Experiments in Physics Education: What do Students Remember?

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Abstract. Experiments have been part of the physics education for a very long time. However, in the last two decades their effectiveness as tool for teaching the students scientific concepts has been questioned. Aim of this contribution is to compile current prevailing opinions on what goals can be achieved by including experiments in physics lessons. Furthermore, we designed a questionnaire for high school students which should evaluate what they remember from the experiments they saw during physics lessons. This questionnaire is right now going through its pilot phase.

Introduction

‘Sir, are we doing any experiments today?’ Sentence heard by every physics teacher from every class of students at least once if not once a lesson. Experiments are expected to be part of physics lessons by students and teachers alike. Eagerly anticipated by the former, and sometimes dreaded by the latter, experiments have been part of the physics education for well over a century. While their inclusion hasn’t been significantly opposed yet, the idea how they should be done has changed dramatically over the years.

In the early days, the teacher demonstration was the most prevalent form experiments took. While its methods were perfected over the years, effectiveness of this form as tool for teaching was eventually deemed limited. Towards the latter part of the nineteenth century, influenced by the work of H. E. Armstrong, the notion of students performing experiments themselves became common part of school science curricula in many countries. Hand in hand with this, focus of the pedagogical research turned away from teacher demonstration towards the science labs and this trend is continuing till today. Armstrong’s discovery based approach was changed to more recipe-following form of laboratory work as the heuristic approach to teaching fell out of favour. Heuristic approach had, however, reappeared again in 1960s and 1970s, advocated by a common phrase: ‘I hear and I forget, I see and I remember, I do and I understand’. Nevertheless, in late 1970s concerns were raised over the artificial and constrained nature of discovery learning in science. Students were expected to try to ‘be a scientist’, while engaging them in activities that always lead to predetermined ‘right’ answers, thus misrepresenting the actual research practice. These concerns lead to another shift in laboratory work aims and their associated methods. Specifically, the so called ‘process and skills’ approach became the mainstream favourite. This approach places emphasis on teaching what scientists do, rather than on teaching scientific facts. Students are therefore expected to master such diverse abilities as precise observation, hypothesizing, classifying and so on. Since the rise to dominance of the ‘process and skills’ approach, scientific debate was mainly focused on specifying what is it that scientist actually do, what skills do they use and how to teach them to the students. Information contained in this paragraph can be found in greater detail in Bennett [2003].

While basic ideology of the ‘process and skills’ approach is yet to be seriously challenged, methods commonly used to achieve its goals were criticized for their low effectiveness and relatively high requirements on both the student and teacher time and equipment needed.

For example Hodson [1991] argues that:

‘Despite its often massive share of curriculum time, laboratory work often provides little of real educational value. As practiced in many countries, it is ill-conceived, confused and unproductive. For many children, what goes on in the laboratory contributes little to their learning of science or to their learning about science and its methods.’ [Hodson, 1991]

Furthermore, even the motivational aspect of the practical works has been questioned.

‘For whilst these pupils [who claim to like practical work and also claim to have little, personal interest in science] do like practical work, their reasons for doing so appear to be primarily that they
see it as preferable to non-practical teaching techniques that they associate, in particular, with more writing.’ [Abrahams, 2009]

This criticism had, in the last decade, lead to a rise of plethora of new teaching methods in Physics laboratories (e.g. Micro-computer Based Laboratory (MBL), spreadsheets, simulation software, inquire based labs etc.) which, hopefully, might remedy the situation. But what do we actually expect to achieve by including experiments in physics lessons? As we can see, ideas about how experiments should be done and consequently what should students learn from them has changed over the years. To evaluate the effectiveness of a task we first must decide what the ideal results should look like. And so the questions that ought to be answered are twofold. What goals do we want to achieve and are we successful in our efforts? Purpose of this paper is to summarise current expert opinions on the matter and how they believe the situation could be improved. In the final section I would like to present my future research plans, namely questionnaire aimed at evaluating effectiveness of experiments in physics lessons.

