KLEINE FORSCHER
Naturwissenschaften und Technik für Mädchen und Jungen

TECHNOLOGY – USING FORCES AND ACHIEVING EFFECTS

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"HAUS DER KLEINEN FORSCHER" FOUNDATION

The "Haus der kleinen Forscher" Foundation has set itself an ambitious objective – namely, to enable all children between the ages of three and ten to have everyday encounters with science, mathematics, and technology topics.

The aim is to give the children the opportunity to discover this exciting field for themselves in an enjoyable way. With a nationwide professional development programme, ideas, and a steady flow of new pedagogical resources, the "Haus der kleinen Forscher" Foundation supports early childhood educators and primary school teachers in fostering children's spirit of discovery and in accompanying them in their inquiry activities in a qualified way.

The focus here is on (a) joint learning and inquiry on the part of the children and the adults (who act as facilitators of learning) and (b) learning itself. The integration of the Foundation's offerings into the everyday lives of children between the ages of three and ten fosters not only their understanding of science, mathematics, and technology but also the development of their language, learning, personal, social, and fine motor skills. In this way, the Foundation wants to contribute with its offerings to improving the education of children of pre-primary and primary school age and, thus, to fostering the next generation of science, engineering, and technical professionals in Germany.

The development of the professional development programme and the pedagogical resources of the "Haus der kleinen Forscher" Foundation is informed not only by the specifications of the education plans and framework curricula of the German federal states (*Länder*) but also by current research findings in the areas of early childhood education, developmental psychology, learning research, and subject-specific didactics. Moreover, it draws on a wealth of practical experience and substantive suggestions gathered (a) at the seminars for the trainers who deliver our professional development workshops, (b) during regular visits to early childhood education and care centres, after-school centres, and primary schools, and (c) in the context of training observations in the Foundation's local networks.

The Foundation's partners are the Helmholtz Association, the Siemens Stiftung, the Dietmar Hopp Stiftung, the Deutsche Telekom Stiftung, and the Autostadt in Wolfsburg. The Foundation is supported by the German Federal Ministry of Education and Research.

FOREWORD

Dear teachers and educators,

One of the most vivid memories of my days as a primary and lower secondary school teacher is of a group of children who were working on a "tower construction" project. They tried at length and with great perseverance to stack as many wooden slats as possible on top of each other in order to create a particularly high structure. But no matter what approach they tried out, the construction invariably collapsed or toppled over. Then, one of the children remembered the Eiffel Tower, which he had seen during a visit to Paris. He recounted that the struts were mounted "diagonally and crookedly". The group took up this idea and built a latticed structure comprising triangularly arranged modules. The tower grew taller and taller, and it was so stable that it remained upright without further support – a huge success for the young architects!

This example clearly shows just how easy it is to incorporate even technical education into everyday pedagogical practice. It also shows the exciting aspects that are addressed. Hence, when it comes to solving a technical problem, almost all children show wholehearted commitment. As teachers and educators we are often amazed at how high the children's level of frustration tolerance is. They keep on trying until it finally works! Technical projects also foster collaborative endeavour. For, irrespective of whether it is a matter of finding ideas or carrying heavy objects, when you collaborate, you reach your goal more easily. In practice, we find that technology is not always about inventing completely new solutions. Often, it is precisely by returning to tried-and-tested techniques and procedures that we find ideas with which new technical challenges can be successfully met. The really great thing about technical education is that, together with the children, we encounter ideas and occasions for it everywhere in everyday life. That is because our world is shaped by technology through and through.

In this brochure you will find lots of ideas and suggestions for, and exciting background information about, early technical education. We wish you and the children lots of enjoyment with your endeavours and explorations and, of course, every success with your joint technical projects!

Michael Fritz
Chairman of the Executive Board of
the "Haus der kleinen Forscher" Foundation

Working with different age groups

In what follows, you will sometimes encounter this “ladder” symbol. It indicates that the inquiry activity in question presupposes that the children have already had certain basic experiences and/or have developed certain skills (e.g., in the area of perception, cognition, or motor development). As a rule, these experiences and/or skills are not acquired until the children are of primary school age (i.e., between the ages of six and ten). Ideas and inquiry activities that do not bear this symbol are suitable for children of all ages.

ABOUT THIS BROCHURE

With this brochure, the “Haus der kleinen Forscher” Foundation wishes to support teachers and educators at early childhood education and care centres, after-school centres, and primary schools in jointly exploring the exciting field of technology with the children.[1] It is not only a question of developing technical skills and acquiring technical knowledge but also of gaining initial insights into the nature of technology. This brochure marks the starting point of a comprehensive technology offering on the part of the “Haus der kleine Forscher” Foundation, which will be gradually expanded in the coming years.

The thematic focus of this brochure is on forces and effects. Friction, lever force, spring force, gravity, inertia, and centrifugal force: We encounter these forces and their effects in all kinds of situations – not only when we build something or use technical products, but also when we move. From early childhood, we learn through socialisation – that is, simply by imitation – how to deal with, and make use of, these forces. But when we systematically engage with them, for example with the help of the practical ideas provided in this brochure, then we not only gain new insights but also create undreamt-of possibilities for ourselves. The more we practise using these forces and achieving the desired effects, the better able we are to successfully meet minor and major technical challenges and develop really good solutions. This applies equally to young and old and to simple activities, such as opening a stubborn jam jar lid, and more demanding undertakings, like inventing an automated rubbish collection robot.

