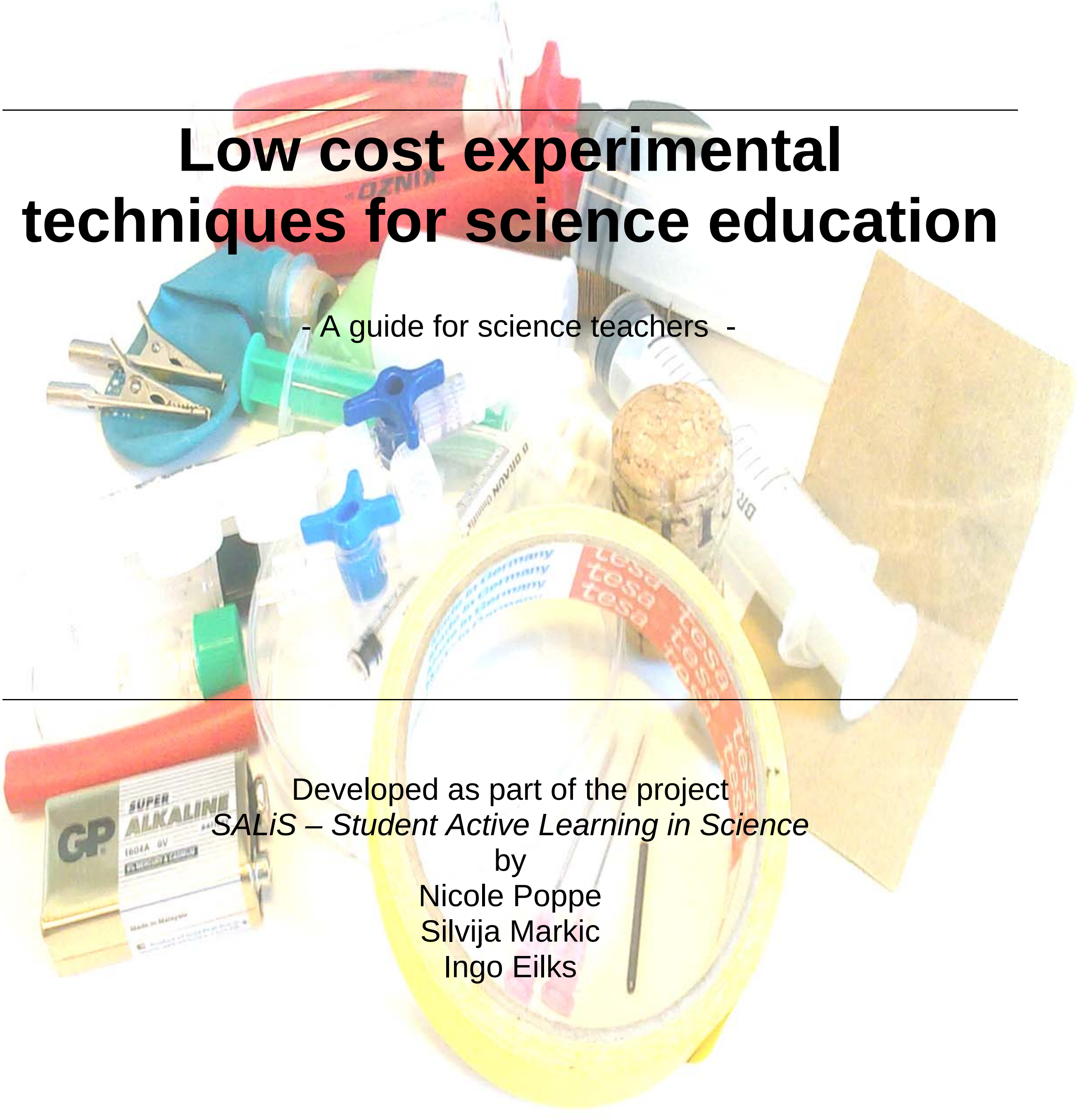
SALiS
Student Active Learning in Science



# Low cost experimental techniques for science education

- A guide for science teachers -

Developed as part of the project
*SALiS – Student Active Learning in Science*
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**Preface**

From 2010 to 2012, as part of the Tempus program the EU is promoting the SALiS project at ten partner institutions from six countries. Involved are partners from Georgia, Germany, Ireland, Bulgaria, Moldavia and Israel.

SALiS stands for *Student Active Learning in Science*. This project aims at promoting active student, experimental and research-based instruction in the science subjects. For this purpose, education and training modules for science teachers are developed and implemented as part of SALiS. Additionally, teaching and training resources are developed, which are supposed to support teaching in the manner described above.

The presented manual is a guide to the use of various low-cost experimental techniques for teaching science. The low-cost experiments use equipment and chemicals from contexts of everyday-life. These can be found in supermarkets, in home improvement stores, in medical engineering or in aquarium store. Thus, they are available everywhere at a very low cost. Also, they take into consideration factors such as low pollution and safe experimentation.

Low-cost experimental techniques in a science class can help to lower costs, decrease risk, and mitigate the expense of disposing pollution. This leads to more frequent experiments in the classroom, in particular, in student-centered approaches.

In this sense, we wish you fun and success in using the low-cost experimental techniques in the teachers' training and teaching.

Marika Kapanadze and Ingo Eilks

(Coordinators of the project SALiS)

SALiS

Student Active Learning in Science

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## 1. Terminology

Experiments are a fundamental part of thinking and working in science (Eilks et al., 2004). Research in science or engineering is not possible without conducting experiments. This is true in equal parts for the field of science as well as for its later implementation in engineering and industry. If nothing else, experiments are part of science education (Ferdinand, 2007).

Experiments help to follow and to understand science. The students experience the unique side of science, that is to say, they ask questions and make hypotheses and let nature respond through experiments and observations (Eilks et al., 2004). However, experiments also help to develop manual skills, illustrate abstract theories and promote problem-solving thinking (Bradley, Durbach, Bell & Mungarulire, 1998). The inherent value in experiments in science is that they provide breaks in classroom activity and act as motivation for students (Kranz, 2008).

However, experiments in science are always associated with costs. Classes with over 30 students quickly create higher financial costs if, apart from demonstrations, students must also conduct experiments. The acquisition of traditional laboratory equipment and instruments for the entire class is associated with considerable costs. Equipment that has been broken has to be replaced on a regular basis. The additional financial expenses refer not only to the necessary equipment but also to the chemicals and consumable supplies. When conducting experiments with students, the necessary chemicals and consumable supplies have to be provided, and afterwards disposed of, according to each student group. Obviously, there are costs associated with this procedure as well. However, it is not only the costs that matter. In addition to the financial costs, the production of pollution is a negative by-product of experimentation in the chemistry class.

Thus, traditional experimentation is associated with numerous burdens. This is not only the case for less developed countries but also for industrial countries. In these countries as well, the budget for science education has decreased while at the same time, the related burdens due to risks and hazardous substance regulations have increased. Traditional laboratory equipment, formally very common in schools, has become less common nowadays. As a consequence, science teaching is now more often required to take place in a traditional classroom setting (Bradley et al., 1998). This leads to further limits in conducting classic experiments and traditional experimental techniques.

Thus, one has to be aware of the fact that each experiment is associated to certain risks. This is true for traditional chemical experiments in particular due to the bigger quantities, which are being worked with. Also, Obendrauf (2006) points out the fact that even simple glassware such as test tubes and beakers can become a hazard as a result of broken glass. Risks like these increase in relation to the difference between the features of the individual classrooms from the normal laboratory.

In this regard, the low-cost experimentation offers alternatives. In the low-cost experimentation cheaper and more easily accessible equipment replaces expensive equipment. Equipment and chemicals from every-day life reduce costs and are accessible everywhere. A key aspect of this principle is its simplicity and its good overview of the used instruments (Schwan, 2005). The use of alternative experimental equipment as well as the type and quality of the used chemicals lead to a reduction of cost (Bradley et al., 1998). At the same time hazardous equipment as well as chemicals are replaced with safer alternatives.

The term ‘hands-on experiment’ is often used as a synonym for the low-cost experiment in the German language. A hands-on experiment is defined as following:

> “*…an experiment that can be conducted by using objects of the every-day life or by using easily self-made devices.*” (Eckert, Stetzenbach & Jodl, 2000, p. 4).

Other definitions are more likely to emphasize the experiments rather than defining the equipment:

> “*Amazing effects, clever and memorable, introduced without major expenditure and without equipment that shadows the main focus – that is the ideal hands-on experiment*” (Kircher, Girwidz & Häußler, 2001, p. 283).

In this way, the low cost or hands-on experiment follows quite different strategies. An important technique, in particular for the chemical aspect, is the minimization of used chemicals. Following this approach, Bader (2003) transfers an idea of sustainable chemistry to the practice of experiments in science education. Here, sustainability is understood in the sense that science education is supposed to adopt an environmentally sound management of chemicals and their proper disposal. The best way to conserve resources and avoid pollution as well as avoiding disposal problems is to use smaller amounts, less hazardous and less toxic chemicals. Thus, already in the 1980s the idea of "microscale chemistry" was developed (Singh & Szafran, 2000):

> "*Microscale chemistry is a laboratory-based, environmentally safe, pollution-prevention approach accomplished by using miniature glassware and significantly reduced amounts of chemicals.*" (Singh, Szafran & Pike, 1999, p. 1684)

Microscale experiments are supposed to diffuse problems of pollution disposal. Furthermore, they are also supposed to reduce the potential risks in handling substances because much smaller amounts of chemicals are used in these experiments (Wood, 1990). The equipment and the substances are reduced as much as possible without compromising accuracy (Black & Lutz, 2004). Thus, this approach shows a variety of advantages (Pike, 2006):

- Reduction of cost for chemicals.
- Reduction of complexity and costs of disposal.
- Reduction of potential contact with toxic substances.
- Less potential risks of accidents.
- Shorter reaction times.
- Reduction of time during heating and cooling processes.
- Reduction of space required for storage of chemicals.
- Improvement of the quality of air in the laboratories.
- ...

| Method | Amounts of chemicals used | |
|---|---|---|
| | Solid | Liquid |
| Macro technique | > 0,1 g | > 5 ml |
| Semi-micro technique | 0,01 – 0,1 g | 0,5 – 5 ml |
| Micro technique | 0,001 – 0,01 g | 0,05 – 0,5 ml |
| Ultra-micro technique | < 0,001 g | < 0,05 ml |

*Table 1.1: Classification of experimentation approaches due to the amount of chemicals (Pfeifer et al., 2002)*

Thus, the multitude of chemicals in chemical experiments can be reduced from traditionally several milliliters to a few micro liters in liquids or from several grams to a few milligrams in solids (Singh & Szafran, 2000). In this case, one speaks of the transition from the macro technique to the semi-micro, micro or ultra-micro technique (Pfeifer et al, 2002; Tab. 1.1).

