

The Effectiveness of Practical Work in Science Education

Bachelor's Thesis

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1 Introduction

Practical work is seen as an essential part of teaching and learning physics [Abrahams and Millar, 2008; Hodson, 2005; Jenkins, 1999; Millar et al., 1999; Solomon, 1999]. Indeed its position has been confirmed by researchers, teachers as well as national curricula. Students seem to enjoy practical work and it is thus generally regarded as adding to the students' motivation to study physics (these views, too, have been challenged; the interested reader is referred to Abrahams 2011). In most countries practical work is either considered a central part of physics classes or its status is wished to be lifted to such a position [Hodson, 2005; Millar et al., 1999]. However, questions have been raised about its efficiency as a learning and teaching method. This has yet to be thoroughly studied in Finland but for instance in England and North America researchers of science education have been interested in the efficiency of practical work for decades.

However, it cannot be lightly argued that practical work does not have its place in science teaching. Solomon [1999] talks about the importance of practical and theoretical learning supporting each other: she uses an example of a medical student who, when seeing his very first X-ray picture in a lecture, could not first make sense of either the picture or the lecturer's words but when comprehension came both the picture and the theory made sense simultaneously. Her point to make is that "neither the one nor the other is the primary [representation], and that neither of them alone corresponds to the full internal image". This can be easily applied to the meaning of practical work in science teaching: scientific phenomena are such that they cannot be fully understood by neither practice nor theory. The empirical and the theoretical are intertwined and cannot be separated.

It is our job, as science teachers, to help the students see the connections between the theory we teach them and the phenomena they see in the experiments. To reach this goal it is important first to recognize the problems students have in making links between the practical and the theoretical and deduce the reasons behind them. Once this is done changes can be made in the way we instruct students in practical work. Suggestions on how this should be done as suggested by research can be found in this work.

1.1 Aims

This work is an overview of the modern studies conducted during the last few decades on the subject of efficiency of practical work in promoting the students' conceptual knowledge and understanding of physics. The studies analysed are conducted mainly in the countries where practical work in school

science has long traditions such as the UK. Due to the large number of articles written about the topic I have primarily chosen the most frequently referenced ones to be discussed in this work.

I shall commence in chapter 2 by giving an overview of the usual problems and contradictions concerning practical work based on the aforementioned studies. I aim to bring forward the reasons why this area is worth looking into. In chapter 3 I will present several possible reasons behind the problems as suggested by the articles. Chapter 4 is dedicated to the solutions to the problems, after which I will conclude by summing up the key points in chapter 5. Throughout the work I shall attempt to keep the discussion linked to the classrooms. I wish to put together a body of useful information for science teachers.

2 Problems concerning practical work

Using laboratory work as a teaching strategy has many rationales. They are usually categorized in 3-6 aims. These categorizations are done in almost all articles that concern practical work (see for instance Hodson 1996; Jenkins 1999; Ntombela 1999; Wellington 1998; White 1996) and they are strikingly similar. An example will be given from Millar and Abrahams (modified from 2009:61):

The main objectives of the practical activity is:

- 1) to help students develop their knowledge of the world and their understanding of some of the main ideas, theories and models that science uses to explain it
- 2) to help students learn how to use some piece(s) of scientific apparatus and/or to follow some standard scientific procedure(s)
- 3) to develop students' understanding of the scientific approach to enquiry (e.g. of how to design an investigation, assess and evaluate the data, process the data to draw conclusions, evaluate the confidence with which these can be asserted).

In the light of this vast variety of aims Jenkins [1999:27] "prompts the question of whether laboratory work is being burdened with responsibilities it cannot realistically hope to meet". Self-evidently practical work is the best approach when the objective is the second one in the list above. In comparing methods of instruction, Hodson [1990:36] argues that the only field where practical work seems to be a good method is laboratory skills: the "area the other

methods did not attempt to teach". However the first and the third aims are not so self-evidently reached efficiently through the use of practical work. From now on this work only deals with the first one.

Practical work's status as a teaching method in national curricula is discussed in chapter 2.1. Two examples will be presented: Finland and the UK. The former one is a self-evident choice concerning the framework of the thesis. The second one is chosen because practical work's history in science instruction in England is perhaps the longest in the world and because "students in UK schools undertake more practical work in science than do students in most other countries in the world" [Dillon, 2008:3]. It should be noted that although the text namely speaks of the UK in effect it only applies to England and Wales; Scotland and Northern Ireland have their own autonomous educational authorities. In chapter 2.2 some critiques towards the use of practical work as a teaching strategy concerning conceptual knowledge are presented.