Definitions

First let’s shed some light on few complications in the terminology. In English speaking pedagogical literature the word experiment is used solely to describe complex planned tasks performed by scientists. What we (meaning in The Czech Republic) call school experiments is referred to as practical work. However, this term has several different definitions. I’ll start with the one used by Nuffield foundation [2015].

‘By 'practical work' we mean tasks in which students observe or manipulate real objects or materials or they witness a teacher demonstration.’ [Nuffield foundation, 2015]

Other authors exclude teacher demonstrations.

‘...practical work’ will be used to mean any science teaching and learning activity in which the students, working individually or in small groups, observe and/or manipulate the objects or materials they are studying..... ‘Practical work’ will refer to activities undertaken by students, not carried out by teachers.’ [Millar, 2010]

This significant difference in usage of phrase ‘practical work’ can make correct interpretations of research papers on this topic difficult. From now on, I will use the definition of the Nuffield foundation. I will refer to practical activities excluding teacher demonstrations as labs.

Goals of practical work

One of the most quoted list of goals, that can be achieved by practical work, was created by Kerr J in 1963. Seven hundred teachers from 150 schools were asked in a survey to write down what goals they believe can be achieved. These are their top ten answers:

- to encourage accurate observation and careful recording;
- to promote simple, commonsense scientific methods of thought;
- to develop manipulative skills;
- to give training in problem-solving;
- to fit the requirements of practical examinations;
- to elucidate the theoretical work so as to aid comprehension;
- to verify facts and principles already taught;
- to be an integral part of the process of finding facts by investigation and arriving at principles;
- to arouse and maintain interest in the subject;
- to make biological, chemical and physical phenomena more real through actual experience,

[Kerr, 1963 cited in Bennett, 2003].

According to Bennett [2003] and Millar [2010] this list has been further augmented and used by Beatty & Woolnough [1982]. This elongated list contained 20 items. More recently the same list was used by Swain et al., [1999, 2000] to compare the views of teachers in Egypt, Korea and the UK. Several other lists were made. For example in [Hodson, 1990] following list of aims is proposed:
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• to motivate pupils, by stimulating interest and enjoyment;
• to teach laboratory skills;
• to enhance the learning of scientific knowledge;
• to give insight into scientific method, and develop expertise in using it;
• to develop certain ‘scientific attitudes’ such as open-mindedness, objectivity and willingness to suspend judgement.

Wollnough and Allsop [1985] suggested a shorter list consisting of only three fundamental aims:

• to develop practical scientific skills and techniques;
• to be a problem-solving scientist;
• to get a ‘feel for phenomena.’

These three examples of lists are but a small sample of all the lists there are.

Summary
The number of lists and diversity of their approaches suggests that deciding what can be achieved by practical work is a complex issue without simple solution. What conclusions can we draw from these lists?

According to Bennett [2003] majority of the lists that came from studies amongst teachers shared the following goals:

• to enhance understanding of scientific ideas;
• to encourage accurate observations and description;
• to make scientific phenomena more real;
• to arouse and maintain interest;
• to promote a scientific method of thought.

Some of the goals that appear in these lists are interlinked and cannot be achieved separately. For example, we cannot hope for any concepts or scientific ideas to be taught by practical work, unless the students are capable of accurate observations.

And finally, number and complexity of the aims clearly shows that expectations for practical work and especially labs are very high.

Research findings on attainability of goals
Are these expectations met? There are number of goals we would like to achieve by practical work but results of common classroom practice can be quite different from our plans and wishes. Majority of research evaluating effectivity of practical work that was done in last thirty years explored laboratory work only and therefore in this section I will deal solely with science labs. According to Berg [2009] six extensive reviews of research on the outcomes of laboratory teaching ([Bates, 1978; Hofstein & Lunetta, 1982 and 2004; Lunetta et al, 2007; Garrett & Roberts, 1982; Hodson, 1993]) have concluded that:

• Labs are not better than other methods in teaching science concepts and ‘content’;
• Labs probably are not better than other methods in learning to do research and acquiring research skills;
• The lab is better than other methods (demonstrations, lectures) in teaching measurement skills and techniques;
• Labs can lead to a better motivation but that does not necessarily result in better achievement;
• Labs do not lead automatically to a better understanding of the experimental nature of science, unless labs are explicitly designed and taught for that purpose.