The micro or semi-micro technique is in particular well suited for science teaching in schools and teachers' training. Overall, the amount of chemicals used in a consistent execution of experiments is reduced by a multiple of 10 following the microscale fast principle, where a reduction by a factor of up to 100 is possible (Singh & Szafran, 2000). The mentioned reduction applies to both the amount of the expended substances and the amount of the substances, of which have to be disposed. As originally requested, experiments in the laboratories of universities and industry become therefore less hazardous, more environmentally friendly and more cost-effective. Thus, the low-cost principle according to Latzel (1989) ensures that experiments in science education are not failing due to high cost.

Regardless of the amount of chemicals, in the low-cost experiment a replacement of the traditional experimental and laboratory use takes place. Here, materials from the household are used for scientific experiments in the school context. Examples include containers from the household, such as pots, jars, bowls or old plastic bottles. However, materials such as disposable articles of medical engineering, or that come from a home improvement store, an aquarium store or an electronics specialists store are used. Following Obendrauf (2004), the minimization of the equipment in combination with the use of inexpensive resources has a double saving potential. Thus, the possibilities of a more frequent and flexible use are increased. Schwarz and Lutz (2004) and Wood (1990) describe the benefits of using alternative equipment as following:

- Lower costs through the use of resources taken from medical engineering, home improvement stores, electronics specialist stores or everyday use.
- Availability of the resources in large numbers due to the lower purchase price. Thus, it is possible for almost all experiments to be carried out in small groups of students.
- Reduced risks in comparison to traditional glassware due to the lower fracture risk.
- Less time required for the preparation and post-processing for the teachers.
- Increasing of mobility because the equipment can be transported and used without restrictions; specially equipped laboratories are not required.
- Experiments can also be carried out as homework.

Similar to the replacement of traditional laboratory equipment, the used substances can also be replaced. Experiments with food, detergents, household chemicals or solids taken from the kitchen and garage complete the techniques mentioned above. These substances cannot only be purchased in supermarkets, home improvement stores or pharmacies for a lower cost, but also dealing with and transporting them is less regimented. In addition, the handling of these resources is more motivating, since the students are working with substances which already play a role in their lives.

Overall, the presented principles are therefore ideal to promote student-based active experimentation and learning in science (Joling, 2006).

## 2. Reduction of costs and environmental impacts due to microscale experimental sets

In the 1980s and 1990s, the approach of the microscale experiments initially started at the universities. *Microscale kits* have the intention of facilitating experiments following the microscale principle (du Toit & du Toit, 2006). This was achieved by offering an entire set of glassware instruments that was matching. With these kits, reactions in small amounts and corresponding reaction chambers can be conducted.

Shortly after, appropriate school experiments have also been described, so that microscale kits for schools were increasingly offered. Examples include the *Williamson kit*, the *ACE-Microscale glassware kit*, the *Chem-pro System*, the *Micro glass kit* according to *Baumbach* or the *Mini-lab* (Schallies, 1991).

At this point, the mini-lab (Zinsser Analytic, 2011) is presented as an example. The mini lab contains a variety of cylindrical tubes with a flat bottom (Figure 2.1). The reaction vessels have a capacity of 24 ml. Due to the flat bottom, it is possible that the chemicals are introduced directly, special supporting stands and tripods are not necessary. Compounds of various containers are made via screw couplings, whose use has been made very easy. In addition, some metal blocks for heating or well suited thermometers are needed (Schallies, 1991).

An example will illustrate the use of the mini-lab. Figure 2.1 (right) shows a traditional distillation instrument and one from the mini-lab. The distillation instrument of the mini-lab uses a distillation vessel with a capacity of 24 ml. Schallies and Schilling (1991) propose to distill a liquid volume of 10 ml. Using this measurement, about 1 ml of alcohol can be distilled from wine for example. A potential risk with those amounts is reduced as well as the significant chemical or disposal costs. In traditional distillation instruments usually up to 200 ml of liquid are poured into the distillation flask. This setup reduces the amount of used chemicals and possible resulting pollution by 20 times.

*Figure 2.1: Distillation instrument in the mini laboratory and with traditional equipment for the laboratory*

The use of *microscale kits*, however, does not only have benefits. Thus, Singh and Szafran (2000) describe that with severe reductions, possible losses due to moistening of the vessel walls must be considered. Furthermore, a certain start-up capital is essential for the conversion of the laboratory resources. Thus, the acquisition cost for laboratory equipment following the principle of the *microscale chemistry* is about 120 € per execution (Sigma-Aldrich, 2011). Even though the acquisition cost can be balanced by reducing costs for chemicals, insurance and disposal in the long term. For instance, Singh and Szafran (2000) state that the required investment costs in the field of universities can be compensated, depending on the dimension of the internship of 6 months to 2 years. However, the investment cost at the beginning is not negligible and lost or damaged parts must be regularly reordered.

Thus, in the last few years the search for cheaper alternatives to commercial *microscale kits* has begun. They combine the idea of *microscale kits* approaches with the principle of the low cost experimental equipment. Here the traditional laboratory glassware and microscale glassware is replaced by less expensive alternatives. These are often made of plastic. This is cheaper and the risks of glass breakage can be reduced.

An example is the "RADMASTE kit", according to Bradley (2006), which has found its first use in southern Africa. This kit is available in different versions, e.g. as "RADMASTE primary microscience kit", “RADMASTE basic microchemistry kit", "RADMASTE microscale biology learner's kit" and many others (Figure 2.2; The-Radmaste-Microscience-System, 2010).


*Figure 2.2: RADMASTE -Kit for water (Image: www.radmaste.org.za)*

Similar to the commercially available offers, teachers can also produce such compilations by themselves. Eppendorf-cups, snap-lid glasses, plastic spot plates and much more serve as *microscale* reaction chambers. Connections and transitions may originate from the medical engineering or aquaristics that allow more complex devices to be composed. Examples will be discussed in the following chapters.

# 3. Experiments with resources in medicine and aquarium engineering

A common problem with experimentation in chemistry classes is the time consuming setup and the quality of equipment. Such instruments are often made of glass. This glassware is expensive and can easily get broken. Therefore, it represents a potential source of risk to the students and must be replaced when damaged, which might be associated with extensive costs (von Borstel & Böhm, 2004).

A wide variety of medical equipment taken from the medical engineering or aquarium business represents alternatives to traditional laboratory devices. Syringes, cannulas, cut-off cocks, infusion tubing and infusion bags are produced in large quantities for the medical sciences. Thus, they are priced accordingly. However, hoses, pumps and distributers used in the aquarium business offer a variety of applications for natural scientific experimentation. They are also often made of plastic and rubber and thus resilient. Due to their size they are often well suited for the *microscale* experimentation.


*Figure 3.1: Luer-Lock-Connection*

Medical engineering is particularly well suited for experiments with liquids and gases, since these devices are often developed for the administering and dispensing of liquids. Thus, there are special clutch systems, in particular the luer or luer-lock system (Figure 3.1). These systems have been established as a combination system of individual items in medical engineering.

*Figure 3.2: Adapter*
*Top: „female“ – „female“*
*Bottom: „male“ – „male“*

The two coupling elements are usually described as "male - female". According to the luer-principle, the connectors are fitted together. For the luer-lock principle, another additional screw system as a locking device is required (Brand, 2010; Figure 3.1). Thus, connection can be easily and safely made and is gas-tight without sliding apart during an experiment. Since normally only "male" - "female" connections are possible, there are additional adapters that make "female" - "female" and "male" - "male" connections work (Figure 3.2).

A more versatile device group from medical engineering is the disposable syringe. The disposable syringe has a transparent cylinder with well-read graduation, which is smudge-proof.

Disposable syringes are available in different shape and texture. The sizes vary from 1 ml insulin syringes to variants that have a capacity of 50 ml. Above all, insulin syringes are for dosages of small quantities. In particular, slow charging and discharging is possible with these syringes.

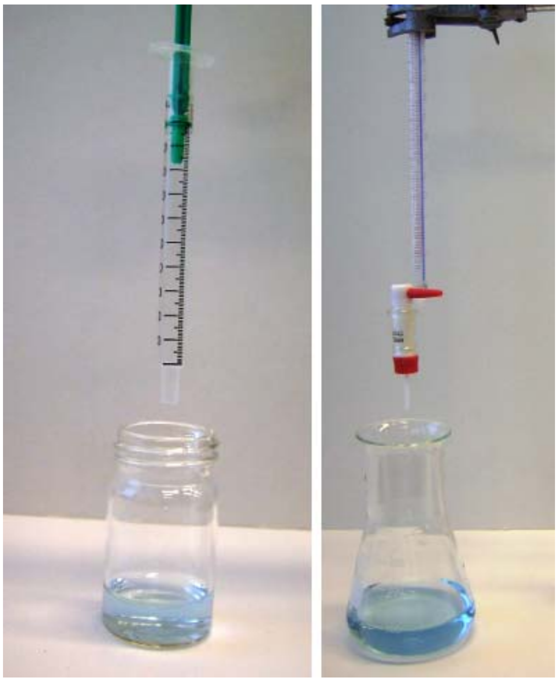

*Figure 3.3: Disposal syringes as burette replacement*

For instance, El-Marsafy (2004) proposes medical disposable syringes as a replacement for pipettes and burettes in a microscale titration (Figure 3.3). When using disposable syringes as burette replacements, liquids must be filled in the syringe without any air bubbles. For this purpose, first some liquid is taken up with the syringe and then abruptly forced out again. If this process is repeated several times, the bubble-free filling of the syringe can be managed.

The piston stop, which is part of all the disposable syringes, is a major advantage compared to a gas syringe. In this way, the ability of filling up to the maximum volume is guaranteed. Then again, after a quantitative use of the syringe usually a minimal residual volume remains in it.

The use of the syringes depends largely on the nature of the Syringe plunger. The plungers of the syringes are equipped either with or without sealing rings. Disposable syringes with sealing rings are also distinguished between single and double sealing rings (Figure 3.4).

