Science Teaching with Self-made Apparatus(*).

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(*)*This work has been partially financed by the European Commission (project "Hands-on Science" contract number 110157-CP-1-2003-1-PT-COMENIUS-C3). The views expressed represent the authors. Neither the European Commission nor the authors may be held responsible for any use of the information provided here.*

Abstract. *The laboratory practice, for the students of the Pedagogical Departments and the for the schoolteachers, constitutes an important presumption for the future teaching of Science in the schools. Self made apparatus, especially when used in measurements, give the students, the ability to have an integrated control of the experimental steps, to improve their searching capabilities and to induct conclusions, through the measurement and the manipulation of their errors. Some examples of self made apparatus from different areas of Physics, are described in this work together with hints on their incorporation to the Teaching of Science.*

Keywords. Self-Made Apparatus, Science Teaching, Measurements.

1. Introduction

Literacy in Science and Technology (STL) is fundamental for the welfare of modern, technology dependent societies. As more and more of the regulations of modern, technology dependent societies are based on the advances in Science and Technology, the basic constituent of democracy, i.e. citizens' participation, requires STL. In this sense, STL becomes a "right to democracy", a view also pursued by UNESCO. Within this framework Science Teaching in general education should be based on principles and methodology rather than on factual knowledge [1] and poses specific demands on the skills and knowledge of the Science Teacher [2]. A sound knowledge of the basic principles is considered, in general, a prerequisite for the Science teacher. Although teachers in Primary Education, at least, lack this knowledge, our experience shows that a major problem hindering the effectiveness of Science Teaching is the teachers' attitude towards Science; in general they should change their approach from factual knowledge on specific data, techniques and themes or from the "successful performance" of an experiment, towards a "scientific inquiry" approach [3], in which, in accordance with a Piagetian context, Science knowledge is not acquired by the student but it is discovered or, at least, negotiated anew. This teaching approach is heavily dependent on systematic Science observations and experiments and this makes experimentation a basic required skill of the Science teacher. In this work we discuss one parameter (the use of self-made apparatus) of experiments in Science teaching. We also present examples from different areas of Physics.

2. Assumptions

In experiments, the use of sophisticated complex equipment may give accurate measurements. However, it removes the authentic creative activity and converts the experiment to a demonstration process in which the student observes the results of an apparatus he-she does not understand. This, combined with the general attitude to get the results of the experiments instead of inquiring a situation of a Natural phenomenon, hinders, at least in general Science, the understanding of the phenomenon under study. Even teachers with a sound scientific knowledge lack, in general, the skill to transform their scientific knowledge into teaching practice [4]. As a consequence, Science and Technology are considered as difficult subjects [5] although they are rather simpler (as may be inferred from the fact that, in human history, they appear and advance earlier than other sciences) and possess inherent advantages. For example their subjects of study are easily perceptible through the senses, an irrefutable advantage for most of the compulsory education students who, in a Piagetian context, have not as yet reached the formal logic stage. This constitutes a significant problem in most of the advanced countries. The construction, totally or partially, of the apparatus to be used in classroom Science experiments is a very creative process associated with the development of cognitive and psycho motive skills and facilitates the logical process of induction. In a groupwork construction, the development of social skills is also facilitated while the "pleasure of creation" covers the sentimental sector. The use of self-made apparatus exhibits also other inherent advantages; it facilitates query situations and the process of planning an experiment; it demonstrates an immediate application of some of the relevant Science issues; it removes the "black box" feeling often associated with the use of modern hi-tech devices; it develops the ingenuity of the teacher, especially the primary school Science teacher for alternatives to the usually expensive equipment on sale; it also makes clear the discrimination between observations' data and their interpretation [9]. Incorporated into the education of the Science Teacher, the construction of self-made apparatus to be used in Science experiments is another example of polymorphic practice [10] and facilitates the transformation of scientific knowledge to school practice.