The brochure begins with an introduction to technology: What are its characteristics? What are the differences and commonalities between technology and the natural sciences? This is followed by an overview of the objectives of technical education and desirable technology-related learning processes in children of pre-primary and primary school age. The chapter concludes with some brief excerpts from the education plans and framework curricula of the German federal states.

The second chapter offers many practical ideas about how technical education can be realised with children. The first section presents four methods from the didactics of technology. The second section is devoted to the problem-based learning approach, which is illustrated using the example of a fantasy story about another planet. The final section focuses on the transmission of force and motion in a chain reaction created by the children themselves.

This chapter is followed by a contribution by Dr Hermann Krekeler, who shows that, with a few drinking straws, some physical effort, and a lot of fun, it is possible to grasp the laws of mechanics. In the final chapter, the main facts about the aforementioned forces and effects are summarised in a clear and concise way so that you can not only look them up quickly if you need them, but you can also find out the one or other new fact.

At the very end of the brochure you will find tips for further reading and some useful links.

1 In what follows, educational institutions that cater for children between the ages of three and six (e.g., kindergartens, *Kinderläden*) are collectively referred to as “early childhood education and care centres”; half- and all-day primary schools, after-school centres, and extracurricular offerings are collectively referred to as “after-school centres and primary schools”; and early childhood educators and primary school teachers are collectively referred to as “teachers and educators”.

TECHNOLOGY AND GENERAL TECHNICAL EDUCATION

What is technology?

This question cannot be answered in just one sentence. The term *technology* refers, first, to all the technical achievements (e.g., devices and machines) developed by man, and second, to their creation and use. Therefore, technology also covers all the knowledge and skills that go into inventing and using these artefacts. Moreover, technology has a great impact on the society in which it is created and used: Depending on the way technology evolves, it changes the way we communicate, work, and spend our leisure time, for example. In other words, technology is very closely intertwined with the economy, with society, politics, and culture. Hence, there are different definitions of technology that stress different things.

The technology offering of the “Haus der kleinen Forscher” Foundation is based on a concept of technology used in general technical education, which can be described in the following definition:

> *“Technology is the purposeful design of the world by man.”*[2]

The central characteristics of technology are as follows:

- Technology is always oriented towards a specific purpose. We act technically in order to fulfil a need or a desire.
- A typical characteristic of technology is that there is not only one conceivable possibility, but rather there are many different possibilities.
- Another characteristic feature of technology is that problem solving often involves the use of objects or devices and the application of technical procedures.

For example, if we want to get warm in cold weather, we can put on warm clothes, wrap ourselves in a blanket, light a fire, turn on the heating, fill a hot water bottle, or go into a building that is well insulated against cold and draughts. So there are lots of ways of satisfying the need for warmth, for example technical products, such as hot water bottles or heating, or technical procedures like lighting a fire or manufacturing clothing.

2 Binder, M. (2014), p. 15

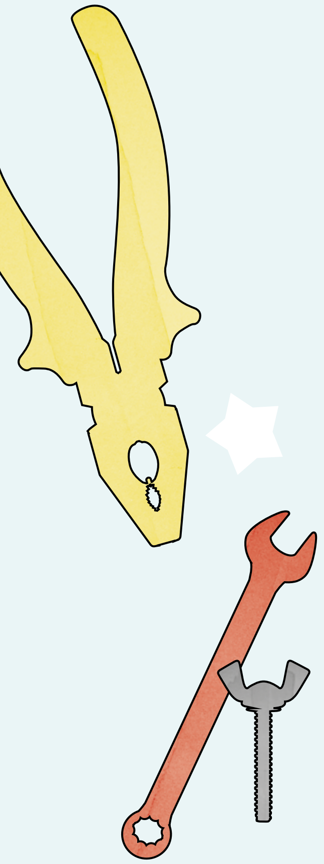
Using forces and achieving effects

In this brochure, we focus on the forces to which we are constantly exposed in our everyday lives. Not only do we experience them physically, they also play an important role in many technical devices and procedures. These forces include:

- friction, without which no knot would hold and no match could be lit;
- lever force, which we use on a seesaw or when hammering nails;
- spring force, which makes mattresses comfortable and the refills in ballpoint pens spring back;
- centrifugal force, which pushes drivers to the outside of the curve when they take a bend;
- inertia, which makes it so hard to push a heavy box of books forward;
- gravity, without which we, and everything around us, would go floating off into space.

Sometimes these forces are a hindrance to us; sometimes they are a help. We constantly take targeted action to offset, reduce, or intensify their effect. To help us open a slippery jam jar, we use a rough towel, but we oil a door hinge so that it does not creak. In the first case, we increase friction, in the second case, we reduce it. We find ourselves a soft, springy cushion because it is more comfortable to sit on than a hard wooden chair, but we would not cushion the handle of a hammer, because it is supposed to be stiff and firm. Many of our dealings with everyday things have to do with these forces, and when we handle them, we act technically: We pursue a specific purpose.

In the seek-and-find picture on pages 12 and 13, the children can discover numerous situations from their everyday lives in which these forces play an important role. Because all these forces are constantly active, and a particular effect is often influenced by several forces, it is not always easy to identify which force deserves special attention in a certain situation. The more the children have found out about forces and effects – for example, with the help of the practical ideas in this brochure and in the accompanying sets of cards – the more forces and effects they will recognise in the seek-and-find picture. Thus, it is worthwhile studying it several times because you are sure to discover something new each time.



Is that not physics rather than technology?