Ed van den Berg also states that:

‘The conceptual or research goals of the laboratory get lost in the attention for equipment and there is no conceptual learning, nor learning of research methods or research skills.’ [Berg, 2009]

Thus we can see that while our hopes for practical work are high, common practice is far from ideal.
Possible solutions

Many possible solutions were suggested that could improve the situation. Following ideas are recommendations I selected from [Berg, 2009].

Integration of inquiry based labs

Inquiry based labs are aimed at teaching students scientific methods, skills and thought processes. What distinguishes them from usual labs is inclusion of students from the very beginning of the planning process for experiment they will be conducting. Students are given research task and with the help of a teacher design experiments, decide what instruments will they need and how will they analyse data gathered.

Pre-lab skill practice

As was mentioned earlier, students often cannot see the phenomenon or concept they are supposed to learn, because they are too preoccupied with manipulating instruments, taking measurements and performing statistical analysis. This can be alleviated by practicing the necessary instrument skills in short pre-lab exercises. This way, students can focus on the research question of the lab.

Clear separation of lab experiments by their goals

Labs can be separated by their goals into three distinct groups and each group should be planned with that particular goal in mind. These three groups and the relevant goals are:

- Concept labs — teaching concepts or overcoming misconceptions (how does nature work);
- Inquiry or research labs — exercising intellectual skills needed for generating and validating knowledge (how to do research);
- Instrument labs — learning manipulative skills (e.g. how to operate microscope).

By tailoring the labs to their purpose their effectiveness in achieving the goals we have in mind can be increased. Details on how to plan particular type of labs can be found in [Berg, 2009].

While they did not implicitly separate labs in different types the importance of planning laboratory work with all its learning goals in mind was also suggested in [Abrahams & Millar, 2008]. Their suggestion was to give both manipulating instruments, measuring and observing; and thinking about models, reasons and explanations significant proportion of time during the actual laboratory work. Thus students could be led to manipulate ideas while they perform the experiments rather than in post lab lessons and this can potentially lead to better learning and memory retention of scientific concepts.

Research plans — memory retention concerning practical work

In the text above I have mentioned the issue of effectiveness of practical work. This topic, which has been debated for over 30 years, raises some serious questions about the teaching methods that should be used. But how can one measure the effectiveness of an experiment? Effectiveness is a complex idea that has many different aspects contributing to its overall value. In order to simplify this task I decided to design a questionnaire that would focus on more or less single aspect of it, which is memory imprint it leaves in the student. Though remembering is at the lowest level of Bloom’s taxonomy and practical work surely aims at higher levels of cognitive skills, it is natural to suppose that in order to be effective, practical work has to be remembered by the students at least to a certain degree. That includes both retention of physics concepts and details of the particular experiments.

To evaluate what is remembered I ask the respondents questions that ascertain:

- How many experiments do they remember
- Which experiments do they remember
- What details do they remember about a chosen experiment

The details of the questionnaire do not fit into this short paper and will be described elsewhere. I would like to analyse data gathered individually and then map the typology of students using cluster analysis. Additionally, I’m planning to accompany the student testing with teacher interviews for data triangulation. Currently, the questionnaire is going through its pilot phase.
Conclusion

Practical work is an inseparable part of physics education and nothing will probably change that. There are many goals that are believed to be achievable with it. However, including practical work blindly into the lessons can be contra productive. Every science lab or experiment has to be well thought through and planned with particular goal in mind otherwise it might become giant waste of time and resources. In order to better evaluate the effectiveness of the various methods that experiments can use I have designed a questionnaire that measures students memory retention of them. This will hopefully prove to be useful tool for measuring the effectiveness of practical work.

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