3. Principles and examples

In order to be useful to Science Teaching, the construction of self-made apparatus must follow some principles, in accordance to the context exposed previously, i.e.:

3.1. Simplicity and Safety

The construction must be simple. The materials used must be easily available from the everyday environment of the school and the students. The assembly should be within the abilities of a "do it yourself layman". During the construction process, dexterities and knowledge on the properties of the materials used and on how to handle them become a clear task. Simple constructions facilitate the understanding on the apparatus functioning and minimizes safety problems. Safety is always an important issue that must be stressed, even over emphasized. When students, especially children are involved this statement is obvious; it helps also to the development of good safety awareness attitudes. The situation is also similar for teachers, especially teachers in primary schools who, in general, lack a professional training in Science.

3.2. Problem solving

The whole process must provoke the ingenuity and creativeness of the students. On this basis, the guidance offered must remain within the general goal, leaving the initiative to the student. Detailed guidance should be limited to specific queries related to technical or specialized issues.

3.3. Accuracy, sensitivity and calibration

As the prime goal is to understand the principles ("natural law") involved, high levels of accuracy are not required. The apparatus constructed, however, if used as a measuring instrument, must be accurate with an appropriate sensitivity. Calibration is a necessary step for apparatus used as measuring instruments. Usually it is done by comparison with a professional instrument but a discussion on the principles used to make the standards is very enlightening. Estimation of the accuracy and errors is very helpful on the conceptual meaning of measuring errors and their treatment.

3.4. Assessment

When the construction is finished, a retrospective evaluation on the whole process, on the choices made and on the other possible alternatives and, also, a comparison with apparatus made by others is advised. It recapitulates on the subject under study and facilitates meta-cognitive effects. Although highly subjective, aesthetics of the final construction is an important issue mainly from the viewpoint of practicality and as an indication of deliberation and diligence.

4. Some examples

In the following we present some examples of self-made apparatus. All have been realized in the Department of Primary Education of the University of Crete within the normal teaching activities in Science. For a couple of them notes on their usage within teaching are also given.

4.1. Gas Thermometer

The task is to construct a thermometer. Additional aims include basics on glass treatment, a useful skill for chemistry experiments, the notions of calibration, accuracy and sensitivity of measuring instruments and of the measurement error. The construction is shown schematically in Fig 1. A glass test tube (similar to the ones used in chemistry) is heated (a). When the glass is soft enough we elongate the tube with a quick steady straight outward motion (b). We cut (break) the glass near the open end of the test tube (c), the result being a bulb chamber with a thin elongated pipe. This is a device with many uses (see also later on). When the chamber is warm to the highest temperature range we plan to use the thermometer (e.g. by holding the chamber in our warm palm), we touch the open end of the pipe to a drop of coloured water (d) leaving the chamber to cool so that the coloured drop enters the pipe. We fix the device on a piece of cardboard (e) and proceed to calibration. Calibration is achieved by immersing the chamber into water of different temperatures so that the coloured drop inside the pipe traverses the whole length of the pipe. Although the two extreme temperatures would be sufficient, because the pipe's cross section is not constant one or two intermediate points are necessary. Intermediate temperatures may then be noted to construct the scale. During the construction the (unsuccessful) trials are a good starting point for a glass handling dexterity. Observing the coloured drop dropping into the chamber or going out of the open end of the pipe when the temperature is too low or too high for the specific construction, a discussion on the range and the parameters it depends may be initiated. Observing differences between different constructions may arise in a discussion on the measuring errors. Checking repeatedly the accuracy of this thermometer against a standard one may unveil the dependence on the atmospheric pressure which may lead to an improvement, for example, another bulb chamber on the open end.