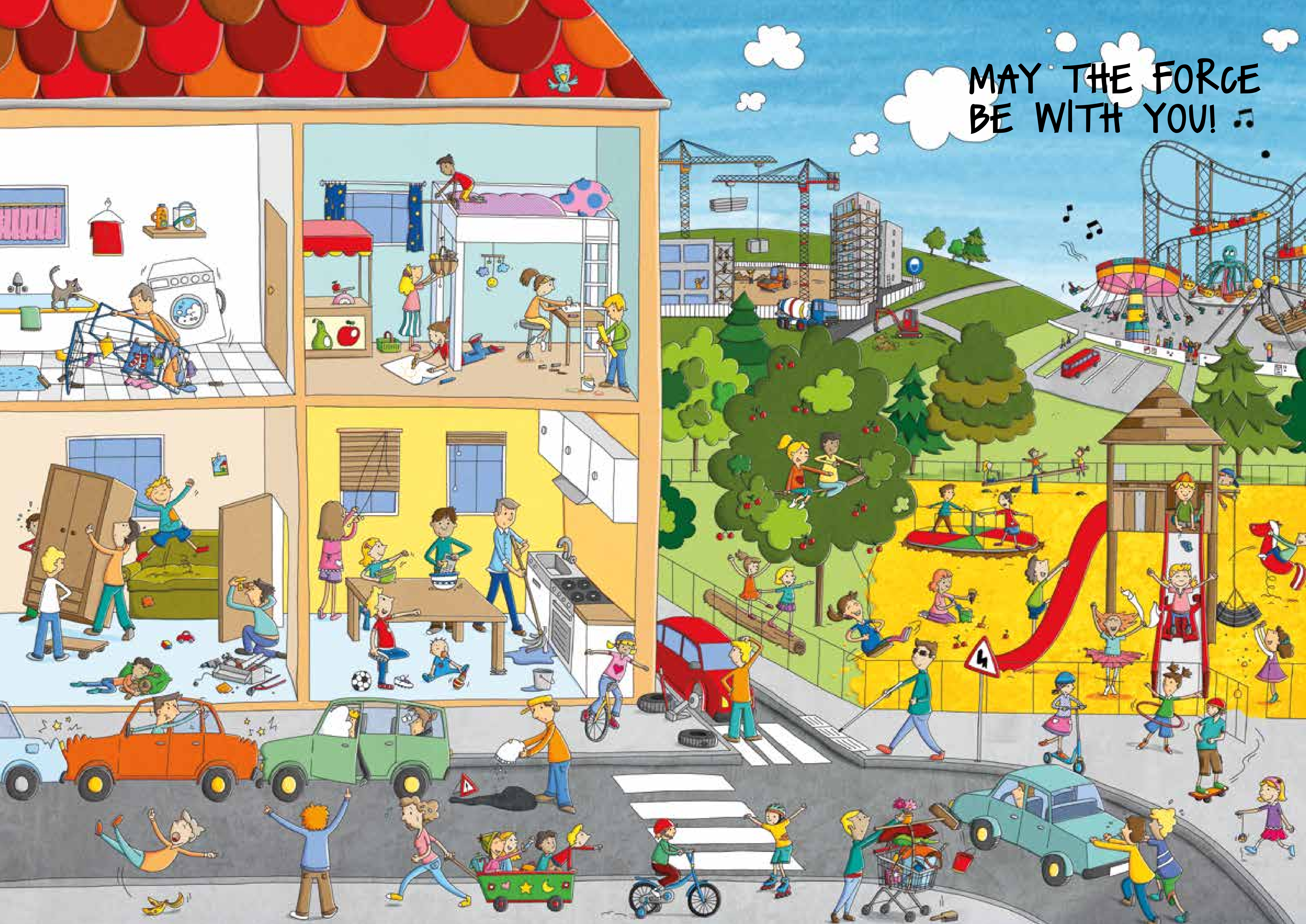
We often associate forces, effects, and mechanical laws with physics rather than technology. In fact, this topic is characterised by a significant degree of overlap between technology and physics. However, there are also major differences that are characteristic of these sciences.
Technology is about finding solutions to concrete problems. In technical education, problem-based learning is of primary importance. Here, forces and effects constitute a set of rules that must be taken into account if our solutions are to be successful. Only by observing these rules do the mechanisms that we devise and the technical actions that we take (e.g., oiling door hinges) have the desired effect. Moreover, there are always several conceivable technical solutions to a particular problem. Whether a specific solution is good or bad depends on how successfully it fulfils the respective purpose.

The aim of technology is to solve problems

The aim of the natural sciences is to gain universally valid insights and to find answers to research questions. In science education, therefore, the focus is on inquiry-based learning. From a natural science perspective, forces and effects are objects of research that are investigated in order to discover laws and interrelations. If you are pursuing a specific question, then you usually look for a single, unequivocal answer – a scientific insight. Whether this answer is true or false depends on how accurately it can explain the (latest) research findings.

The aim of the natural sciences is to gain universally valid insights

For younger children, who are only just beginning to engage with these forces and effects, this sharp distinction between natural sciences and technical sciences is of secondary importance. Hence, it is recommended that the children be allowed to playfully explore the way in which these forces are of relevance to them and the situations, actions, or devices in which they are noticeable. The children are able to discover initial qualitative differences – for example, that a trampoline is springier than a cushion, or that they can slide down a slide faster with a felt mat than with a rubber anti-slip bath mat. Only after they have had such experiences of these forces can they purposefully implement their own ideas.


