pupils have fun with it. Making objects swim or fly is a great joy for children. The box works "by itself" without necessity for the teacher to supervise, motivate or help the children (with the exception of Experiment 4). Thereby, regarding the principles of PAR-interactivity, this helps creating the flow-state necessary for a deep occupation with the subject, the acquisition of a positive attitude towards science and memorability if they meet the same subject later in their lives.

## CONCLUSION

The research box on buoyancy in the *Research Workshop* of the University College of Teacher Education Vienna (PH Wien) creates a learning environment which is appropriate to the needs of 9-12 years old school children.

Our research questions can be answered as follows:

1. How must a research box be designed in order to be accessible for pupils of different age and knowledge and to enable inquiry-based learning?

The inclusion of four experiments with different scientific and technical difficulties appears to be appropriate for the target group. The instructions work well if they comprise a sufficient number of pictures. The research questions on the "research pass" guarantee active prolonged engagement (APE) of the children with the subject and also turn out to work well (if formulated precisely enough) in consolidating scientific understanding of the pupils.

2. To what extent is it possible for visitors to use the research box as a learning environment for experiments? How much guidance is necessary by a teacher or trainer to enable pupils to implement the experiment instructions?

In total, the research box works quite well without further guidance. In particular, no further motivation has to be given by the teacher. So the box is a true learning environment. Only for the last experiment, where a candle flame comes together with a paper bag, the supervision of a teacher is necessary. This undesirable (but sometimes unavoidable) side effect is more than compensated by the very insightful experiment which gives a true understanding of physical facts.

Activity-oriented education is challenging for pupils *and* teachers. Especially during implementation, pupils have to be carefully made familiar with this new way of knowledge generation in order to avoid initial overload. The teacher acts as coach who increasingly leaves responsibilities to the pupils, starting with simple sub-steps

up to complex tasks within the scientific process. Thereby, in class the focus goes from the teacher to the pupils.

A crucial point is to decide for which pupils this open form of education is suitable. Our experience suggests that activity-oriented education is difficult for children with learning disorders (concentration, behaviour). Reducing the number of experiments for a group, specification of the order of experiments, or precise rules of conduct can be helpful. Also avoidance of frustration by use of positive feedback and a helping hand can be useful.

Keeping these aspects in mind, it is in general possible to guide 9-12 year old pupils to the topic of buoyancy with the presented research box. The *Research Workshop* considers itself as coordinated organisational, contentual, and pedagogical concept for activity-oriented education. Understanding of scientific structures is promoted by a practical dialogue with the subject. As we have shown in our paper, the new research box "buoyancy" is a further, carefully created building-block within this promising concept.

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