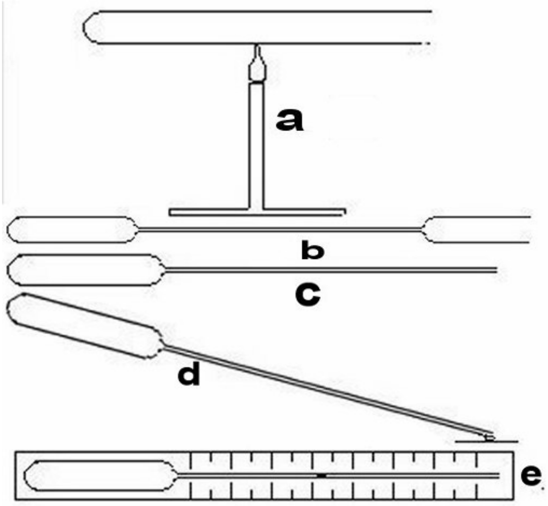

Figure 1. Gas Thermometer

4.2. Hydrometer

The construction is similar (Fig 1 point c) as in the Gas Thermometer discussed previously. For calibration purposes however, the pipe should not be too thin. Having the device shown in (a) of Fig 2 put into it small lead balls (e.g. thin shot) or even sand and immerse it into liquids of different densities so that the chamber of the device is totally immersed into the liquid while the pipe is either outside (as in b in Fig 2 – a relatively dense liquid) or inside the liquid (as in c in Fig 2 - a relatively thin liquid). By fixing the device into a cardboard the scale may be drawn and then the open end of the pipe is sealed with a gas flame. Liquids more dense than water

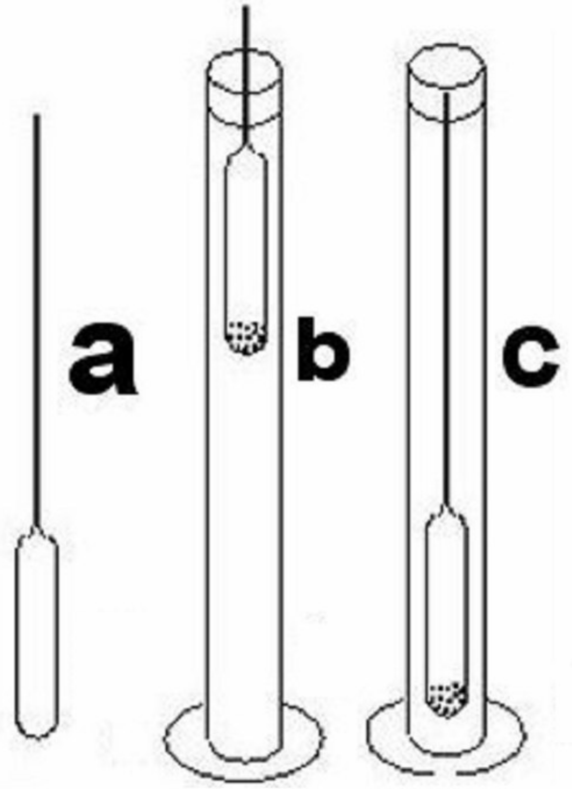

Figure 2. A Hydrometer

may be prepared by dissolving salt into water while liquids less dense than water may be prepared by mixing alcohol spirit with water. In both cases the density may be determined by weighting a known volume (e.g. through a volumetric cylinder) of the resulting solution. The device may be used to measure the density of different liquids, for example wines and spirits or must and "infer" the alcoholic content. This construction, especially the calibration process, is advantageous to the understanding of density, of the different ways of titration of solutions, etc.

4.3. A weighing-machine

This device (see Fig 3) may be used for the teaching of mechanical moments. The construction is made with materials used to hang slide curtains in house windows. The weight, W, hangs from a hook used to hold the curtain within the slide rod. Similar hooks are used for the joints in p and s. The educational value of this device is in the process of calibration where different aspects on the mechanical moments may be clarified. The construction, if done with diligence, may be very accurate. It is also used in other apparatus (see for example "An amperometer" later on).