MAY THE FORCE
BE WITH YOU!

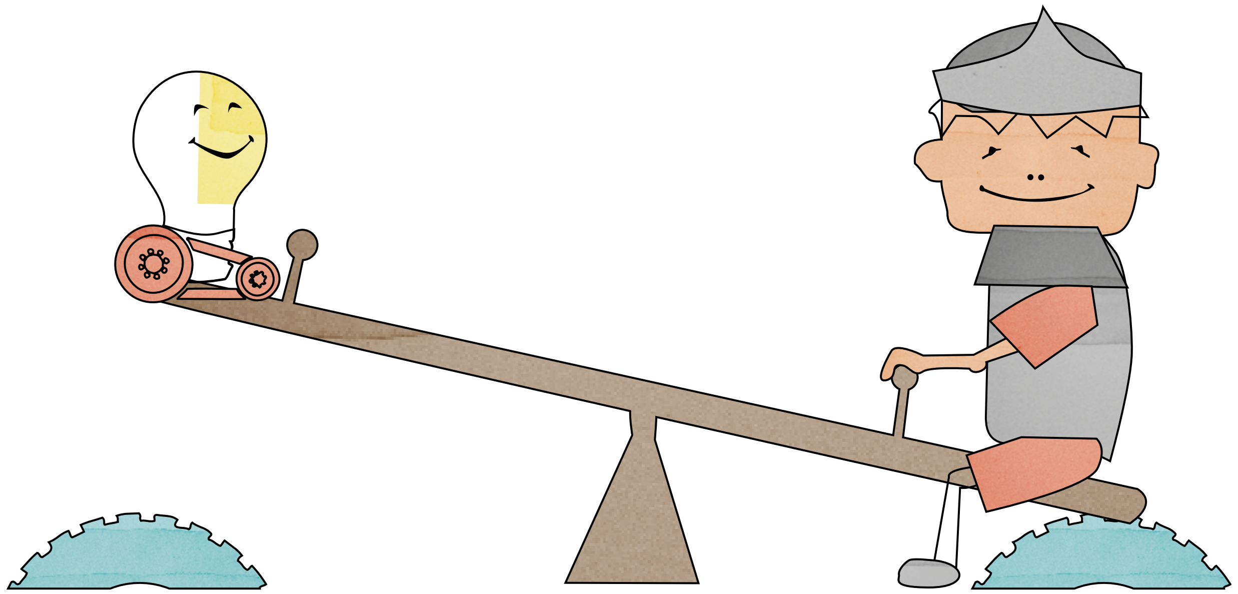
Early technical education

The objective of general technical education is to enable people to use, handle, and assess technology in their everyday lives. Technologically literate citizens should neither be afraid of, nor have uncritical faith in, technology.[3]
The "Haus der kleinen Forscher" Foundation's offering "Technology – Forces and Effects" aims to contribute to this superordinate objective and to help children of pre-primary and primary school age to acquire and develop basic, technology-related knowledge, skills and capabilities. The individual learning processes that are aspired to in this connection can be divided into four categories.

Thinking and action when dealing with technical matters

Technology involves many typical activities and approaches in which the children can try things out and, when doing so, hone their skills in an age-appropriate way. By using the practical ideas provided in this brochure and the accompanying sets of cards, they can plan, develop, and construct their own products and gradually optimise them. They may even be able to produce them in series. Further suggestion s provided relate to the systematic investigation of existing technical solutions to find out how they are operated and used. Moreover, the children practise describing and evaluating technical matters and making informed choices between different solutions.

The younger the children are, the more playful and small-scale their first encounters with these typical technical activities and approaches should be. For example, the investigation and analysis of technical devices can take place simply by trying them out. How do you use it? What is it suitable for? What is it not suitable for? What might have to be taken into account to ensure that it works best? Even simple questions such as these offer lots of opportunities for technical explorations and give rise to further individual and age-appropriate questions.



3 See "Haus der kleinen Forscher" Foundation (Ed.): Wissenschaftliche Untersuchungen zur Arbeit der Stiftung "Haus der kleinen Forscher" (Scientific studies on the work of the "Haus der kleinen Forscher" Foundation), Volume 7. To be published in 2016 (available in German only).

Technical knowledge

The area of "technical knowledge" comprises four components: The children develop a (meta-)understanding of what technology actually is, they learn basic operating principles and technical mechanisms based on these principles, and they acquire knowledge about material properties and about tools and devices.

In the present brochure, the focus is on the first two components: the basic operating principles and an initial understanding of the fact that technology is more than just the devices and machines that surround us.

The children explore the forces that they constantly encounter in their everyday lives – for example, friction, lever force, and inertia. They use them for their own purposes and discover them in the operational mechanisms of everyday devices. Both for younger and older children, their own physical experiences offer a good introduction to the topic: We all feel the effects of these forces on our own bodies. The children experience them especially when they are playing and horsing around, for example on a slide, a seesaw, or a swing, or when they are hopping and running.

Understanding technology includes the insight that a problem has many possible solutions and that whether a solution is more suitable or less suitable depends on the specific situation. The children can discover this, for example, when they compare different products that have the same purpose, or when they develop their own ideas about how to solve a particular problem and test whether and how their approach is effective. The evaluation of whether one solution is better or worse than another is always based on very personal criteria. Even very young children often have a favourite when they are allowed to choose between several products (e.g., scissors) that have the same purpose. A first step towards systematically evaluating and comparing products can be to ask the children to put their preferences and dislikes into words and to describe them in such a way that the other children can understand them.

