LOW COST - HIGH TECH HANDS-ON EXPERIMENTS

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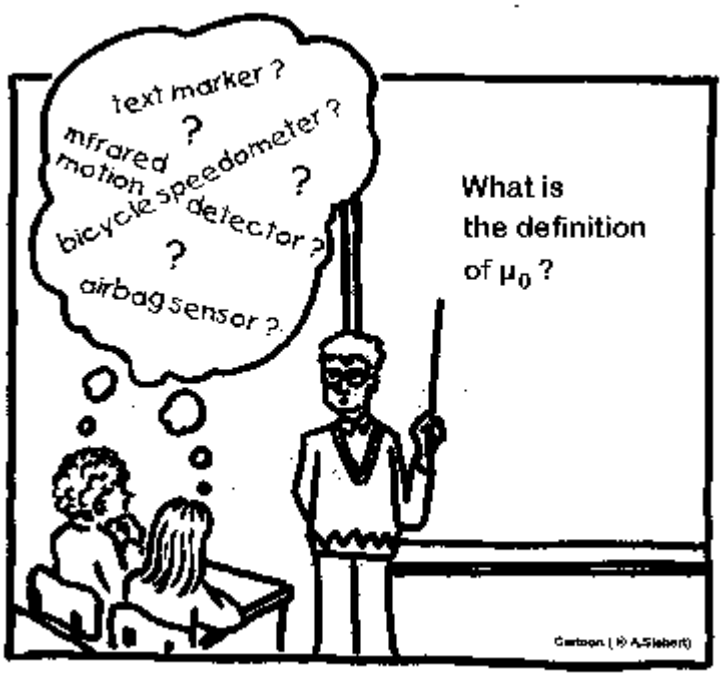
Motivation

In recent years a variety of new materials and techniques have found their way into day-to-day life and into the hands of pupils, e.g. audio-CDs, cellular phones, remote controls etc. In contrast to this tendency, no experimentally and methodically equivalent approach can be claimed in teaching - in terms of the full-scale implementation of new materials and techniques into teaching as well as in terms of a straightforward and cost-saving approach. The objective of this workshop is to give examples of low cost experiments with a high tech background. It will further be explained how these experiments can be integrated into the classical collection of low cost experiments.

Hands on experiments are not a recent phenomenon. Hands on experiments were known rather as magic tricks, where astonishment and entertainment were favoured to the explanation and the understanding of the physics behind the experiment. It was in the 19th century that the 'classical' hands on experiment found its way into teaching. The quality of the experiment was merely determined by the teacher's choice of materials and instruments (from day-to-day life). Since then, the classical definition of hands on experiment has been as an experiment that is based on the use of day-to-day gadgets or simple setups which can very easily be assembled.

The overall number of books at the American, English and German market dealing with hands on experiments and their application in educational physics has been estimated to be around 50. Some of these books also cover how toys or other low budget gadgets can be implemented into teaching physics. A good part of these 50 books can be seen as a mere enumeration of experiments. Only 15 of these books are available to the public (e.g. (1-7), a more complete list is available from us (8)). However, the number of articles in magazines and journals about teaching, which give further ideas for hands on experiments, approaches about one thousand - in English as well as in German. The articles are however unsystematically distributed in the literature. Our main point of criticism is the fact that most of the experiments, when tested, did not work out; the descriptions contain not even a simple schematic diagram on how to set up the experiment, they give only qualitative results or deal with very special cases instead of the broader phenomena. For the most part, a discussion of the historic development of hands on experiments to their modern form (with new materials and day-to-day items) is practically non-existent.

Physics is among the least liked subjects in today's schools in Germany as well as in other countries. The reasons for this have been addressed by pupils and teachers alike: too much mathematics, no obvious relation to day-to-day life, only a small number of experiments (which are then conducted by the teacher, not by the pupils), and too much scribbled writing on the blackboard instead of practical work.



In school pupils get answers to questions they never had asked.

One approach to a better way of teaching physics

Taking into account the above, our suggestions are therefore:

- Teaching physics has to consider the pupils' real-life experience and day-to-day life.
- The educational context of implementation should be broadened.
- Experiments should be based on simple setups and low cost items which can be found in any typical household or school.

These suggestions take the reasons for disliking school physics into account, but they are also based upon the following:

- our own experience with hands on experiments and the 'improvements' found, as well as on
- completely redesigned experiments based on new materials (e. g. Teflon, Velcro tape, Gore-Tex) and modern devices from day-to-day life (e. g. electric toothbrush, audio-CD, cellular phone, airbag sensor, bicycle speedometer).