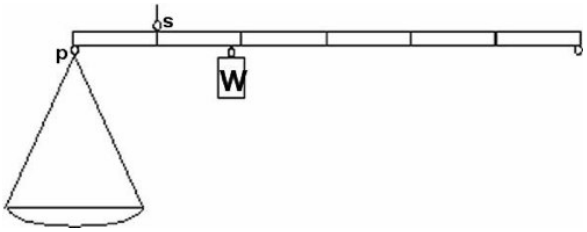

Figure 3. A weighing/machine

4.4. An amperometer

The construction (see Fig 4) is based on the weighing machine discussed previously. The plate has been replaced by an iron washer fixed on the balance rod and a coil around an iron bolt. Connecting the coil serially to an electric circuit, the current induces an electromagnetic force which holds the washer to the bolt. Moving the weight along the rod the electromagnetic force may be measured by comparing the corresponding mechanical moments. The main objective of the variation presented here is to help understanding the electromagnetic forces. An adaptation could be the following: replace the weight by a (coil) spring. Fix the bolt in the place of the washer. Increase the height of the rod supporting the balance rod. When the electromagnet is activated the bolt is attracted into the (hollow) coil and the corresponding force may be measured by the elongation of the spring. By fixing the spring in different distances from the supporting the balance joint, different current ranges may be measured.

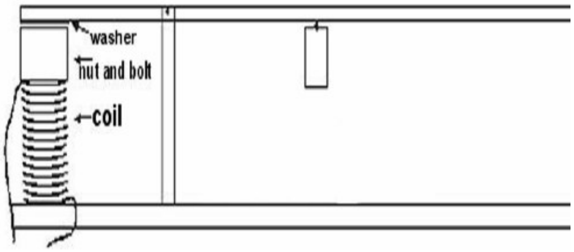

Figure 4. An amperometer

4.5. Geographical coordinates

The device needed is a simple vertical rod OA on a flat horizontal surface (see Fig 5). During the day we mark the end of the shadow of the rod (the s points in Fig 5) together with the time and draw the corresponding line. For demonstration purposes the **s**-point line is shown curved. In practice it is almost a straight line. The point B of the line which is the smallest distance from the rod determines the local meridian (the direction O to B is the North direction for locations in the northern hemisphere). The time the shadow of the rod is along this OB direction is the local noon time and determines the Longitude of the place. For example for Rethymno-Crete, Greece where political time is GMT+2hours, if local noon occurs at 12:22 local political time, the Longitude is 2 (because of the 2 hours difference from Greenwich mean time) times 15 arc degrees minus 22 (the 22min in 12:22 local time noon) times 15 arc minutes, that is 24.5 arc degrees. The corresponding angle φ is related to the local Latitude. It is equal to the Latitude on the equinoxes (21st of March and 23rd of September). On the solstices, the angle φ takes its extreme values, L±e, where L the local latitude and e ~23.5 arc degrees is the obliquity of the ecliptic. A plot of the angle φ versus the day of the year is periodic with extremes at the solstices and may be used also to determine the beginning of every season i.e. the days of the solstices (23rd of December and 21st of June) and of the equinoxes (21st of March and 23rd of September). This simple construction and the corresponding measurements may help in clarifying the generally difficult subject of the relation between Earth's movements and the seasons, etc. It also offers a good example on the manipulation of the original measurements, to get results with an estimation of the measurement error. Using advanced mathematical processes very accurate results may be obtained for the estimation of local time (and thus of the Longitude of the place) and of the angle φ (and thus of the latitude of the place). However, the results may also be obtained with adequate precision of the order of 0.5-1 arc degree and the beginning of each season with a precision of 1 day with the sole use of graphs.