The (meta-)understanding of technology also includes knowledge about the way in which technology comes about. Technical products do not exist in nature, rather they are man-made. Technical actions are not innate; they are developed and honed, and they can be learned. The children should also explore the typical characteristics and activities of a technical occupation. For example, what tools does a shoemaker need? What kind of work is done in a car repair workshop? What kind of work do waste collectors do? A visit to a handicraft business can be very instructive and can prompt the children to ask further questions about technology.

As a rule, younger children really enjoy imitating in play the activities and characteristics discovered during these excursions – for example, playing builders in the sandpit and not only using shovels and toy excavators but also cordoning their "building site" off with self-made tape, or putting on gloves. This can be an occasion for a joint discussion in the children's group about why such aids are important although they do not directly contribute to the actual building activity. The more experienced the children are, the more inspiration they can gain from such visits for their own technical activities.

Perhaps they will notice how accurately watchmakers divide up their work surfaces: on one half of the workbench, the tools are carefully sorted; on the other half, there is a free, clean space for working. How about doing the same thing in your own project?

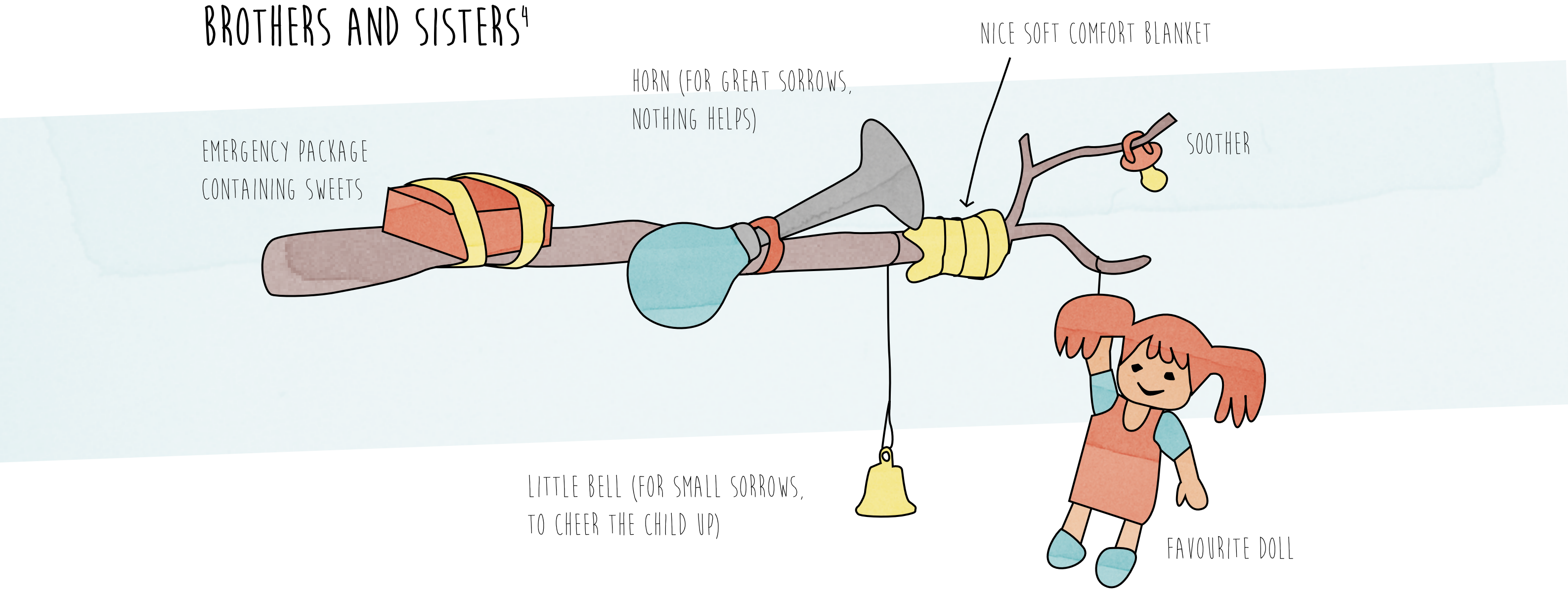
Motivational and emotional aspects of dealing with technology

Most children of pre-primary and primary school age are very open towards technical questions and very motivated to realise their own ideas or produce their own products. This positive attitude is a wonderful prerequisite for the open and objective attitude to technology that technically mature citizens should have. Therefore, one aim of the ideas and methodological information in this brochure is to support learning processes on this level, too. Children should be able to realistically assess what technical challenges they can successfully master themselves. They should be able to make a meaningful choice between the approaches, materials, and tools that they know and that are available to them in order to achieve their (technical) objectives.
Moreover, as they get older, the children should be able to get to know the significance of technical activities and occupations for society. All these skills contribute to ensuring that their interest in technology is shaped by the experience of their own capabilities rather than by social prejudices or stereotypes.

Technical creativity

Technical creations call for creativity on the part of the creator. The emphasis here is not on innate ability but rather (a) on the children's visible and observable (creative) behaviour during the cognitive and work processes and (b) on the solutions that they arrive at. Therefore, not only is the ingenuity of the ultimate solution of importance but also the perseverance displayed by the children while they try out and optimise their solutions or abandon them in favour of other, different solutions until they reach the point where they are satisfied with their results. The aim of the practical ideas and methodological guidelines provided in this brochure is to help you as facilitators of learning to initiate learning processes in which the children develop their technical problem-solving skills further.