We consider these experiments as **low cost** and **high tech**. Introduction of the high tech aspect to the traditional understanding of low cost experiments is proposed due to the role of hands on experiments having changed in recent years to become more and more important in terms of motivation, explanation and simplification. As an example: the trajectory of a thrown balloon will illustrate the effects of friction, after having discussed the ideal trajectory with a computer simulation.

One experiment will be presented on the following pages, marked by frames. The instructions typically cover two pages and follow a straightforward format: the headline contains

information about the area of physics being discussed, about the level of experience necessary to conduct the experiment in order to achieve the greatest advantage, and about the time necessary to prepare and actually perform the experiment.

About 60 low cost - high tech experiments covering subjects have been developed in detail in the same manner as the example presented here (9). The entire discussion can be found in various theses (*Staatsexamensarbeiten*), which resulted from the project. In addition, about 20 experiments have been evaluated in didactically oriented seminars (one seminar per semester). The overall results of the developments will be published in a book in the near future (10).

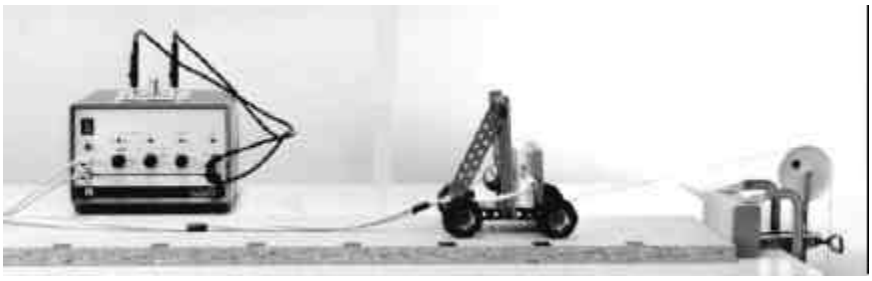
Example: The Airbag Sensor

school level	general theme	special theme	theoretical level	practical level	provision preparation experiment
secondary	mechanics electricity	inelastic collision piezoelectric effect	X X	O O	1 hour 10 min 10 min

The function of an airbag sensor will be simulated.

Materials

- piezoelectric crystal (Leybold)
- vehicle (kit) - 2 wires (length: 0.5 m)
- metre ruler
- fender block with foam padding
- 100 g mass
- steel ball (m = 100 g, r = 1 cm)
- pulley wheel with support
- 2 wires (length: 2 m)
- board (length: 1m, breadth: 0,2 m)
- 4 V-bulb
- direct current amplifier
- 1 m string
- 10 cm string
- lubricating oil



Preparation

A structure must be constructed upon the vehicle to suspend the steel ball. The piezoelectric crystal is attached to the vehicle at a distance of about 5 mm from the steel ball, such that the ball hits the crystal exactly when it is swung. The voltage produced by the squeezed piezoelectric crystal must be amplified in order to light the bulb. The bulb is therefore

connected to the piezoelectric crystal via the d.c. amplifier. The 2 m-wires between the amplifier and the piezoelectric crystal should be bound together for better handling. The board should be divided up into steps of 10 cm. The scale can be attached by short adhesive tapes. The wooden fender block is positioned at the end of the board such that the foam can absorb the impetus of the vehicle. The vehicle itself is connected to the 100 g mass by the 1 m string which runs over the pulley wheel. The vehicle will be accelerated by gravity acting on the mass which hangs vertically over the edge of the table.

Experiment

The vehicle will traverse various distances. The axles should be oiled to improve running. In order to stop the connecting wires influencing constant acceleration, they should be held up by hand or positioned such that they do not impede the vehicle's smooth running.

The vehicle rolls against the fender block, the steel ball strikes the piezoelectric crystal and the bulb lights up: the brightness depending on the distance, h, travelled by the vehicle. This particular brightness will be defined as the moment of inertia of the airbag.

The velocity of the vehicle after the distance, h, (in other words, the moment of inertia) will be determined by energy conservation: $\frac{1}{2} mv^2 = mgh$, e.g. after a distance $h = 0.4$ m the velocity v was determined to be about 10 km/h.

Explanation

When the piezoelectric crystal is deformed by mechanical forces, electrical charges are accumulated at the crystal surfaces. The charge on the crystal is proportional to the mechanical deformation (tension or pressure).

The brightness of the bulb used in the 'airbag sensor' is proportional to the force transferred by the steel ball, which is in turn proportional to the velocity of the vehicle.

In reality the acceleration of the car in the longitudinal direction is registered by a flexible piezoelectric beam to which a mass is attached. In the latest generation of sensors the voltage is fed to a computer via an analog-digital converter. Beyond a defined deceleration, the voltage produced by the crystal leads to inflation of the airbag within ca. 10 ms.

Variations

Alternative to the bulb, an oscilloscope can be used. The voltage deflections one can then see increase in proportion to the distance travelled, h. It is possible to define a threshold graphically, beyond which the airbag would be actuated.