*Figure 3.4: Syringes with simple, double or no sealing ring*

Syringes, which have a plunger with double sealing rings are very dense and can be installed in gas-tight instruments. However, if gases are used, which can make the rubber-sealing swell (e.g. chlorine gas), only syringes with a simple rubber-sealing should be used. Syringes without a sealing ring are well suited for liquid dosages.

The possibilities of application of disposable syringes are widely diversified. For instance, von Borstel and Böhm (2006) Propose to build a Hofmann voltameter by using syringes (Figure 3.5). In the low-cost version of the described experiment, the cases of two medical disposable syringes are rebuilt into a Hofmann voltameter. In doing so, the cannulas belonging to the disposable syringes are used as electrodes. Moreover, two medical engineered stopcocks as well as two short pieces of tubing (for example from an aquarium store) are used to take out the evaporating gas. The cannula-electrodes are connected to copper wires with the help of terminal strips. These are in turn brought into contact with a flat battery in order to start the electrolysis reaction. The cost of the materials used is around 3 € in the low cost version, while the degradation instrument by Hoffman, according to NeubertGlas (2011), costs about 70 €.

*Figure 3.5: Comparison of an instrument by Hoffmann made of medical engineered elements and one made of glass.*

However, the synthesis and the absorption of gases by Obendrauf (2006) have been well established as well (Figure 3.6). A typical figure of 80 € per experimental instrument has to be paid for the conventional glassware for gas developers (Mercateo, 2011; NeubertGlas, 2011; Omikron, 2004). In the low-cost version of the experiment by Obendrauf (2004; 2006) only a low-cost gas developer is required, which can be constructed with a test tube, a 2 ml disposable syringe without a sealing ring, several 20 ml disposable syringes with double sealing rings, two cannulas and a soft rubber stopper. The materials can be purchased for about 1.50 € per test instrument (Mercateo, 2011). The soft rubber stopper, which is pierced with two cannulas, is set on a conventional test tube and a 2 ml as well as a 20 ml disposable syringe will be put on the cannulas. The 2 ml disposable syringe is used to allow liquids to drip into the tube, while the evaporating gas is collected in the 20 ml disposable syringe. In the low cost gas developer, many gases can be synthesized. Table 3.1 shows some examples of the use.

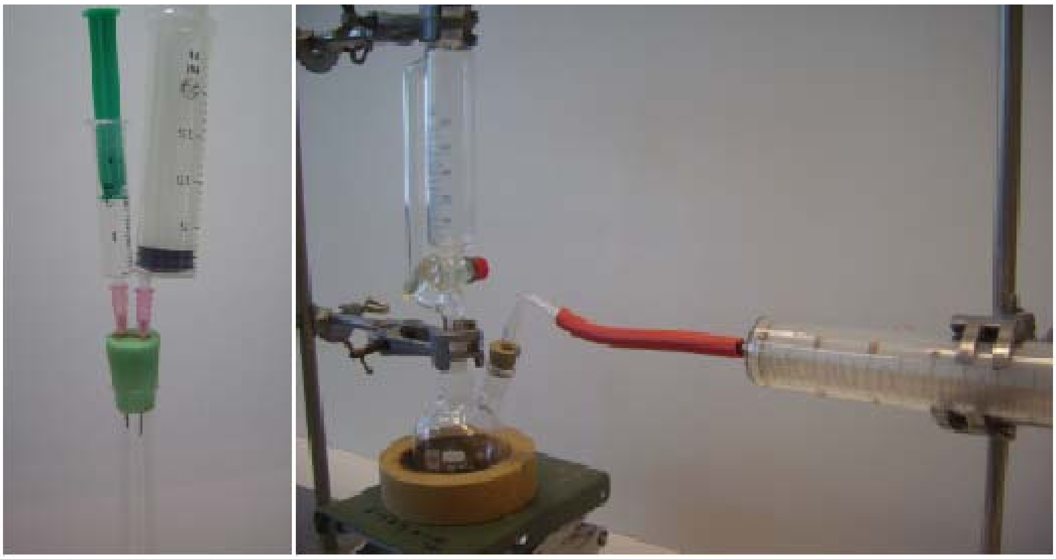

*Figure 3.6: Low-cost instrument for developing gas instrument with conventional laboratory equipment*

Not only the disposable syringes, but also the associated cannulas can be used for experimentation. Just like the disposable syringes the cannulas are also available in different sizes. The difference lies in the length and diameter of the syringe needle. Cannulas can be connected to the syringes of different sizes via the luer-connection. The tip of the cannula includes a potential risk of injury to the students and should be cut before experimentation with a wire cutter. In doing so, it is important to make sure that the channel of the cannula is not being crushed.

| *Synthesized Gas* | *Chemicals in the test tube* | *Added liquid* | *Notes* |
|---|---|---|---|
| Chlorine gas | Kaliumper magnate powder | Concentrated hydrochloric acid | Use syringe with a simple sealing ring |
| Ammoniac | Ammonium chloride, Natriumhydroxid - biscuits, distilled water | - | The test tube has to be heated up in order to start a reaction |
| Hydrogen | Granularities Zinc, thinned copper sulfate-dilution | Concentrated hydrochloric acid | - |

*Table 3.1: Possibilities of application of the low cost gas developer*

According to Brand (2010), the cannulas can provide an even more accurate drop. Also, the use of cannulas as a replacement for electrodes is possible according to von Borstel and Böhm (2006). Most importantly, however, is that the cannulas can be easily inserted into rubber stoppers, and thus, a liquid or gas exchange is possible with a closed reaction chamber. It is worth noting that when canulas are put through the rubber stoppers they can sometimes become slightly clogged with the material.

*Figure 3.7: Urine bags*

There are also many other parts of medical engineering devices that can be used. Thus, urine bags (Figure 3.7) can be used as gas or liquid collection containers, which are connected by hoses and multi-way valves (Figure 3.8). Both Brand (2010) and von Borstel and Böhm (2006) point out suggestions for the use of these valves. Thus, they can be used as alternatives to the removal of gases from test equipment. In this context, infusion tubing and bags can be used as well. Infusion tubes serve as replacements for conventional silicone tubing, while infusion and urine bags (see Figure 3.7) are preferably used for the collection or storage of gases. Thus, different systems for handling liquids and gases are easily created. Expensive laboratory equipment can easily be replaced by medical engineered alternatives.

*Figure 3.8: Medical enigneering three-way-volve*

*Figure 3.9: ChemZ student case*

| Article | Volume | Quantity | Costs |
|---|---|---|---|
| Disposal Syringe without sealing ring | 2 ml | 100 | 2,09 € |
| | 10 ml | 100 | 4,54 € |
| Insulin disposal syringe | 1 ml | 100 | 12,18 € |
| Disposal syringe with sealing ring | 10 ml | 100 | 9,86 € |
| | 20 ml | 100 | 13,64 € |
| | 60 ml | 60 | 26,03 € |
| Cannulas | - | 100 | 1,36 € |
| Medical engineering three-way valve | - | 1 | 0,95 € |
| Infusion tube (0,75 m) | - | 1 | 0,75 € |

*Table 3.2: Costs of medical disposal articles*

Medical disposable products are particularly well suited for the implementation of microscale experiments. This is shown by an example of a whole microscale kit, the chemZ-case, which consists entirely of these materials (von Borstel, 2009; Figure 3.9). The chemZ student case contains a stopcock manifold with multiple ports, several syringes of different sizes and characteristics, eight three-way valves, two extension tubes, two probes for filling and refilling of fluids, ten plugs and a variety of luer-lock adapters and connectors.

A variety of equipment taken from medical engineering is available in pharmacies or online shops, such as the online pharmacy in Wolfsanger (2006) or at the shipping business Mercateo (2011). Table 3.2 summarizes the approximate cost of materials needed in medical engineering.

*Figure 3.10: Aquarium pump*

However, the aquarium business offers many alternatives for experimentation in the sciences. Particularly well suited are pumps, filters and hoses.

Pumps (Figure 3.10) are essential in the aquariums. They come in different versions but they always consist of a pump and a filter. The pumps are needed to clean the water from dirt particles in an aquarium, such as food leftovers. For this purpose, the water is absorbed, mixed with oxygen and pumped back into the aquarium. This function is also well suited for scientific experimentation in the school-context. Thus, aquarium pumps are used to generate a regular flow of air, such as the fermentation of alcohol into vinegar, or the comparison of the formation of carbon dioxide of yeast under anaerobic and aerobic conditions.

There are also a variety of hoses, clamps and distributors, which help to channel the gas and liquid flows and regulate them. These tubes (Figure 3.11) can be used as a cheaper substitute for silicon and vacuum hoses in the laboratory.

*Figure 3.11: tube from an aquarium market*

Kappenberg (2011) suggests a very extensive use by constructing a gas chromatograph with the help of an aquarium pump as well as corresponding tubes and connections. In doing so, the aquarium pump uniformly pumps air as a carrier gas through the column, which is located in a plastic tube.

The materials taken from the aquarium are available in the zoo or specific aquarium stores as well as in online shops. When purchased here, an aquarium pump costs about 10-15 € and 2.5 m hose costs about 3 €.

## 4. Experiments in petri dishes and spot plates

Many experiments in science, which are carried out in glassware, beakers or crystallizing dishes, can be easily conducted in petri dishes containing one, two or three compartments (Figure 4.1) or on spot plates made of plastic (see Figure 4.2).

*Figure 4.1: Petri dishes*

*Figure 4.2: multiwellplates*

For instance, Schwarz and Lutz (2004) as well as Köhler-Krützfeld and Gruvberg (2000) suggest the so-called wellplates or multiwellplates as small reaction vessels for experiments with liquids and in solution. These are spot plates made of plastic, which have several wells with different capacities.

Originally *multiwellplates* were developed for medical diagnosis or biochemistry. The plastic plates were then used for microscale scientific experimentation at the University of Peking. The "RADMASTE *advanced microchemistry kit*" (see page 11) also contains such a spot plate with 60 wells.

According to Zhou (2004) the advantage of experiments with a *multiwellplate* is that all the important experiments can be transferred into the micro scale. Schwarz and Lutz (2004) listed other benefits of these plates. According to the two authors, several experiments can be conducted parallel and directly compared with each other. This is useful, in particular, for precipitation, color change and catalytic reactions, or for experiments on electrochemical series. In addition, experiments on salt tolerance of plants can be conducted easily and inexpensively.