2.1 Practical work in Curricula

The Finnish National Core Curriculum provides the frame where the schools construct their own specific curricula. The Core Curriculum clearly states that practical work is expected to be used as a tool of teaching physics concepts. The following extract illustrates the cognitive skills that are expected of a student in the final assessment of the sixth grade (the second year of studying physics) for "good performance: ...the pupils will know how to draw conclusions from their observations and measurements" [Finnish National Board of Education, 2004:187]. Subsequently in lower secondary school the meaning of practical work is described as "to help the pupils to learn new scientific concepts, principles, and models" [Finnish National Board of Education, 2004:188] and in upper secondary school "Experimentation will be used to support students as they absorb new scientific concepts, principles and models" [Finnish National Board of Education, 2003:148].

The UK House of Commons Science and Technology Committee [2002] has proclaimed the status of practical work in science education as follows:

"In our view, practical work, including field work, is a vital part of science education. It helps students to develop their understanding of science, appreciate that science is based on evidence and acquire hands-on skills that are essential if students are to progress in science." (Paragraph 40)

This paragraph illustrates that practical work holds a fundamental position in science teaching in the UK similarly to that in Finland. In fact, as mentioned previously in chapter 1, practical work is seen as a prominent part of science

teaching worldwide. However, interestingly enough the countries with the strongest tradition in practical science teaching are the ones where the most strict critique comes from: practical work doesn't seem to help the students learn in the way science educators wish them to [Millar et al., 1999].

2.2 Research findings on the effectiveness practical work

As mentioned earlier the topic of practical work as a tool of promoting conceptual understanding has been widely researched over the last decades. Very few studies have found that practical work would improve the understanding of scientific knowledge using pen and paper tests: only one example was found during the course of writing this work. Quite on the contrary, there are several studies (for instance Abrahams 2011; Hodson 1990; Millar et al. 1999; Wellington 1998) indicating that experimental work is not effective as a tool of promoting understanding or learning the theoretical concepts of physics. Only a few examples are going to be given in this chapter because the problems found are usually quite similar. However, first I shall present the aforementioned positive result.

In 2011 the Finnish National Board of Education conducted a broad follow-up assessment in teaching and learning of natural sciences [Kärnä, Hakonen, and Kuusela]. The effect of several *modi operandi* were evaluated by correlating the mean amount of a certain method of teaching reported by the pupils with the mean result of the tests. This was done school by school. The subjects of the study were students in the ninth grade (the last year of lower secondary school). The result of the study concerning practical work was that practical work is the strongest contributor in developing cognitive physics knowledge. The evaluation of exercises and the results gained during practical work was the second strongest, almost as significant as practical work itself. As mentioned earlier these results are rare ones: more often contradictions are found between the views held by educational authorities and the learning outcomes. This brings to mind two possibilities for an explanation: either there is some aspect of the study that makes the result incommensurable or practical work in science is used in Finnish schools in such a way that it actually does work as a strategy in teaching conceptual knowledge.

Abrahams and Millar [2008] state that although practical work is a somewhat effective tool in getting the students to remember the practical aspects of an experiment the ideas behind the phenomena are rarely learned and even more so recollected later on. However, they go on to argue that teachers expect students to learn scientific ideas from practical work. This clear contradiction between learning outcomes and the actual results is at the heart of the

problems in practical science teaching. Hodson [1990, 1996] states that practical work is only effective as a teaching strategy for some teachers, some students and in some concepts. In a prior article he argues that since laboratory work is often the following of recipe-style instructions, they are at best “a waste of time. More likely, they are confusing and counter-productive” [Hodson, 1990:36]. White [1996:768] offers a similarly pessimistic view: he argues that there is insufficient evidence that practical work would be a useful tool in teaching and illustrating theoretical knowledge or scientific enquiry at all. In the light of arguments such as these and taking into account the relatively high demand of practical work concerning resources and the use of time a question of its usefulness as a teaching and learning strategy has to be addressed.

3 The reasons behind the problem

In this section I shall present problems that have been found essential in the studies. I shall use a systematic approach in discussing these issues.

