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Effectivity evaluation of experiments in physics education by memory retention

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Abstract. Evaluating effectivity of various forms of experiments and practical work in physics lessons is a very complex problem. The goals that we as educators would like to achieve by practical work are broad. Examining all the aspects of practical work and evaluating them would be very difficult to do from a technical standpoint. It would be very time consuming, challenging to implement in normal school courses and in turn very costly. The aim of this study was a development of relatively simple method that would give insight into what methodologies of practical work are effective in teaching high school students’ conceptual knowledge. Based upon the framework for considering the effectiveness of a practical task proposed by Abrahams and Millar (2008), we believe that this information can be ascertained by examining which experiments students remember and to what extent. We expect that more effective methodologies of performing classroom experiments will leave more permanent and complex imprints in the student’s mind and therefore these experiments should not only be remembered more often, but also to a greater detail. To this end a relatively short questionnaire was developed, consulted with experts and piloted, that focuses on finding out what types of experiments do students remember from the last six months of their physics education course. The Questionnaire is constructed in such a way, that it doesn’t specifically work with any part of physics curriculum and therefore can be used across all school institutions and all school years without any modifications. Validity of the data can and should be increased by cross-referencing gathered data with information gained by interviewing the teachers of the respondents. Gathered data should also allow us to map what general types of students exist in regard to their relation to practical work and if certain methodologies are more effective when used on different groups of students. Hopefully, these findings will give us some insight into what forms of practical work are actually effective and if so, then on what type of students.

1. Introduction
As stated above, the evaluation of effectivity of practical work as a teaching tool is a difficult issue. This is due in no small part to the high expectations we as educators might have when introducing it in the classroom. The goals we would like to achieve by practical work are broad, as stated for example by Hodson (1990) and Bennett (2004), and range from mere motivation to teaching good science practices. Research of practical work effectivity in teaching all of these goals would be too complex, time consuming and in turn too expensive to do. For that reason I decided to focus on only one of these goals and that is teaching conceptual knowledge. Furthermore, there was no possibility for me to conduct a controlled experiment that would put sufficient number of students through a physics course constructed in such a way that it would contain selected experiments taught in ways we would also select while maintaining a control group. To find enough willing teachers to partake in an experiment that would require from them so much additional work without any monetary gain is nigh impossible. With these limitations in mind, I opted to conduct research in such a way, that it would not require me to force the teachers to use preselected experiments and methodologies.
2. Theoretical framework
As a basis for my work I chose the framework for considering the effectiveness of a practical task proposed by Abrahams and Millar (2008). In it he describes his model of the design process and evaluation of a practical task as a four stage endeavour. My research focuses on the transition between the third and fourth stage, e.g. between “what the students actually do as they undertake the task” and “what the students learn as a consequence of undertaking the task” (Abrahams & Millar 2008). However, how can you evaluate what students learn, when you can’t control what topics are taught? This lack of curriculum control makes creation of tests for evaluating particular concepts very difficult?

This issue had to be tackled from a different angle. Based upon the first levels of Bloom’s taxonomy of cognitive domains, students should be able to recall and apply knowledge they learned. These two tasks can therefore form a viable probe into students learning. However, question arises if evaluation of memory retention can in turn help evaluate effectiveness of an experiment. Our method is built upon the current knowledge of inner working of human memory and memory loss of school knowledge. As stated by Semb and Ellis (1994):

*Any theory about loss of information learned in school should be more concerned about loss of semantic content than episodic content.*

The same authors also write:

*As new information is assimilated, existing knowledge structures/schemata should be modified and extended. For example, when prior knowledge is repeated during instruction, overlearning should occur. This should result in higher levels of retention.* (Semb & Ellis 1994)

Since academic knowledge is ideally incorporated into a scaffolding of previously learned knowledge and interacts with it to form a coherent web of information, we expect an effective experiment to be linked with knowledge taught in such neural scaffolding. Therefore, such experiment should help in recollection of the knowledge taught and vice versa. Complexity and quality of such mental construct should positively affect the memory retention, therefore an experiment that teaches concepts effectively should also be more memorable.

However, we acknowledge that even ineffective experiments could be very memorable due to explosions, social aspects and other novelty factors. So we conclude that pure memory retention of an experiment isn’t a sufficient sign of its effectiveness as a teaching tool. Recollection of the experiment has to be accompanied with the recollection of concepts involved and possibly with the ability to use those concepts.