Depending on the size of the well, 0.5 up to 5 ml can be poured into it. The use of plastic reaction chambers instead of glassware reduces the risks of injury in case of breakage. The aquisitation costs of *multiwellplates* depend on the size. Thus, *multiwellplates* with 96 wells cost about 6 € per piece, while the purchase of 6 well spot plates cost less than 2 € (Mercateo, 2011). However, one must be careful with organic solvents as these may damage the plastic.

Similar to the spot plates, petri dishes made of polystyrene can also be an interesting and effective reaction chamber for experiments. 500 petri dishes with one chamber can be purchased for about 30 €, while the cost for 500 petri dishes with multiple chambers is about 60 €. Thus, the price of a single petri dish is about 5 or 12 cents. The petri dishes are low priced, easy to store and due to their material more robust than comparable glassware. Oxidation, precipitation reactions, radical substitutions and galvanic cells are just some examples of the type of experiments one can conduct in petri dishes with small quantities (Full, 1996). Seilnacht (2002) also proposes to use petri dishes for experiments on temperature-dependent solution processes and reactions, while Choi (2002) suggests examples for the synthesis of gases.

Many experiments that are being carried out in petri dishes can also be conducted in *multiwellplates*. One-chambered Petri dishes have a capacity of 12 ml, while divided petri dishes have a correspondingly smaller capacity. Spot plates can be filled with a maximum of 5 ml depending on the size of the well. Thus, the amount of chemicals used in *multiwellplates* is smaller.

However, petri dishes open up additional possibilities. For instance, the lid of the petri dish can create a closed space. In this case, a gas exchange between the chambers of the petri dish can take place. However, gas exchanges with the environment do not take place. An example is the synthesis and the detection of carbon dioxide (Full, 1996). Here, one chamber of the petri dish is filled with limewater. The second chamber is filled with a piece of marble, which is in contact with hydrochloric acid (Figure 4.3).

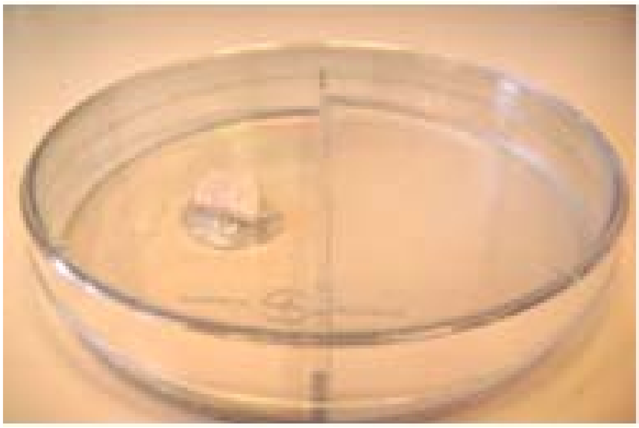

*Figure 4.3: Synthesis and detection of carbon dioxide*

Furthermore, petri dishes can be prepared for the conditions of the different experiments. For instance, it is possible to insert electrodes in the outer and partition walls, by simply heating and inserting them through the plastic. An example is the electrolysis of zinc iodide (Figure 4.4). For this experiment, a two-chambered petri dish is used. A pencil lead as a replacement for carbon electrodes is inserted through each of the outer walls of both compartments. If the electrodes are fragile, a hole can be cut in the outer wall of the petri dish with a hot nail, through which the electrode can be pushed and fastened with a hot glue gun. The partition wall of the two-chambered petri dish also has to be cut in several places with a hot nail if one wants to simulate a membrane. Of course, a salt bridge in the middle of the petri dish can also be created with the use of a piece of filter paper. Manipulations as described in the example of zinc iodide-electrolysis are only possible with petri dishes. Spot plates made of plastic can rarely be prepared in this way.

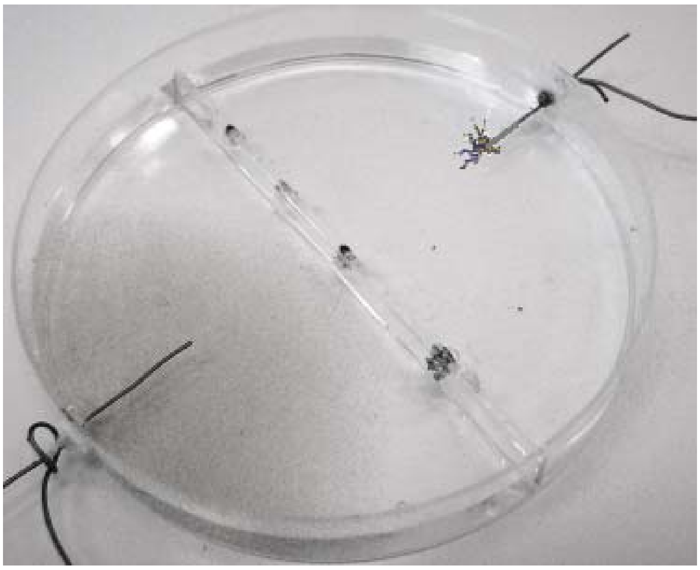

*Figure 4.4: Electrolysis of zinc iodide*

Finally, another potential use that evolves from the utilization of petri dishes will be demonstrated. The implementation of demonstration experiments is increasingly difficult due to the efforts of minimizing the amount of chemicals. Small quantities are hard to see from a great distance. The projection of reactions can avoid this problem. Therefore, petri dishes are especially well suited (Full, 1996).

Petri dishes are well suited for overhead projection due to their good stability and transparency. The reaction in the petri dish can be magnified by the projector on a diameter of 2 m. The demonstration of an experiment in the form of a projection is well suited for all reactions where there is a change in color or clouding of the solution. Moreover, gas developments and precipitation formation can be visualized well on a projector as well (Full, 1996). An example is the precipitation of silver halides. For this purpose, a petri dish is filled with distilled water prior to adding a little salt on one side and some grains of silver nitrate on the other side of the petri dish. The diffusion leads to the formation of silver chloride, which precipitates (Figure 4.5).

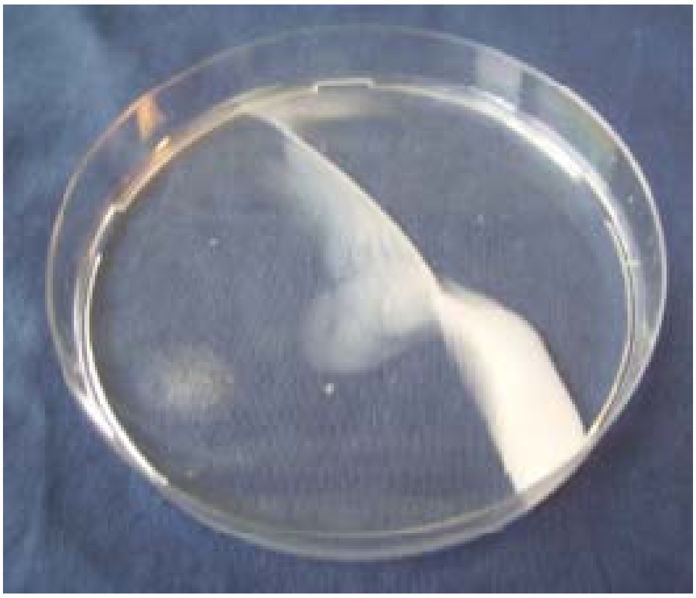

*Figure 4.5: Formation of silver halide*

Overall, spot plates and petri dishes are well suited as reaction chambers in many chemical reactions in natural science education. For this purpose, both petri dishes and spot plates are made of plastic so that the potential risks for the students, which may be caused by glass breakage, is completely bypassed. Spot plates have two crucial advantages over the petri dishes. For one thing, far more experiments can be carried out side by side. Furthermore, their low capacity makes them a suitable choice. Whereas petri dishes without a partition wall have a volume of about 12 ml. While this is larger than the volume of the spot plates, it is still smaller than the volume of normal glassware. In addition, the volume of each chamber of the divided petri dishes is correspondingly smaller. Petri dishes offer compelling advantages over the plastic plates due to the variability and the possibility of projecting reaction processes.

## 5. Experiments in household packages

All of the materials that were presented in previous chapters for the implementation of low cost experiments had to be purchased without exception, even if the required costs were affordable. However, empty package material, which is produced in many households as waste products, can also be used as reaction chambers for chemical and physical experiments. For instance, the use of empty pill packages, glass, tin cans, plastic cups or containers of cosmetic products are very well suited.

*Figure 5.1: Empty pill package*

The design of pill packages (Figure 5.1) is strikingly similar to the previously presented spot plates made of plastic. These empty pill packages also have the same benefits as the *multiwellplates*. Once the aluminum foil is removed from the drug packages, all the experiments, which can be conducted in spot plates, can also be conducted in an empty pill package. The individual drug packages differ in their size and shape, so that experimental vessels with different amounts of wells and capacities can be used. Like the volume of the individual wells of the spot plates made of plastic, the volume of a pill package is very small, so that only minimal use of chemicals and substances is necessary.

An example of the use is the creation of serial dilutions. For instance, Kruse-Özcelik and Schwarz (2004) propose to let students test the measuring of volume by preparing a serial dilution of milk. The experiment can be initiated by the question: "How much milk can a fraud dilute with water before the fraud is detected?” In this case, 2 ml of milk from the first compartment are gradually diluted by a factor of 10. The liquid becomes more and more transparent until eventually a cross on the bottom of the compartment can be detected (Figure 5.2).

*Figure 5.2: Serial dilution of milk in a drug package*

If a larger capacity than the capacity provided by the empty drug package is required, glass (e.g. cleaned jam or honey jars; Figure 5.3), tin cans (e.g. cleaned cans; Figure 5.4), or the cup of a tea candle or plastic cups can alternatively be used as reaction vessels.

*Figure 5.3: Empty Jam jars*

*Figure 5.4: Tin cans*

Due to the different materials of the containers, it is possible to choose accordingly to the needs of the respective experiment. Moreover, the containers exist in various sizes, so that even in this respect the necessary choices may be made.

The reaction vessels themselves may be part of the experiment. For instance, a metal can is well suited for the construction of a battery, since the wall of the can may be used as an electrode. The upper part of the can should be removed and the cleaned container is filled with a sodium chloride solution. The cup of the can serves as an electrode and is connected to a consumer or a voltmeter by using cable material. In order to complete the circuit, a graphite electrode or a pencil lead is dipped into the solution by using a consumer or a voltmeter (Schmittinger, 2011; Figure 5.5).