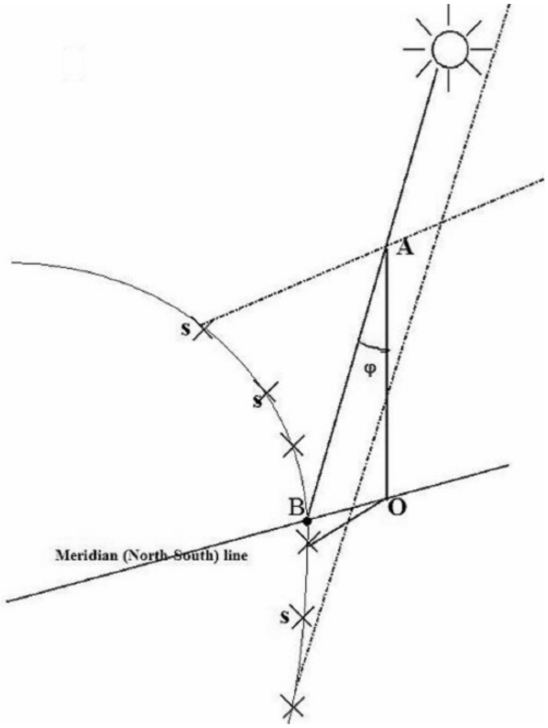

Figure 5. Geographical Coordinates

4.6. More examples

The main objective of the self made devices exposed previously is to make a working construction that will help the understanding of the concepts involved. Making measurements with an adequate precision is also feasible. In the web site http://www.clab.edc.uoc.gr/hsci other examples are given [13].

5. Epilogue

The self-made constructions, examples of which have been presented in this work, have all been used during the teaching of Science and/or Science Teaching courses in the Department for Primary Education of The University of Crete. All of them have been realized as assigned projects by students subscribing to the relevant courses. These constructions have the characteristics of "Polymorphic Practice" and many of them have also been realized partially or totally by school students. Some indicative responses from the University students are:

- I imagined that for Science experiments a special laboratory was necessary but I realized that doing experiments is not so complicated a matter.
- I learned to work on my own (a comment made more often by female students).
- I realized that what we had learned in school may have direct applications.
- What I learned can be used directly to schools.
- The construction helped me to understand what I had only memorized.
- I realized that there is a difference between the graphs in the Science books and the actual data obtained (referring to the scattering of measurements due to measurement errors, a fact usually absent in the graphs of textbooks).

However, there is a significant percentage of students that drop out of the courses. The reasons may be pursued in the direction of the following comments:

- It was difficult but I learned to work on my own.
- A good course, but the effort I made was worth of two or more other courses.

In conclusion, the experience is very positive. Students' comments, in schools and in the University, show an acquired positive attitude towards Science, an increase of their self-esteem and confidence on their abilities and an increased interest in Science [14].

9. References

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[5] Piaget (“the future of Education”) assigns this difficulty in relation to Science while students are performing well in the rest of the subjects to the type of instruction offered with a more probable cause the fast passage from the qualitative management of natural problems to the quantitative mathematization through the use of Physical Laws that enter the instruction in the student’s absentia.

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[7] See [2]. Polymorphic practice (measurements, experiments...) in Science includes a common psycho motive activity (doing measurements, experimentation...) which consequently is morphed into different levels depending on the (previous) cognitive attainment and/or the mentality of the students. They resemble multilevel teaching i.e. teaching pursuing more than one sectors and levels of learning. The need for polymorphic practice teaching arises usually in the training of Science Teachers where there is a requirement of teaching in an advanced level for the teachers themselves, and the requirement of teaching in a level more accessible for the pupils. The difference in the teaching levels is not only on the didactics but also on the subject matter and the attainment levels.

[8]This site is also used by students and is under continuous restructuring. Please report, by e-mail, any difficulties to access the site to michail@edc.uoc.gr.

[9] Note that the majority of the Students in schools consider Science as difficult subject (see [4]). Note also that when relevant data were collected, more than 80% of the students in the Department for Primary Education had only the minimum required Science courses in school.