3.1 Discovery learning

Abrahams and Millar [2008] introduce an observation linked to the inefficiency of practical work in teaching theoretical knowledge: in their study the teachers expected the students to learn the ideas through the work but yet did not plan or implement any sort of actual effort to bring this about. Similarly Ntombela [1999] states that amongst teachers and teacher-students “there is a strong belief that by following steps given in the worksheets pupils can ‘discover’ the theory for themselves”. Clearly the teaching strategy behind these findings must be inductive or discovery learning.

Hodson [1990:37] argues that teachers’ views on discovery learning are distorted by some faulty assumptions about the importance and potential of observations, for instance that “Explanations of these [gained] trends and generalizations, in the form of principles, laws and theories, can be extracted from these data”. In both these cases the problems has to do with discovery learning and inductive teaching strategies. He goes on to argue that discovery methods are “psychologically unsound and pedagogically unworkable” as it is very unlikely that students will without the needed theoretical framework make the correct deductions from the data. Such a situation usually has two possible outcomes: either the students make the wrong observations and draw inaccurate conclusions or the teacher issues clear recipe-like instructions which ends up in the students doing instead of thinking.

3.2 Learning outcomes

A significant factor in the use of any method of instruction are the intended learning outcomes: what does the teacher want the students to learn from the task? Referring to the objectives of practical work presented in chapter 2, if the aim of the task is to teach practical skills or has do with the domain of observables and objects, as Millar and Abrahams [2009] express it, surely the cognitive demand of the task is much smaller than in the case of trying to understand new ideas or develop scientific thinking. Indeed in the latter cases, to gain the optimal results the students ought to process the exercise on the practical level and simultaneously, depending on the learning objectives, on the micro level, symbolic level or both. This is expressed as doing with ideas as well as objects by Millar and Abrahams [2009]. Hodson [1990, 1996] emphasizes the teacher's and learning material's role in bringing this about: the more demanding the task is for the students, the more rigorously the teacher has to design, structure and prepare as well as instruct the task.

3.3 Ontology

Leach [1999] states that "in order to appreciate how scientific knowledge is used, students need some rudimentary understanding of its ontology". Ontology (the branch of philosophy addressing the status of the entities in the material world) is in this context used to apprehend the relationships between the concrete objects used in the experiments and the abstract models used in the theories. These matters are quite self-evident to teachers who are used to thinking about and seeing the experimental set-ups as representations of scientific knowledge, but the situation is not so for most of the students. This discrepancy in views of knowledge easily causes deficiencies in learning outcomes [Leach, 1999].

Similarly Tiberghien [1999] states that the scientific knowledge of students is much more fragmentary compared to that of the teachers. As students make interpretations of the world, they do so through modelling it: the objects and events of the tangible world are used to model the theories and models of science. Teachers as experts in their own respective fields have categorized their knowledge and organized it so that the relations between different categories such as the practical world and scientific models are clear whereas a student's knowledge consists of separate pieces of information which are not necessarily connected in the correct ways if at all. Tiberghien reminds that the ability to understand both of these worlds, skills and abilities on the one hand and argumentation and procedural knowledge on the other, is required to correctly learn and comprehend physics.

3.4 Class talk

In a broad study on practical work by Millar and Abrahams it was found that a gross majority of talk in the classroom has to do with the practicalities of the tasks, that is handling the objects and producing the phenomena. Almost no time at all was devoted to discussing the ideas behind the phenomena or the scientific enquiry. The focus in the classroom was on the 'hands on' side of the task, not on the 'minds on' side, leaving little time and attention for discussion about the ideas behind the phenomena [Millar and Abrahams, 2009].

Another observation concerning students' talk was made by Tiberghien [1999]: even though students might take into account both the practical and the theoretical side of things during an experiment, most of their time is spent handling the equipment and discussing the practicalities. Furthermore, when the time came to put the equipment aside and analyse the data, the discussion moved almost completely to the theoretical and numerical level: very few connections were made to the measurements.

However, after the practical and the analytical part of the experiment there were activities to further probe the relationship between the concrete and the theoretical. It was found that during this time, when discussing a physical quantity derived from the experiments and its dependency on the experimental set-up, the conversation was mainly based on the relations between the theoretical and the practical. Connections were also made to the numerical models. Furthermore, the theoretical was discussed as an independent subject but the practical or numerical were not. This suggests a transfer from the concrete level of classroom talk to a more theoretical and abstract level of discussion. The reason for this obviously desirable change was the nature of the tasks: in order to complete the activities the students simply had to make connections between the practical and the theoretical. The discussion was mainly qualitative as opposed to it being quantitative during the experimental part of the activity. A point well worth noting here is that handling equipment and making measurements did not seem to "lead the students to establish relations between the objects and events, measurements and physics concepts" [Tiberghien, 1999:188]. These activities are often needed in order to do practical work, but independently they do not lead to learning!