*Figure 5.5: The Coke-Can-Battery*

Another example demonstrates how glass is well suited for the conduction of an experiment. With the help of a tea candle (or another candle), an empty jam jar or a bowl, it can be shown that air is a mixture of different gases (Ardley, 1997). For this experiment, the bowl is filled with water; the tea candle (or any other candle in a candle holder) is put into the bowl and is lit up. Then the empty jam jar is carefully placed over the burning candle (Figure 5.6). It shows that the water level in the jar rises before the flame finally extinguishes.

*Figure 5.6: Burning candle in a jam jar*

Furthermore, containers of cosmetic products can also be used as vessels in scientific experiments. Empty glass containers of lotion can be used similarly to the rest of the glasses from the household, while empty make-up containers for eye shadow may be used like spot plates made of plastic or drug packages. Other cosmetic materials, which are well suited for experimentation, are vaporizers (e.g. for perfume or nasal spray) or empty shower gel bags, which can be used for the storage of gases.

Almost all of these materials are waste products in households and can therefore be collected for free in sufficient quantities. However, the required amount for student active experimentation is not instantaneous, so the collection has to be carried out continuously over a prolonged period of time. Also, the students and other colleagues may want to participate in the collection of materials from the household.

# 6. Experiments with plastic bottles

In the previous chapter the use of household packaging in chemical and physical experiments has been discussed.  This section discusses how plastic bottles (Figure 6.1) are well suited for various experiments.

*Figure 6.1: Plastic bottle*

Wilke (1998a) states that the use as well as the preparation of plastic bottles is a good way of promoting the students' independence when experimenting. These bottles are produced as waste in every household and therefore, they can be easily collected in sufficiently large quantities for the active student experimentation. Wilke points out that these items are well suited as experimental tools, in particular for teaching physics, due to their special features. He describes the following benefits:

- Plastic bottles exist in different shapes, sizes and designs. For this reason, the selection of the well suited experimental equipment may be made with reference to the respective requirements.
- Plastic bottles with a large volume ensure good visibility. Especially the fact that the bottles are transparent ensures good visibility of the processes that occur inside the plastic bottle during an experiment.
- Plastic bottles have a small mass and wall thickness. This makes an easy handling possible.
- Plastic bottles are very durable and virtually unbreakable. Furthermore, the bottles do not shatter in case of experiment failure. This makes it possible to reduce the risks for the students, so that the plastic bottles may be used for experiments involving letting them drop or throwing them.

- Plastic bottles are very resistant to pressure. This fact makes it possible to carry out pneumatic and hydraulic experiments. In experiments of this type, the pressure resistance ensures a high stability, despite the low wall thickness. On the other hand, plastic bottles may be easily deformed from the outside by only applying light pressure.
- The easy preparation and handling of the plastic bottles is a crucial factor in their use for experimentation. The bottles can easily be sawed, drilled or cut accordingly to the requirements of the particular experiment. Moreover, it is also possible to melt holes with hot objects in the plastic bottles and to seal them again with hot glue.

In general, a distinction is made between thin-walled and thick-walled plastic bottles. The preparation of thin-walled bottles is much easier, which is why the use of bottles that have a thicker outer wall is usually avoided. The use of thick-walled bottles is preferable when the aim is to produce stable set-ups without any deformability (Wilke, 1998a).

| Required materials | Physics experiment |
| --- | --- |
| Plastic bottle, bendable straws glue, thin thread, plastic bowl | Waterwheel by Segner for the demonstration of the 3rd Newton's law |
| Plastic bottle with stopper with a hole, piece of a hose, two glass tubes | Recoil boat for the demonstration of „*action*" equals „*reaction*" |
| Big plastic bottle filled with sand or water, preferably long thread (attached to the ceiling) | Experiment of the alternating conversion of potential and kinetic energy or for the demonstration of the magnus effect |
| Big, thin plastic bottle (filled with water), with a screw cap cylindrical piece of styrofoam, screw | Cartesian diver to demonstrate the all-round pressure equalization in liquids |
| Plastic bottle with a screw cap, rubber thread, beads small propeller, paper clip | Model of a motorboat |
| Plastic bottle, needle, funnel | Experiment of the dependence of the gravity pressure from the height of the water column |
| Plastic bottle with pierced screw cap, drilled stopper, U-shaped glass tube | Goethe-barometer for measuring atmospheric air pressure |
| Thick-walled plastic bottle, bicycle dynamo, cable materials light bulb | Wind turbine with horizontal shaft |

*Table 6.1: Diverse experiments with plastic bottles*

Overall, the various plastic bottles can be used in different ways for experimentation. Table 6.1 provides an overview of the versatility of plastic bottles in the experimental physics education (Wilke, 1998a, 1998b, 1998c).

The table only represents a small part of the experimental possibilities, which can be achieved by the use of plastic bottles. To get a better impression on the applicability of plastic bottles in physics experimentation, two examples are discussed in detail: the waterwheel by Segner and the construction of a motorboat.

*Figure 6.2: Straws in a plastic bottle*

According to Wilke (1998) an experiment for the demonstration of the third Newton's law can be conducted if a plastic bottle is suitably prepared. As already shown in Table 6.1, some bendable straws, glue, a thin thread and a plastic bowl are required. For the experiment, the plastic bottle is placed closely above the ground with the help of three drill holes, which have a length of 4 mm each and which are set apart by 120°. A bendable straw is inserted in each of these holes. One of the side lengths of each straw has been shortened (see Figure 6.2). The straws have to be attached to the plastic bottle using the glue. Also, the straws have to be bent in an angle of 90 °.

The ends of the straws have to be pressed together so that only an approximately 2 mm wide slot is left. In order to do this, the ends have to be first placed in boiling water. Then the two heated end pieces have to be firmly pressed together with a pair of pliers until the straws have sufficiently cooled off. To carry out the experiment, the bottle has to be hung by a thread. In order to do so, it is recommended that the bottle may be drilled horizontally in the area of the screw thread. Then a thread has to be pulled through the bottle (see Figure 6.3). Finally, the bottle is completely filled with water and then released to start the experiment. The recoil caused by the emerging water jets causes a rotational movement of the bottle.

*Figure 6.3: Screw thread of a bottle (with a thread pulled through)*

Another example is the model of a motorboat (Wilke, 1998). As described in Table 6.1, for this experiment a plastic bottle with a screw cap, a rubber thread, some beads, a marine propeller made of plastic and a paper clip are required. For the construction of this model, first a hole of a diameter of 4 mm has to be cut into the bottom of the plastic bottle. Also, a hole of a diameter of approximately 2 mm has to be cut in the cap. A rubber thread of about 5m has to be tied up at its ends in order to construct the rubber engine. The resulting ring is folded into a loop, whose length is slightly shorter than the length of the plastic bottle. Then a paper clip is bent apart to attach the folded rubber thread. At the end of the paper clip a marine propeller made of plastic is attached. In order for the marine propeller of the motorboat to stay under water, beads can be put on the bent paper clip. Finally, the paper clip is inserted into the opening of the screw cap and bent so that the rubber loop can be attached to it. The prepared screw cap is screwed on the plastic bottle. With the help of a second paper clip the folded rubber thread is lead through the hole in the bottom of the bottle and attached (Fig. 6.4).
One additional piece of wood helps to add weight to the model motorboat. Thus, it is ensured that the boat will not rotate around its own longitudinal axis. The engine will eventually be started by turning the propeller.

*Figure 6.4: Model of a motorboat*

# 7. The home improvement store as a source of equipment for experiments

In the previous chapters, the usefulness of household items for scientific experimentation has been demonstrated. However, not only everyday items taken from the household are well suited. Also items found in home improvement stores are inexpensive, can be purchased in sufficient quantities and are well suited for experimentations.

*Figure 7.1: Metal pipe*

Examples of materials that can be purchased at the home improvement store are plastic and metal pipes (Fig. 7.1), silicones, polystyrene, wire (Fig. 7.2), nails, light bulbs (Fig. 7.3), tiled backsplash, large, transparent or glass panes. These materials offer a variety of possibilities for natural science teaching. The items from the home improvement store are in particular well suited for experiments in mechanics, electronics and electrochemistry. Experiments include designs with mass, floating and sinking, pressure, stiffness and elasticity or leverage laws as well as light, electricity, conductivity, electrochemical cells, up to the construction of an electromagnet and the construction of a piezo-electric igniter. However, this type of experimental material may also cover other topics as well. As examples serve an experiment for the law of reflection and an experiment for transmission of impulses (Menzel, 1990; Kuhn & Rech 2003; Mellert et al., 2001; Köthe, 2008).

*Figure 7.2: Wires*

*Figure 7.3: Light bulbs*

Two examples will be discussed in detail, in which items from the home improvement store are used: an experiment on the law of reflection and another one on the construction of an electromagnet.
According to Kuhn and Rech (2003), two tubes made of cardboard or plastic, a mirror and a flashlight are required for the experiment for the law of reflection. The materials are arranged as shown in Figure 7.4. By using the flashlight to light one of the tubes, the law of reflection can be derived.

*Figure 7.4: Experiment on the law of reflection*

Another example is the construction of an electromagnet by Mellert et al. (2001). Here, a screw made of iron, about 2m bell wire, a 1.5 V battery and small metal parts for testing the magnetic features of the constructed electromagnet are required.
For this construction, the end of the bell wire is removed from its plastic insulation so that the bare wire is exposed. Then the wire is wrapped around the screw (see Figure 7.5), so that the bare ends of the wire hang down at the ends of the screw.

*Figure 7.5: Screw wrapped with bell wire*

It is important to ensure that the wire is not bent. If necessary, the wire has to be fastened in place with tape. Finally, the ends of the bare wire are connected to the positive or negative terminal of the battery. When using the electromagnets, one has to make sure that the wire is not connected to the battery for too long. After about 1 minute, the ends of the wire become hot.