3. Research questionnaire
In order to get enough teachers to volunteer themselves and their pupils for our research, its method had to be implementable with as little effort for them as possible. Therefore, a questionnaire was selected as a primary data gathering device. Measured data would be triangulated and cross-checked by interviewing the teachers afterwards. Additionally, the questionnaire for students had to be relatively brief, or we would risk that significant number of students wouldn’t answer it seriously or even answer it at all. For those reasons a two page limit was set with a 20-minute time frame in mind. The questionnaire was consulted with experts and went through two separate pilot runs. In its current final state it consists of two distinct parts.

**Low-level retention**
The first part and also the first page of the questionnaire maps the low level retention of experiments. Students are asked to compile a list of experiments they remember from last six months of their current physics classes and put each of them in a specific column depending on what methodology was used. Students are presented with following classes.
Table 1. Classes of experiments as used in the questionnaire

| A | B | C | D |
|---|---|---|---|
| Experiments performed by teacher | Showing video recorded experiment (YouTube, DVD, …) | Laboratory work – Significant teacher supervision | Laboratory work – you manage your own work |

This list is then evaluated in two ways. First and foremost, how many experiments from each class does this student remember? And additionally, since the name of the experiment is constructed by the student, how many of those names contain an idea or concept as opposed to how many were based upon an observable world. For example the same experiment was called “A truck and a ball” by one student and “Conservation of momentum – track, ball” by another. The usage of a concept in the name can be symptomatic of the student forming a connection between that particular experiment and the scientific concept. This link between the domain of ideas and the domain of observables is also part of Millar’s framework.

**High-level retention**
The second part of the questionnaire deals with in-depth recollection, testing of conceptual knowledge and its application. Students are asked to choose one experiment from their list which they believe they remember the best. Chosen experiments are then searched for any similarities like:

- Chosen experiments aren’t recent
- Were repeated the most
- Were of particular class (A, B, C, D as above)
- Were named using a concept

Students are also asked to fulfil following tasks:

- List all the equipment that was used for that experiment
- Describe their observations from that experiment
- Name the concept shown by that experiment if there is any
- Explain the shown concept

Gained information is then evaluated for its correctness and completeness. Since these are open ended questions, their evaluation is open to interpretation. To increase reliability of the results, all filled questionnaires are independently coded by two physics teachers (i.e. experts) in accordance with a written codebook. Both evaluations are then crosschecked and any discrepancies are discussed until both coders are in agreement.

**4. Preliminary results**
The questionnaire was deemed satisfactory after the second pilot run and therefore the data from this pilot phase were incorporated into the data gathered in the “live” inquiry. While data were gathered from about 200 students, they are in various phases of the coding process and so far none of them have been fully analyzed. All the presented preliminary data (from around 30 subjects) are from the second pilot run. Since this data come from a single class taught by one physics teacher, it should be noted, that these results may not represent general school population. Because of that I opted to showcase only a few select pieces of data, data I find interesting, instead of presenting the whole analysis. That I shall publish at a later date when the statistical sample is more significant.

First data I would like to present is an overview of the distribution of experiments listed in the first part of the questionnaire among their classes. Data are shown in Fig. 1.
As you can see, there isn’t any significantly preferred class. However, two of the classes represent ways of performing a laboratory work in class. When joined together, this newly created general class occupies 51% of remembered experiments. This conforms with broadly accepted theory that lab work is more memorable and possibly more effective as a teaching method. When prompted to select the best remembered experiment, students generally chose experiments from the same classes as seen in Fig. 2. Interesting is also a complete avoidance of video experiments in the second part of the questionnaire. This leads me to believe that they were either very ineffective in this particular class or difficult to describe and/or explain and in turn scarcely chosen.

Final data we present is the retention period of chosen experiments. Which in this particular setup means how long it is since the students saw the chosen experiment. Given that memory retention slowly decreases over time, it would be logical to assume that without any other effects the best remembered experiment should be the most recent one. However, data shown in Fig. 3 show that this is rarely the case. Students preferred to describe experiments that were 1-6 months old. Actually, the most frequent time period was 3 months.

Fig. 1. Overview of the distribution of experiments listed in the first part of the questionnaire among their classes.

Fig. 2. Distribution of experiments chosen as best remembered.
Fig. 3. Time since last exposure to an experiment that student selected as best remembered

This leads me to believe that when done correctly, practical work can, to a certain degree, overcome natural memory degradation.

5. Future plans
Data gathered from the live inquiry will be fully coded, triangulated for added reliability and analyzed. We hope to map both the student types present in classroom in regard to the practical work and the effectiveness of various elements of practical work. After the initial mapping is complete, I hope to follow it with additional study that would selectively introduce different teaching methodologies into the lectures. The same questionnaire would be then administered to ascertain the effectiveness of those methods.

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