MACHINE FOR CONSOLING LITTLE BROTHERS AND SISTERS[4]



4 Inspired by the Patus and Tatus Ghost Banishing Machine; see Toivonen, S. (2010)

Technology in the education plans and framework curricula of the German federal states

In the education plans

Diverse aspects of technical education can be found in the education plans of the early childhood education and care centres. Frequently featured topics include recognising and experiencing the effects of forces and getting to know and learning to use tools and materials. Training fine motor skills and eye-hand coordination, and exploring technology in everyday life are also mentioned in the education plans. A further important aspect of technical education that crops up in almost all the education plans of the German federal states is the way in which the environment and technology influence each other.

Besides technical knowledge, technology-related ways of thinking and acting are also mentioned in the education plans. For example, reference is made to building and constructing, conducting technical experiments, analysing technical devices, developing and testing hypotheses, and observing, comparing, repairing, and producing.

Furthermore, motivational aspects feature in the education plans: The children should experience self-efficacy and the pleasure of succeeding at something, and they should learn that it makes a difference for society when they engage with the technology that surrounds them. Besides their creativity, perseverance, and meticulousness, the children's social competence should be fostered through team work, sharing, and mutual consideration.

In the framework curricula

There is no nationally established technology-related school subject in Germany. Rather the technology-related provisions of the curricula differ greatly from state to state. In Bavaria, Saxony-Anhalt, and Thuringia, the primary school subject *Werken* (handicrafts) covers the core areas of technical education. In most of the other federal states – for example, Berlin, Bremen, Hesse, the Rhineland Palatinate, and Saar State – technical education is delivered mainly in *Sachunterricht* (general studies).[5] In the state of Baden-Wuerttemberg, on the other hand, technical aspects crop up in the composite subject *Mensch, Natur, Kultur* (Man, Nature, Culture). Only in Schleswig-Holstein does the primary school curriculum feature a subject entitled *Technik* (technology). However, it should be mentioned that the school subject *Technik* does exist in some federal states in other school types – for example in Bavaria at *Gymnasium* (a type of school covering lower and upper secondary level that provides in-depth general education aimed at the general higher education entrance qualification) and in Baden-Wuerttemberg as an elective subject at *Realschule* (a type of school at lower secondary level, usually comprising grades 5–10).
The framework curricula for the subject *Werken* include the following keywords:

- Knowledge of technical relations and processes
- Knowledge of material properties and tools
- Familiarisation with materials and production procedures
- Planning, producing, and comparing
- Ability to investigate technical artefacts
- Fine motor skills and capabilities
- Maintenance and care
- Technology in everyday life, building sector, transport sector, supply and disposal, electricity

5 The main focus of this subject is on familiarising pupils with scientific and technical phenomena and with social, economic, and historical aspects of their own locality.

Although there are regional differences in the content of *Sachunterricht*, the *Gesellschaft für die Didaktik des Sachunterrichts* (Society for the Didactics of Sachunterricht; GDSU) has developed a "Perspectives Framework".[6] The technology-related content mentioned in that document includes, for example (a) the study of tools and materials and (b) technical actions such as planning, building, designing, inventing, assembling, dismantling, analysing, design drawing and presentation drawing, experimenting, comparing, and evaluating. This entails, among other things, understanding and explaining technical relations, grasping important inventions and their significance, and putting them into an historical context.

Moreover, technical topics are often taken up in other subjects, such as history, science, German, or religion, where they often serve as a motivator. However, they often remain largely isolated from each other.

Through the eyes of the child – The development of intentionality

When do children start to purposefully pursue a goal, to overcome barriers on the way to that goal, and to develop their own strategies to do so? Two cognitive processes play a particularly important role in intentional action: planning and analogical reasoning (i.e., comparing new problems with known problems). What concepts children have at their disposal, and from what age, is of great importance for analogical reasoning. By concepts we mean ideas about how objects, events, or characteristics can be grouped – for example, all cups can be used for drinking or only living organisms are capable of independent motion.

There is empirical evidence to support the following developmental steps:

- From around the age of three months, babies can establish a link between their own activities and the effects and reactions in their surroundings.
- From around the age of six months, they show a desire for rhythmically repeated motion sequences (what the German psychologist Karl Bühler called *Funktionslust*, i.e., the pleasure taken in exercising a mental or bodily function).[7]
- Around the age of one year, children are capable of making and implementing simple plans. For example, one study showed that twelve-month-old infants were able to make and execute a three-stage plan to get to a toy that was beyond their reach. To do so, they first had to remove a barrier, then pull a cloth towards them to which a piece of string was attached, and then pull on the string to reach a toy that was fastened to it.
- Also around their first birthday, children increasingly start making inferences from known objects to new, unknown objects. When doing so, they orient themselves mainly towards the colour, size, location, or motion of the objects. Frequently, they do not use the object as a whole for comparison, but rather only certain characteristics, for example legs for the category *animals* and wheels for the category *vehicles*. Little by little, they also develop the ability to classify objects on the basis of their function – for example, whether they can be used to produce certain noises – and according to the actions that are associated with them, for example drinking or shaking.
- The so-called basic categories used by children between the ages of one and two are similar but not always identical to those of adults. At this age, children also use the term *ball* for walnuts, pearls, or round piggy banks and candles – in other words, more as a class of "things that can roll". Only from the age of around two are they capable of drawing on less striking characteristics, such as the wick of the candle or the slit in the piggy bank, for categorisation purposes. In other words, they are then able to group objects more according to their function than their external characteristics.
- From the age of three, children increasingly use causal relations for the purpose of concept formation. From the age of around four or five, many children start asking the notorious "why" questions. Understanding why objects are the way they are helps the children to form and retain new classes of concepts. There is evidence that even babies are interested in causal relations and that their knowledge of such relations helps them to form concepts.[8]