In experiments following the low cost principle, the actual costs always play a very central role. Table 7.1 summarizes the costs of some of the mentioned materials (Mercateo, 2011).

| Alternative equipment | Costs |
|---|---|
| Plastic or metal pipes | 0,20 € or 1,10 € per meter |
| Wire | 1,50 € for 25 meter |
| Nails | Ca. 5 € for 100 pieces |
| Light bulbs | 0,30 € |
| Tiled backsplash | 1 € for 4 pieces |

*Table 7.1: Costs of equipment found in the home improvement store for experiments*

However, not only the alternative equipment found in the home improvement store is well suited. Also, the chemicals purchased at the home improvement store are very inexpensively as well. Thus, there are varieties of acids, caustic soda, ammonia, lime, acetone, denatured alcohol, various plastics or distilled water etc for sale at home improvement stores. Here, these chemicals are usually much cheaper than in a specific store for chemicals. Additionally, they are of sufficient quality and purity for experiments in school science classes. Table 7.2 shows which chemicals can also be replaced with items from the home improvement store, for which the reference is not so obvious. Please note that the list is not exhaustive and only intends to give an overview of the possibilities.

| Product | Alternative |
|---|---|
| Slaked lime, rapid-hardening cement | Calcium hydroxide |
| Gypsum | Calcium sulfate |
| Dehumidifier | Calcium chloride |
| "pH-minus" (swimming pool accessory) | Sodium hydrogen sulfate |
| Perpendicular | Ammonium chloride |
| Charcoal | Carbon |
| Rico graffiti- killer | 1-methoxy-2-propanol, contains between 20 and 50% |

*Table 7.2: Alternative chemicals found in the home improvement store*

The possible use of these products is very diverse. Thus methylated spirits is a 96% ethanol solution and can be used for example when using a low cost alcohol burner. As a consequence, a gas compound becomes unnecessary. Acetone, various acids and the mentioned alternative chemicals can often be used similarly to conventional chemicals. Thus, it is possible to synthesize carbon dioxide from lime and acid (Seilnacht, 2002). The limewater for the carbon dioxide detection can be made from cement. According to Schwedt (2001) and Köthe (2008) rapid-hardening cement from the home improvement store, which contains calcium hydroxide, water and a bottle are required. 20 g of cement are added into 50 ml of water, which is then shaken or stirred. Then the undissolved solid then settles (Figure 7.6) and the liquid can be decanted. The filtrate may ultimately be used for the detection of carbon dioxide.

*Figure 7.6: Limewater made from rapid-hardening cement*

The use of these alternative chemicals from the home improvement store is particularly well suited for chemistry experiments. The acquisition is very simple since these chemicals can be purchased without any regulations. Furthermore, these products are very cheap, so cost savings can be guaranteed. There is also another advantage in the use of alternative chemicals from the home improvement store. The students may learn in this way that contents involving chemicals are not only relevant in the chemistry class, but also in everyday life and that everyday products play a major role (Schwedt, 2001).

Overall, it can be stated that the use of items found in the home improvement store are well suited for scientific experiments. The examples presented in this guide provide only an overview of some of the possibilities. If items found in the home improvement store are used in a creative manner, they can help to conduct a huge variety of experiments.

# 8. Equipment from the electronics specialists store for experiments

In the previous chapters alternative materials and chemicals from the home improvement store were introduced that are well suited for scientific experiments. Other materials suitable for low-cost experimentation can be purchased at an electronics store.

*Figure 8.1: Simple multimeter*

Just like items from the home improvement store, materials from an electronics store are easily available and inexpensive.

Overall, many different products are well suited for experiments in natural science teaching. Network devices and instruments for DC and AC voltages (Fig. 8.1), experimental cables (Fig. 8.2), crocodile clips, magnets (Fig. 8.3), flashlights, laser pointers, individual hot plates, cartridges, stopwatches as well as certain consoles and vessels serve as examples.

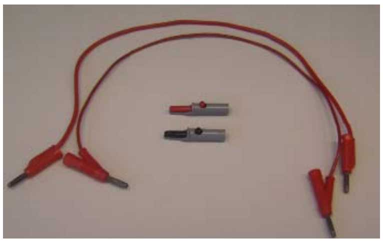

*Figure 8.2: Experimental cables and crocodile clips*

*Figure 8.3: Magnets*

Due to the materials from an electronics store, many experiments in the field of electronics and electrochemistry are possible. Among these are examples of the construction of an electric motor, the construction of an electrical circuit and the construction of galvanic cells and electrolytic cells. In particular, light emitting diodes (referred to LEDs from now on) for the indication of a current flow (Fig. 8.4) and/or multimeters are emphasized here, because they are by far cheaper than special laboratory instruments (Fig. 8.1). However, they are sufficiently accurate for almost all of the relevant experiments in science classes in school. Moreover, these materials help to experimentally develop many other scientific subjects, such as the construction of a magnetic compass made of cork, experiments on vibration or experiments on the law of refraction and reflection (Schlichting & Ucke, 2004. Mellert, el al, 2001; Tillmann, 2011; Kieninger, 2008).

*Figure 8.4: Light emitting diode*

Examples may illustrate this, too, like the construction of an electric motor, an experiment on the law of reflection and the use of LEDs for measurement of voltage. According to Schlichting and Ucke (2004), a 1.5 V battery, a screw, a small bar magnet and a piece of wire are required for the construction of an electric motor. If the magnetic cylinder and the screw are attached at one pole of the battery and connected to the other pole with the help of a wire (see Fig. 8.5), the magnet and the screw start to rapidly rotate.

Schlichting and Ucke refer to this experiment as the easiest and fastest way to manufacture an electric motor. In general, electric motors are considered as a complicated system of a wire coil and a magnet. Using the materials described, a structure may be built costing only a few Euros. Its efficiency is low and its construction is unstable, but it follows the principle of the oldest electric motor by Michael Faraday (Schlichting & Ucke, 2004).

*Figure 8.5: Self constructed electric motor*

The second example is an experiment on the law of reflection. For this experiment a mirror, graph paper, a pen, a set square and a laser pointer are required. Laser pointers can often already be purchased for 1.50 € (Mercateo, 2011), tiled backsplash can be purchased at a home improvement store for less than 1 €. The experimental design for the law of reflection costs therefore about 2 €.

First, a division of angles is drawn on a clean piece of graph paper by using the set square (Fig. 8.6). Then, the mirror has to be put on the created division of angles, as shown in Figure 8.7.

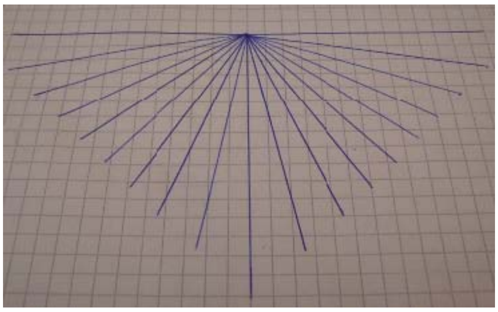

*Figure 8.6: Division of angles*

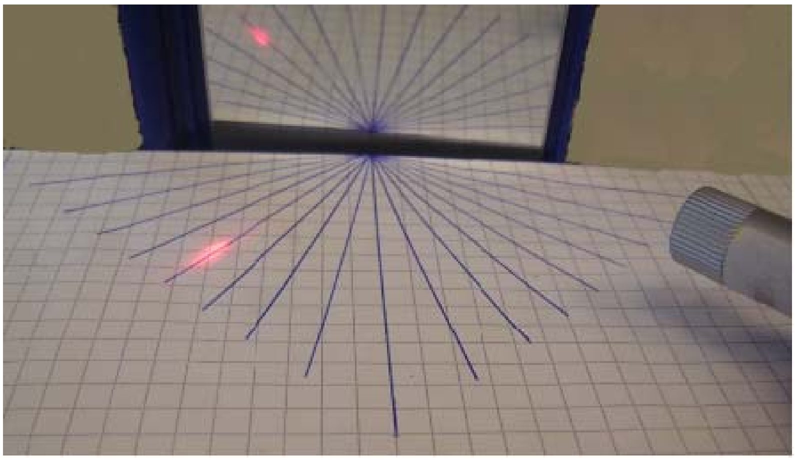

*Figure 8.7: Experiment on the law of reflections*

The room should be darkened when the perpendicular is irradiated along the lines of the pen with the laser pointer. The reflected ray of the laser can be seen on paper, which leads to the conclusion of the law of reflection.

Finally, it will be demonstrated with the help of a Daniell element how an LED can be used as a current and voltage meter. This requires a two-chambered petri dish, a piece of zinc wire, a piece of copper wire, cable material, a LED, a zinc sulfate and a copper sulfate solution. The materials are put in order as shown in Figure 8.8.

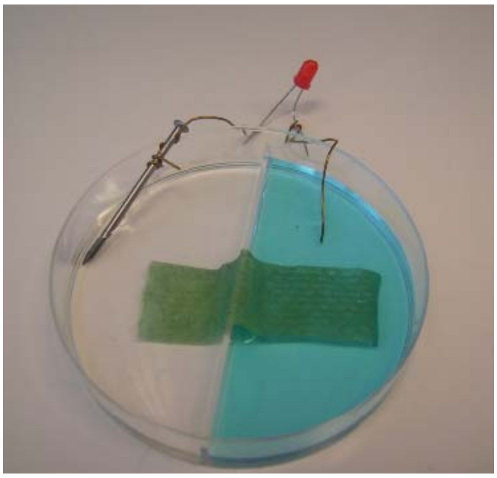

*Figure 8.8: Daniell element with LED for power verification*

The glow of the LED indicates the voltage generated by the potential difference. The advantage of the LEDs in comparison to other lights or motors is that they react to even very low voltages. Thus, a visual effect may occur for the students.

At the end of this chapter the costs of alternative equipment that has been presented in this chapter will be discussed. Table 8.1 lists the main materials found in an electronics store (Mercateo, 2011; Conrad Elektronik, 2011).

| Alternative equipment | Costs |
|---|---|
| Experimental cable | 3 € per piece |
| Alligator clips | 0,50 € per piece |
| Magnets | Starting at 0,15 € per piece (depending on model) |
| Small flashlight | Starting at 1,20 € |
| LED | 0,04 € |
| Laser pointer | 1,50 € |
| Hot plate | 10 € |
| Stop watch | 2 € |

*Table 8.1: Costs of alternative experimental equipment found in the electronic specialists store*

# 9. Cost-effective alternatives for quantitative studies

In science classes quantitative measurements can often be conducted. These range from time, distance, temperature, or current and voltage measurements to photometric measurements, the determination of charges or reaction enthalpies. The acquisition of various analytical instruments requires major expenses, which makes it too expensive for the school context. The absence of student-centered experiments in quantitative measurements, however, is not necessary in all cases, because many instruments can be purchased for a low price at home improvement stores or electronics stores or they can be self-constructed with easily procured materials.

In home improvement stores or similar specialty stores, many inexpensive alternatives to traditional quantitative instruments, which could be used for scientific experiments, may easily be found. Multimeters, digital thermometers, levels (Fig. 9.1), laser rangefinders or digital scales (Fig. 9.2) from the kitchen store serve as examples. Many of these devices can be used similarly to the conventional laboratory equipment for experimentation. They are sufficiently precise for educational purposes and generally easy to use.