The acceleration can also be achieved without a drawing mass by allowing the vehicle to roll down an inclined plane. The steel ball is removed and the piezoelectric crystal is placed at the front of the vehicle. Upon striking against the block, the accelerated mass of the vehicle itself will deform the piezoelectric crystal.

Estimations

"Why does the airbag not work, if the car hits a barrier at certain angles?" This aspect can also be demonstrated by allowing the vehicle to impinge on the block at different angles. Because

the direct force on the piezoelectric crystal is not so great, the crystal does not always produce a sufficiently large voltage.

Real forces and energies etc. can also be evaluated: the collision energy, the time to release of the airbag or the braking acceleration.

Implementation

The experiment can be used in a motivating fashion to present both inelastic collision and energy conservation as well as the phenomenon of the piezoelectric crystal. Pupils are able to carry out the preparation and the experiment themselves, e.g. in a project.

Conclusions

Our discussion of low cost - high tech experiments will satisfy both present and future demand. We not only supply teachers with a list of well documented and tested experiments, but are also updating the classical method, here for the case of educational physics, in terms of its content. The classical method of teaching physics starts with the physical phenomenon and deals with it in an academic manner (say, the demonstration of electromagnetic induction by means of coils, magnets and voltmeters). The result is then translated into a formula. The relevance and the implications of the result to day-to-day life is just the final point of discussion, and is often neglected. A reversed procedure, starting with a gadget known from day-to-day life ("How does a speedometer work?"), and leading to the discussion of the phenomenon afterwards, will establish a higher level of motivation. Questions about the relation of the physics subject to real life will hardly come up.

It is self-evident that such high tech - hands on experiments offer the following:

- they are cheap to set up (low cost),

- they allow a broad field of application in terms of the role of the experiment (demonstration, hands-on group lab work, project, homework) and teaching methods (analytical, synthetic, learning by models, learning by doing),

- they can be applied in a wide range of school types at different levels (depending on the extent of mathematical evaluation in the experiment and the physical background knowledge of the pupils),

- they allow a reduction of a variety of phenomena in the pupils day-to-day experience to a small number of elementary laws of physics,

- they offer an interdisciplinary approach to education.

The individual objectives of physics teaching per se need not be further discussed at this point. However, in the context of teaching in general, certain overall objectives - which can be more easily achieved through low cost - high tech experiments - will be discussed with regard to the following:

The approach to physics. This type of experiment offers the possibility of acquiring a more practical handling of and a deeper insight into modern techniques and new materials. Highly complicated devices are often based on a few elementary laws of physics, e.g. the law of inertia in the case of the airbag sensor, adhesive forces in the case of contact lenses or the modulation of infrared radiation in the case of remote controls. The *black box* is no longer a mystery, the way in which the device works gains transparency (in a physical sense) and, with respect to application in the school, the box will be experienced directly or by a model.

Safety: Such experiments are pre-eminently suitable for the development of the pupils' sense of responsibility by means of practical handling as well as by discussion in lectures. For example, the microwave cooker or the cellular phone lead on naturally to the question of the effects and risks of electromagnetic radiation and the practicability involved in its avoidance.

The approach to the future. Low cost - high tech experiments contribute to a higher degree of motivation for physics and the application of physical laws. Moreover, the experiments can remove fears of modern techniques and materials. The pupils can develop their awareness and sense of responsibility (for example by discussing environmental electromagnetic pollution due to cellular phones or new materials in general). Their power of judgement and a critical attitude based on their understanding of physics can be intensified (e.g. by comparing the efficiency of an immersion heater and a microwave cooker).

Skills. Methods of gathering and handling information and material can be learned by the pupils (e. g. by contacting the manufacturers, by searching the web). Practical work (in a project or in homework) is particularly suitable for the training of manual skills and problem solving strategies. The integration of low cost - high tech experiments into lectures appropriately organized with regard to pupils engagement will help them develop such key skills as cooperative learning, planning and organizing, listening and a critical approach.

Interdisciplinarity: Besides the relation of low cost - high tech experiments to technical and electronic problems of interest, these experiments give occasion to think about aspects of human society itself: a deeper insight into the development and utilization of new materials and techniques (e.g. the air bag) will be gained. The significance and understanding of the physics in question can be further extended by discussion of personal data protection (chip cards) in connection with civic law or radiation protection (handy, microwave cooker) in connection with biology.

We have now gathered initial experience in the development and practical application of such methods. The overall positive response (from students in a special seminar, from pupils and teachers in workshops, and from industry) forces us to undertake more work.

For further information please contact the authors or take a look at our web page:

http://pen.physik.uni-kl.de/lc-ht.html

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