3.5 Class time

Abrahams (for instance 2011) raises the use of class time as an issue. He argues that most of class time, that of the teacher's as well as of the students', is

used for dealing with the practicalities of the tasks, that is giving instructions, collecting the equipment, handling them in producing the data and cleaning up afterwards. Very little or no time at all is devoted to discussing the ideas behind the phenomena or otherwise developing the conceptual skills of the students. In a prior study Millar and Abrahams [2009] found that most of the teachers in the study (24 out of 25) devoted very little or no time at all for supporting the development of the students' knowledge through discussion: the time was spent concentrating on the practicalities. They expected the correct deductions to arise from the results provided those were produced successfully.

4 Solutions

Abrahams and Millar [2008] suggest that the outcomes of practical work could be significantly improved should the teachers and the authors of teaching materials recognise the importance of discussion between the domain of objects (macro level) and ideas (micro and symbolic level): the theory and models behind the physical phenomena should be present during the experiment. The key point here is that the correct ideas will not simply arise from the physical actions and phenomena because the students do not possess the scientific way of thinking and expertise that the teachers do. Due to the empirical nature of physics practical work has an important role in making links between the phenomena and the theoretical concepts: Tiberghien [1999] states that in order to be able to fit experimental observations into a theoretical framework, the knowledge in both fields must develop simultaneously.

Similarly to Abrahams and Millar, Solomon [1999] argues that simply seeing a particular phenomenon does not create understanding or make sense to a student any more than mechanically copying down a sentence. She states that learning in practical work happens through connecting scientific ideas with the images of an activity in a student's mind. In doing an experiment the student gains visual percepts of the phenomena: the learning happens when s/he is able to link these to the proper theory or explanation, to "change what is seen to a vivid illustration of scientific ideas" [Solomon, 1999:67–68]. She goes on to suggest a concept of internal envisionment in practical work which means to help the student to imagine what happens 'beneath the observable surface'. The teacher's role is to act as a facilitator in this process.

However, it should be kept in mind that there is a limited amount of information that the students can process at a time. Tiberghien states that "[a practical] task should not demand too many different cognitive activities at the

same time because students only use a few at once" [1999:176]. The minds-on approach or envisionment combined with the practical activity should not overload the students' minds or otherwise none or very little real learning happens. Abrahams and Millar [2008] state that it is very important that teachers are able to distinguish between activities of high and low learning demand in order to be able to provide the appropriate amount of support for the students' learning and not to plan too difficult activities.

A suggestion comes to mind that the practical activity could be discussed in subsequent lessons. However, Abrahams and Millar [2008] argue that if there would be a gap between the activity and the discussion, the effectiveness of the task must diminish compared to a situation where the ideas are present during the activity. Tiberghien [1999] raises the importance of task design as an issue concerning practical work: by posing a question in a certain way the teacher can promote particular cognitive activities. Thus it could be argued that careful task design is key to successfully balancing between the theory and the phenomena. Surely one can state that this is not an easy task for science teachers.

Dillon [2008:53–54] in conducting a wide review on practical work in science teaching found that "In summary, the science education community is not lacking in knowledge of what works in terms of science activities, or at least, what might work better. What is lacking is adequate training and an assessment regime that might facilitate change". This is to say that in order to improve the effectiveness of practical work according to recent studies as described above, the real solution is to train teachers to instruct practical work in line with the research findings. How to manage this time- and resource-wise is a problem.

5 Summary

Research suggests that although practical work is generally regarded as an enjoyable and useful method of developing conceptual understanding, its effectiveness in this particular aim is largely overstated. The rationalisations made by teachers are ample: "I think they learn so much more by actually doing it than by just being told or even watching me do it" or "I think I believe strongly that by doing things you're more likely to remember it" [Abrahams, 2011:11, 82]. Indeed practical work is quite efficient in creating new images of a particular subject. However, the thing that does cause concern is the quality of the images: it usually has to do with practicalities instead of concepts or ideas.