*Figure 9.1: Level*

*Figure 9.2: Kitchen scale*

Particularly well suited are inexpensive multimeters. Simple models of the multimeters to measure voltage, current and resistance can often be purchased for less than 10 € (Mercateo, 2011). Some units even have a digital output and can directly be connected to a computer for data acquisition. An example is the digital multimeter "Digitek DT 4000 ZC". This model is characterized by a particularly wide range of possibilities of measurement. It allows the measurement of DC and AC voltage, DC and AC current, resistance, capacity, frequencies to 10 MHz as well as temperatures up to 750 ° C and is available for about 40 € (ELV Elektronik, 2011). At first glance, this price may seem relatively high, but becomes relative in regard to the number of possible uses.

There are also accessories for quantitative studies in the specialty stores for aquariums. In those stores multimeters can be purchased, which allow the measurement of pH-values. These are, however, relatively expensive to buy with about 150 € per model (Schneiderbanger, 2011). There are also rapid tests that are cheaper and easy to use in order to study the pH-value or the nitrate concentration in the bodies of water.

Additional units can be replaced by self-made constructions with the help of simple, low cost alternatives. Possibilities are the construction of a device for measuring conductivity according to Kappenberg (2011), a low cost calorimeter, a low cost photometer according to Just (1990) and a low cost gas chromatograph. The latter analysis device can be both purchased and self-built. Kappenberg (2011) offers several options for purchase and various self-construction manuals. Such an analyzer can be purchased for about 350 €. Conventional gas chromatographs, which are used in laboratories, cost several thousand Euros (Neubert, 2011). By purchasing a low cost gas chromatograph, instead of a conventional analyzer, a lot of money can be saved. Kappenberg (2011) also provides a self-construction manual for this device in order to save additional costs. Here, an inexpensive way for creating a gas chromatograph on the basis of equipment from the medical engineering is provided. Overall, a gas chromatograph with articles from medical engineering costs less than 50 €. This represents very extensive cost savings compared to the cost of a conventional device. Furthermore, Kappenberg (1998) also describes that self-made gas chromatographs are well suited for different analytical applications. According to Kappenberg good results were obtained for the following school experiments:

- Analysis of lighter gas.
- Catalytic hydrogenation of alkenes and alkynes.
- Photochlorination of natural gas (methane).
- Pyrolysis of plastics (PE film).

It should be noted, however, that volatile components evaporate quickly and accordingly change the composition of the gas and the chromatogram. Despite this disadvantage, the presented analysis-instrument helps the students to easily handle and understand the functioning of such a device.

At this point, the use of self-made instruments for measurement in the classroom will be described using the examples for the determination of heats of mixing and heats of fusions. For these examples, a plastic cup has to be put in a suited beaker (Fig. 9.3). The advantage of this calorimeter is that it is very light. For this reason, liquids can be weighed directly and do not have to be transferred. Compared with the commonly used dewar-vessels, they also have the additional advantage that there is no danger of implosion (Maisenbacher, 2011). Also the low price of just a few cents per plastic cup and about 1.50 € per beaker (Mercateo, 2011) is worth mentioning. In comparison, dewar-vessels cost several hundred Euros. To determine the reaction enthalpy, next to the low cost calorimeter only a scale, a stopwatch and a thermometer are required. It is advisable to isolate the outside of the vessel with styrofoam. In order to determine the water equivalent with this instrument, 50 g of water have to be measured into the vessel and the temperature has to be monitored until it does not change any further. Then the same amount of 40 ° C warm water has to be measured into a second low cost calorimeter. The temperature must also be monitored and recorded for this instance. After 3 - 4 minutes, the cold water is added. The temperature has to be continuously recorded at regular intervals. During the determination of the water equivalent a good mixing has to be guaranteed. This can be ensured by using either a magnetic stirrer or a wooden or plastic stick.

*Figure 9.3: Low cost calorimeter*

Overall, the additional time that it takes to self-construct the various analytical instruments has to always be remembered.

This would not be necessary in a regular purchase. However, the high cost of a conventional measuring instrument may prevent its purchase. Therefore, the approach described here might represent a good alternative.

## 10. Experimentation with substances found in the household

The applicability of vessels for scientific experimentations found in the household has already been discussed in detail. However, in addition many other items found in the household are well suited. Funnels from the kitchen, garden hoses, marbles, beads, balloons, aluminum foil, coffee filters, markers, flat glass dishes (e.g. casserole) and mirrors are just a few examples. A major advantage in using everyday objects as equipment for experiments is that the used items are available in almost every household. This fact makes it possible for the students to conduct experiments at home also. The required items can also be procured easily for the school because they can be found in supermarkets for a very low cost.

Thus, there are also many books that explore the science experiments with household items. Examples of this are offered for instance by Press (1995), Heuer (2010), Ardley (1997), Köthe (2008) and Rüter (2009). These are often directed at parents to playfully explore natural phenomena with the children at home. However, these experiments can be used equally well in biology, physics and chemistry lessons and thus enrich the teaching. There are increasing offers that can be found on the Internet as well. Tillmann (2011) describes several experiments that can be conducted with everyday objects. To demonstrate the versatility of the different materials some examples from the three areas will be demonstrated at this point.

*Figure 10.1: Construction of altered sound perception*

For physics experiments on sound perception and on optics were chosen. For the implementation of the first experiment, two plastic funnels from the kitchen, duct tape, two plastic tubes from the garden and a wooden stick are required. On each of the two funnels a plastic tube is inserted, which in turn is attached to the wooden stick (Fig. 10.1). The sound waves that are coming from the left can be transferred with this construction in the right ear of the learner and vice versa.

The second example for physics comes from the field of optics. With the help of a casserole dish, a flashlight, some modeling clay, a white cardboard box as well as a mirror, a rainbow can be produced by dividing the light from the flashlight into its spectral components (Ardley, 1997). For the implementation of the experiment, the room should first be darkened before a mirror is tilted in a glass bowl filled with water and attached to it with the clay. Then the flashlight is used to illuminate the lower part of the mirror that is covered by the water. The rainbow becomes visible when the white cardboard box is held above the bowl (Fig. 10.2).

*Figure 10.2: Generation of a rainbow*

In chemistry, a simple experiment for the chromatography is presented. The color of markers can be decomposed, by chromatography, into their constituents. In order to conduct this experiment, one felt tip, a glass and a coffee filter are required. First, a thick line has to be painted on the filter paper. The painted coffee filter is then folded over the edge of a glass and hung into the water, as shown in Figure 10.3 (Tillmann, 2011). When the water is spreading, the components of the felt tip are carried to different extents, resulting in different chromatograms (Fig. 10.4). After the coffee filter has dried off, the constituents of the felt tip ink can be seen from these chromatograms.

*Figure 10.3: Low cost chromatography*

*Figure 10.4: Chromatogram of a brown felt tip*

Also, heating and cooling pads, and even heated espresso containers may stimulate interesting research. Heat pads are usually filled with a solution of sodium acetate trihydrate (Fischer, 2011). If the metal plate located in the pillow is bent, crystallization is initiated that releases some heat. According to the author, an overall increase of temperature up to 35 ° C is possible due to the crystallization. If the crystallization is completed and the pad has cooled down, the crystals can be dissolved by supplying energy in form of hot water and thus, the crystallization is irreversible. However, cooling pads cannot be used several times. Other potential possibilities are hot-cold compresses, which are heated in a microwave or cooled down in a freezer, and moreover, self-heating cups, in which liquids can be heated. Heating and cooling pads, compresses as well as self-heating cups are available at low costs (see Mercateo, 2011) or are available in many households.

These items can be analyzed qualitatively, their effect can be quantitatively examined or good copies can be replicated in a competition. The applications are numerous. For a better idea, an additional experiment will be presented in which a heating pad is used to explore the behavior of gases at a change of temperature. A bottle, a straw, clay and a heating pad are required. The bottle is half filled with colored water and the straw is led through the hole until it dives into the water. Then, the opening of the bottle is sealed airtight with the clay (Köthe, 2008). Figure 10.5 shows the experimental setup as described. With the help of the heating pad, the air in the bottle can be heated in the bottle by pushing the pad against the outer wall of the bottle. The expansion of air in the bottle is shown in the change of the water level in the straw.

*Figure 10.5: Experiment on the behavior of gases at a change of temperature*

Finally, it should be noted that not only equipment for experiments is found in the household. As mentioned in the chapters on products from the home improvement store, also various items found in the household and supermarkets serve as a substitute for chemicals. Many alternatives, which have been presented as examples, can be used in the acid-base chemistry. Thus, indicators can be made from red cabbage, eggplant, radish, roses or tea. Red cabbage indicators can be easily made at home with the help of red cabbage, methylated spirits and a cooking pot. In order to do so, the cabbage is cut into small pieces and placed together with the methylated spirits in a cooking pot, in which it has to simmer for about 5 - 10 minutes. Then, the now red colored solution of methylated spirits can be bottled and used as an indicator. With the help of this self-made indicator substances from the household such as soap solution, common salt solution, diluted acetic acid or a pipe cleaner can be tested in terms of their pH value (Press, 1995; Schwedt, 2003). Figure 10.6 represents the color scale that the red cabbage indicator shows in a soap solution, in a common salt solution, in methylated spirits, in a diluted acetic acid, in a curd soap solution and in a mold cleaner.

Besides the already mentioned application areas, there are many more. Schwedt (2001; 2003) proposes among other things to synthesize chlorine, nitrogen or hydrogen gas. However, also the synthesis of carbon dioxide from baking soda and diluted acetic acid as well as the construction of a volcano according to Ardley (1997) or the generation of electricity using potatoes (Press, 1995) are well suited. The latter author also suggests using soda to mimic a cave.

*Figure 10.6: Color scale of red cabbage indicator in a variety of solutions from the household*

As already mentioned, the acquisition of alternative chemicals is easy since only cheap products from a supermarket without any commercial limitation are used. Furthermore, through the use of supermarket products the learners can learn that chemistry does not only take place in the chemistry class, but also in daily life and is found in everyday products. However, the disadvantages of this approach also have to be addressed. Thus, the results in experiments with everyday substances as a replacement of chemicals are sometimes weaker because of the lower purity than in experiments, which are performed with laboratory chemicals.

At this point it should be also pointed out that everyday objects could be used not only for experiments in natural science subjects. Moreover, useful models can be built and used. For example, different colored beads from a necklace or cellulose beads may be well suited in order to make molecular models (Figure 10.7).