An interesting observation with regard to intentional action is that many children are not actually capable of planning their actions and of acting strategically, even in situations in which planning would be advantageous for solving a problem. The fact that they find it hard to plan is probably due to three factors in particular (see Siegler, R. et al., 2008):

- Planning requires the ability to suppress spontaneous actions and the desire to move towards the desired goal without having to make a detour. For the most part, this ability to inhibit develops only from the age of around five.
- Small children are excessively optimistic and frequently overestimate their abilities, for example to memorise things or to imitate a role model. This excessive optimism then leads, for example, to the assumption that they do not need a plan to reach their goal, and causes them to act hastily.
- Plans are not always successful, and even children experience at an early age that they do not reach their goal despite the fact that they had a plan. Irrespective of whether the plan was not well thought out or was inadequately implemented, this insight ensures that planning is not necessarily considered attractive.

However, the more often the children have the opportunity to work with experienced "planners" and, when doing so, to experience that, in most cases, planning makes a significant contribution to success, the more their ability and willingness to plan will grow.

6 For further information, see the GDSU web page "Perspectives Framework" (accessed on 6 March, 2016) http://www.gdsu.de/wb/pages/perspectives-framework.php
7 Regarding both points, see Binder M. (2014).
8 Regarding all four points, see Siegler, R. et al. (2008).

SUGGESTIONS FOR PEDAGOGICAL PRACTICE

This chapter addresses the question of how access to technology can be provided in such a way that it is relevant to the everyday lives of the children. Using a number of different approaches, we begin by presenting suitable content and tasks with which the children can get to know, and practise, typical patterns of technical reasoning and action.

The second section is devoted to problem-based learning (PBL), which involves confronting the children with different kinds of problems and having them develop their own ideas about how these problems might be solved.

The final section of the chapter focuses on the transmission of force and motion in a self-produced chain reaction. This topic offers many possibilities of purposefully employing forces and their effects to achieve a specific result.

Methods of Technical Education

The four methods from the didactics of technology presented in what follows are the analysis task, the technical experiment, the production task, and invention. Each of these methods takes a different approach to technical problems and their possible solutions and is associated with typical questions.

TIP

The methods cards in the set of cards for teachers and educators entitled "Technology – Forces and Effects" illustrate each of these methods in detail using the catapult as a practical example.

The analysis task

Why carry out an analysis?

The aim of an analysis is to closely investigate and understand the functioning of a technical object or a technical process.

The reason for the analysis may be pure curiosity or the desire to understand why this object does exactly what it is supposed to do. Mostly, however, the aim of an analysis is either to answer a more specific question – for example, how the object can be copied or how it can be repaired if it no longer fulfils its purpose – or to decide between different products that fulfil the same purpose but are built differently.

When children conduct an analysis, they learn to understand and describe functions and modes of operation and to identify and name individual components, and they practise developing and testing assumptions about the tasks and the interplay of these components

When conducting an analysis, the children explore very specific and, initially, small-scale questions, which they can answer by trying out and examining the implement, by observing its effect, and, perhaps, by taking it apart. For example:

Children and adults jointly explore how implements work and are used

- What components does the implement consist of?
- How are the components connected with each other?
- Which components are fixed, which are movable?
- What task does each component have? Does it hold something in place? Does it set another component in motion? Does it stop a movement?
- If the component is movable, how does it return to its original position so that the device can then be used again?
- What characteristics of the component are important? For example, is it important that it be stiff or flexible, or round or edged, or that it have grooves or drill holes?
- Could a component be left out without impairing the function of the implement?
- What do you have to do to use the implement? What triggers the initial motion?

When the aim of an analysis is to compare different products that fulfil the same purpose, different questions arise – for example, which components are present in all versions, whether they differ, and what advantages and disadvantages the different designs have. Bicycle bells, for example, usually have a lever which you operate with your thumb. The way in which this lever is attached to the bell, whether it is big or small, whether or not it has a rubber coating, and what it triggers inside the bell may differ greatly.

This is immediately followed by the question of the evaluation: What do the children like about the object? What do they dislike? Which design do they find the most practical, the most attractive, the best? What reasons do they give for their decision?

Analysis of a vegetable peeler

Vegetable peelers have either fixed or movable blades. The blade may be mounted vertically or horizontally. Some peelers simultaneously cut several narrow strips – or even spirals, as a decoration for salads or crudités platters.

Materials:
Have each child bring a vegetable peeler from home.
Also have them bring a piece of fruit or a vegetable.

Off we go: Try out

The children take a look at the various vegetable peelers; they pick them up and try them out. When doing so, they can exchange tips and show each other how they use the peeler.

- How do you hold the peeler?
- What do you have to do? Pull? Push? Turn?
- What happens? What is produced? Long strips? Short shavings?
- Is one peeling process enough? Or do you have to repeat it several times?
- What problems arise? Are the children able to find solutions for them?

Next step: Examine

Now, the peelers are examined more closely. When doing so, the differences and commonalities between the various models are compared.