Studies suggest that the use of practical work as a teaching strategy demands significant work in non-tangible areas. The students should be prompted to handle the phenomena at hand on the conceptual level simultaneously to the practical activity: they should be committed to the task with their minds as well as their hands. In terms of classroom routines, the activities and the exercises should be designed in a way that promotes making links between the practical and the theoretical. Enough time and attention should be dedicated to discussing and reflecting on the connections between the natural world and the ideas of physics. To bring this about science teachers should be actively trained with regard to the latest research to improve their practices.

The purpose of this work has by no means been to say that practical work should not be included in the curricula. There is very little proof that practical work would be more ineffective as a teaching method as the more conventional modes of instruction. The reason to raise conversation is, however, the relatively large amount of resources and time that including practical work in teaching requires. One might wonder if it is worth it all. I say yes, but the quality of practical work in schools as it is now is not good enough. To make it worthwhile actions should be taken in order to implement better and more efficient practices. Further research is required on how to bring this about in a manner that is realistically possible to implement on a national level

Viitteet

- I. Abrahams. *Practical Work in Secondary Science: A Minds-On Approach*. Continuum International Publishing Group, London, 2011.
- I. Abrahams and R. Millar. Does practical work really work? a study of the effectiveness of practical work as a teaching and learning method in school science. *Journal of Science Education*, 30(14):1945–1969, 2008.
- J. Dillon. A review of the research on practical work in school science, 2008. URL http://score-education.org/media/3671/review_of_research.pdf. Last accessed 11.2.2014.
- Finnish National Board of Education. National core curriculum for general secondary education intended for young people, 2003. URL http://www.oph.fi/download/47678_core_curricula_upper_secondary_education.pdf. Last accessed 31.1.2014.
- Finnish National Board of Education. National core curriculum for basic education part iii: Chapters 7.4-7.9, 2004. URL http://www.oph.fi/download/47672_core_curricula_basic_education_3.pdf. Last accessed 31.1.2014.
- D. Hodson. A critical look at practical work in school science. *School Science Review*, 71(256):30–40, 1990.
- D. Hodson. Practical work in school science: exploring some directions for change. *International Journal of Science Education*, 18(7):755–760, 1996.
- D. Hodson. Towards research-based practice in the teaching laboratory. *Studies in Science Education*, 41(1/2):167–177, 2005.
- House of Commons Science and Technology Committee. Science education from 14 to 19, 2002. URL <http://www.publications.parliament.uk/pa/cm200102/cmselect/cmsctech/508/508.pdf>. Last accessed 31.1.2014.
- E.W. Jenkins. Practical work in school science - some questions to be answered. In J. Leach & A.C. Paulsen, editor, *Practical Work in Science Research - Recent Research Studies*, pages 19–32. Frederiksberg: Roskilde University Press, 1999.
- Pirkko Kärnä, Riikka Hakonen, and Jorma Kuusela.
- J. Leach. Learning science in the laboratory: The importance of epistemological understanding. In J. Leach & A.C. Paulsen, editor, *Practical Work in Science Research - Recent Research Studies*, pages 134–147. Frederiksberg: Roskilde University Press, 1999.
- R. Millar and I. Abrahams. Practical work: making it more effective. *School Science Review*, 91(334):59–64, 2009.
- R. Millar, J-F. Le Maréchal, and A. Tiberghien. ‘mapping’ the domain: Varieties of practical work. In J. Leach & A.C. Paulsen, editor, *Practical Work in*

- Science Research - Recent Research Studies*, pages 33–59. Frederiksberg: Roskilde University Press, 1999.
- G.M. Ntombela. A marriage of inconvenience. In J. Leach & A.C. Paulsen, editor, *Practical Work in Science Research - Recent Research Studies*, pages 118–133. Frederiksberg: Roskilde University Press, 1999.
- J. Solomon. Envisionment in practical work: Helping pupils to imagine concepts while carrying out experiments. In J. Leach & A.C. Paulsen, editor, *Practical Work in Science Research - Recent Research Studies*, pages 60–74. Frederiksberg: Roskilde University Press, 1999.
- A. Tiberghien. Labwork activity and learning physics - an approach based on modelling. In J. Leach & A.C. Paulsen, editor, *Practical Work in Science Research - Recent Research Studies*, pages 176–194. Frederiksberg: Roskilde University Press, 1999.
- J. Wellington. Practical work in science: Time for a reappraisal. In *Practical work in school science: Which way now?*, pages 3–15. London: Routledge, 1998.
- R.T. White. The link between laboratory and learning. *International Journal of Science Education*, 18(7):761–774, 1996.