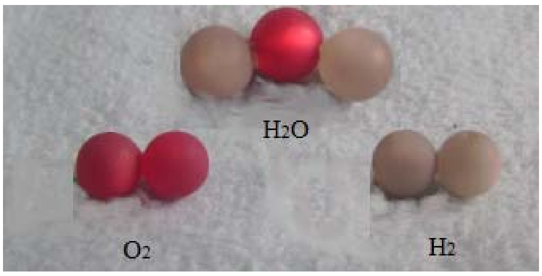


*Figure 10.7: Molecules made with beads*

Even models in biology can be created in such a way, like the model of the eye. Through this model, the students learn about the functioning of an eye. For this model, a cardboard box, duct tape, a magnifying glass, play clay, a paper tissue, a flashlight and a globe vase (or a glass teapot) are required (Ardley, 1997). The paper tissue is glued on the outside of the vase and a figure is cut in the cardboard box. Then the vase, the magnifying glass and cardboard box are built together and stabilized with the help of modeling clay as shown in Figure 10.8.

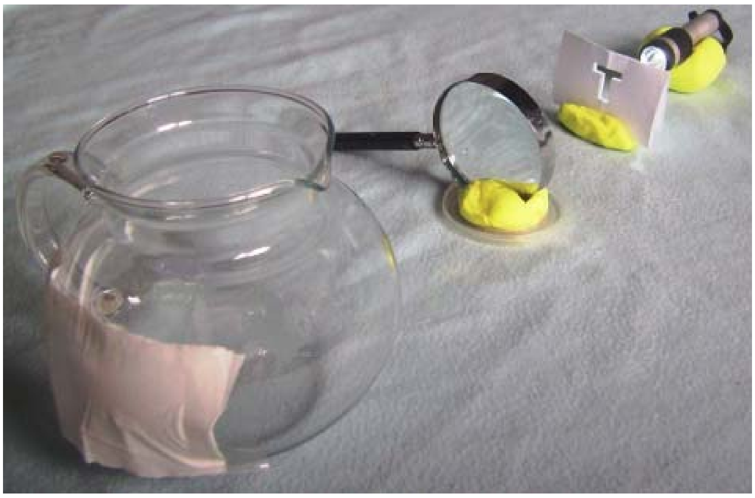

*Figure 10.8: Model of an eye*

If the ray of the flashlight is directed towards the figure in the cardboard box, the same figure appears on the tissue, only rotated by 180 °. The magnifying glass has the effect of a lens in the eye. By moving the magnifying glass, the image on the paper tissue can be focused (Ardley, 1997).

# 11. Low cost approaches for biological experiments

In the previous chapters numerous techniques have been introduced that allow low cost experimentation. At the same time, experimental examples have been presented. However, biological experiments only played a minor role. This chapter covers this topic to a wider extent.

The various techniques can also be implemented in experiments in biology classes. Thus, a lot of materials needed for conventional experiments can be replaced by devices of various low cost techniques. This is the case for a model for respiration by Sapper and Widhalm (2001) for example.

In contrast to chemical and physical experiments, there are numerous biological experiments that can be carried out with the help of plants, leaves, stems or fruits. The sensory detection of essential oils, an experiment on carotenoids in bell pepper, experiments for the detection of turgor and transpiration in plants as well as proof of the formation of oxygen during photosynthesis according to Schwedt (2007), Sapper and Widhalm (2001) and Wild (1999) serve as examples.

The parts of plants required for these experiments can be easily collected before class, in parks or in the schoolyard. Alternatively, potted plants can be placed in the classrooms, so that fresh leaves are available. Many fruits or flowers can be easily purchased for at a low price in supermarkets.

However, in many cases it is also necessary to make the whole offspring of plants available for the students. They can be self-grown according to Keil and Kremer (2004). In order to this the desired seeds have to pre-soak for half a day or overnight in tap water at room temperature (Fig. 11.1). Then they are spread on wet blotting paper in a petri dish. They are supposed to germinate at a temperature of about 25 ° C. After about 1 to 2 hours, the roots will most likely have grown to about 2 inches. Now the seedlings can be placed in a nutrient solution. In this solution, they are supposed to be growing for about 5 to 8 days before they can be used for the experiments.

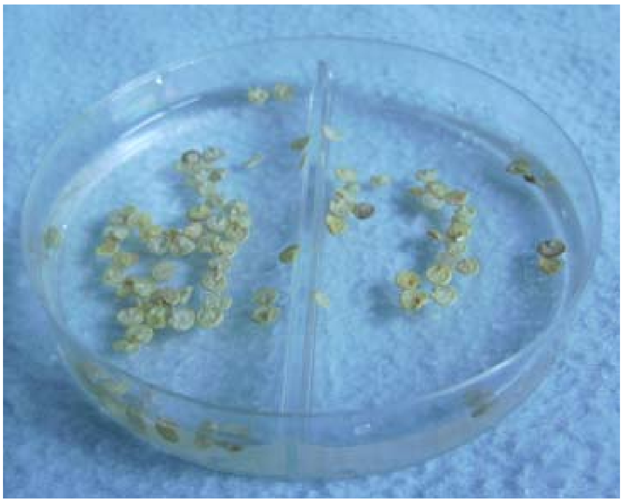

*Figure 11.1: Seeds of a bell pepper plant during the pre-bulging*

For a better understanding of the experiments with plants or parts of plants, an experiment for the detection of oxygen formed during photosynthesis and another one for the extraction of carotenoids from bell peppers will be demonstrated.

For the former experiment, a plant scion, which does not wither too fast, three jars with lids, three tea candles, three toothpicks, a straw, aluminum foil, a stopwatch and tab water are required. In preparation, the toothpicks are placed between the aluminum cup of the tea candle and the candles themselves (Fig. 11.2). This toothpick handle makes quick transportation of the candle possible. Overall, the length of the toothpicks made of wood or plastic sticking in the cup of the tea candle have to fit into the closed jar. Then the jars are covered with aluminum foil (the lid should be left out) and filled with tap water. One of the jars serves for comparison purposes and is now closed. In the second jar a plant scion is placed (Fig. 11.3) and is then also closed. Into the last jar someone has to breathe through a straw and then the jar has to be closed as well.

*Figure 11.2: Tea candlewith toothpick*

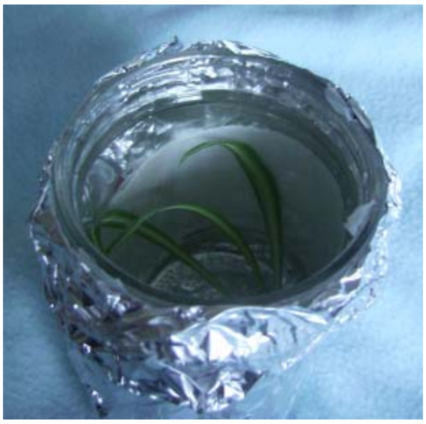

*Figure 11.3: Plant scion in a darkened jar*

The three jars should be placed at the window for several days. In the next lesson the oxygen content in the jars can be compared using the tea candles.

According to Schwedt (2007), for the extraction of carotenoids from bell peppers only different colored bell peppers, methylated spirits, Eppendorf-cups and a cutting blade are required. The bell peppers are cut into very small pieces with a knife, of which a few are placed in an Eppendorf-cup. Then, the cup is filled with methylated spirits and shaken vigorously. Figure 11.4 shows what the expected outcome of this experiment looks like. The carotenes accumulate in the gas phase, while xanthophylls remain in the aqueous-ethanolic phase.

*Figure 11.4: Extraction of a red bell pepper (left) and a green bell pepper (right)*

However, in biology class not only plants are discussed, living creatures are addressed as well. In particular, the topic of human sensory organs provides opportunities of small "self-experimentations" following the low cost principle.

Experiments for visual perception are especially well suited. This will be illustrated with an example of the stereoscopic vision. According to Sapper and Widhalm (2001), a curtain ring, a string and a pencil are required for this experiment. The curtain ring is hung on a string so that it can be well seen by the “test subject” (Fig. 11.5). The test subject then covers one eye and tries to put the pencil through the curtain ring with his or her other hand.

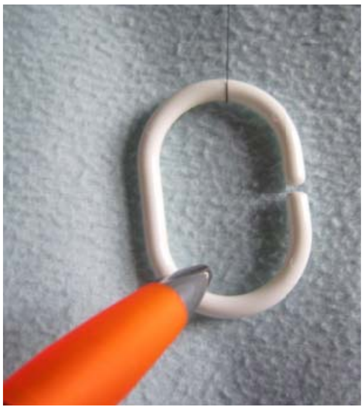

*Figure 11.5: Experiment on the stereoscopic vision*

As further examples, the authors suggest to conduct experiments on accommodation, directional hearing, the coordination of movement or the dulling of the sensation of smell of a student. Overall, it should be emphasized that the experiments presented in this chapter allow a low cost experimentation approach without exception. The use of parts of plants and plant scions as well as the involvement of the students does not cost anything. The purchase of the other materials used is also very cost-effective, as was explained in detail in previous chapters.

Finally, a central aspect of the biology class will be addressed. The microscope plays an important role in biology. There are numerous experimental regulations, which make essential use of the microscope (see Wild, 1999, Sapper & Widhalm, 2001). The purchase of this equipment represents a major cost, a single microscope costs up to 200 € in specialists stores (Henkel, 2003).

In many cases, however, it is possible to avoid a costly acquisition. Thus, simpler models with lower magnification can be already purchased at a significantly reduced price (Tillmann, 2011). Thus, there are simple microscopes already for about 20 €, which corresponds to a cost reduction by a factor of 10. However, Henkel (2003) shows in detail that many cost-effective microscopes are of a poor quality, which does not meet the standards of advanced biology lessons. This can be seen in a decreased magnification, a poorer manufacture as well as in poorer optics. Therefore, before purchasing a microscope one has to be aware of the respective requirements that it has to fulfill. Henkel (2003) also proposes to replace microscopes, especially in younger age groups, by magnifying glasses (Fig. 11.6). These can produce a magnification by the factor 10 and can be purchased in good quality for under 10 € (Henkel, 2003).

An additional advantage of using magnifying glasses instead of expensive microscopes is the fact that magnifying glasses are much more robust. Especially younger students do often not have yet the necessary manual skills to ensure an appropriate and careful use of the expensive magnifying equipment.

*Figure 11.6: Magnifying glass*

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