- Which components are fixed? Which are movable?
- How are the components connected to each other?
- Do all models have similar components? Which components are essential, which ones could you do without?
- Which components produce special effects, for example spirals?

Depending on the children's age and previous experience, you can also offer them the appropriate terms for the components, for example blade, handle, hinge, rivet, screw, and awl (a tool consisting of a wooden handle and a thin, sharp metal point used for making holes in wood or leather). When doing so, it is worthwhile comparing the peelers with a simple vegetable knife. Do the children find it easier to peel, say, a carrot with the knife or the peeler? What exactly is easier and what is more difficult?
What components might be responsible for this?
It is also exciting to explore which type of peeler is suitable for which type of fruits or vegetables. Some peel only hard fruits and vegetables (e.g., potatoes or apples) well, whil they mash soft fruits, such as tomatoes, Why might that be? Is there a peeler that does a better job? If yes, how does the structure of that peeler differ?

Result: This is what we found out!

Organise a little vegetable peeler exhibition. Have the children prepare an overview sheet for each peeler with a list of the components, some tips for use, and details of what they really liked about it or what bothered them. Beside the actual peeler they could place the types of fruits and vegetables that could be peeled well with it. In this way, the parents and the children from the other groups at your institution can benefit from the analysis. Perhaps the purchase of a new vegetable peeler is pending? If so, the children are well prepared to make an informed choice because they now know the particularities and the advantages and disadvantages of the different models.

Further ideas for analyses

There are lots of everyday mechanical implements that are suitable for analysis. You can find them in your pencil case, in the kitchen, or in a toolbox. In many cases, special versions of these implements are available for left-handed and right-handed users. What implements do the children know that are available in a left-handed and a right-handed version? How do these versions differ in terms of their design? How can you feel the differences between the right-handed and left-handed versions when you are using them? When you examine them closely, everyday implements turn out to be surprisingly complex although they appear to be quite simple at first glance. Here are a few examples:

Ballpoint pens with push or a twist mechanism. It is also exciting to analyse multi-colour ballpoint pens, in which a particular coloured refill is selected via the push mechanism.[9]

Drinking bottle closures. Many drinking bottles have very sophisticated closures: Not only can they be unscrewed, they also have a push-pull or twist-to-open drinking spout.

All kinds of pliers. Why are some pliers so big and others tiny? What do the jaws look like: smooth or serrated, straight or curved? And for what are the respective types most suitable? Some pliers return to their initial position after use, others do not. Why is that?

Sharpeners for coloured pencils and lead pencils. There are numerous versions, for example with or without shavings containers, with a rotary handle or even with a motor, and for very thin or very thick pencils.

9 Children of primary-school age can find further ideas for analysing ballpoint pens on the exploration card for primary school students *Kugelschreiber* (Ballpoint Pens).

Nutcrackers. Many nutcrackers use the lever principle. They differ in terms of (a) the way the nut is held, (b) whether nuts of different sizes can be opened, and (c) whether they can accidentally crush your hand. You could compare these types of nutcrackers with nutcrackers in which nuts are crushed by turning a thick screw, for example.

The technical experiment

Why conduct a technical experiment?

In the present context, a technical experiment can serve as a decision-making aid and provide answers that are needed for further steps. For example, if you are looking for a way of stabilising a wobbly tower built of different kinds of cardboard boxes, tin cans, and wooden slats, the question for an experiment could be: “What clear adhesive tape sticks to these materials best?”

The most important thing when conducting a technical experiment is to proceed systematically. Children’s ability to concentrate completely on a single detail of a technical product or procedure develops only as they get older and gain more experience of technical matters.

The more precisely the question is worded, the easier it will be to conduct the experiment and the more unequivocal the results will be. For example, an experiment on the question of “What is the best way to join wood and metal?” will be a lot more complicated and the answers it provides will be a lot more complex if not only adhesive tape but also liquid glue, nails, screws, rubber bands, and string are to be investigated.

Moreover, in order for an experiment to yield the clearest possible results, only one parameter should be changed. In the aforementioned example, only the adhesive tape should be replaced, and not the wooden slats, blocks of polystyrene, or other elements of the tower. If you want to know how these parts contribute to the stability of the tower, then you will have to carry out further experiments in which only the wooden slats or the polystyrene blocks are replaced.

So when they conduct a technical experiment the children practise formulating precise questions, observing things very closely, evaluating their observations, and making informed decisions for their technical projects on this basis.

Technical experiments are also a very suitable way of fostering creativity because ideas for new solutions often arise while engaging with a constituent problem. The approach adopted during a technical experiment is strongly reminiscent of that pursued in the case of experiments in the natural sciences (see Inquiry Cycle Method).[10] Whereas the aim of science experiments is to gain insights into a particular phenomenon, technical experiment are application-oriented.

10 See www.haus-der-kleinen-forscher.de

Technical experiment with a parotiti (“button yo-yo”)

A parotiti (“button yo-yo”) is a simple toy that is very easy to make: You thread a long piece of string or strong thread through a two-hole button and tie the two ends of the string/thread together to make a loop. You hold the loop at both ends, twist it several times, and then alternately pull on each end and allow the string or thread to slacken. The button will begin to rotate quickly, sometimes producing a whirring hum as it does so. (Instead of a button, you can also use a cardboard disk with two holes in the middle.)

Materials:
Stiff cardboard, scissors, nails, awl or hand drill, possibly a hole punch, buttons of different shapes and sizes, thread and string

Off we go: Getting to know the porotiti and its components

Before conducting the technical experiment, make one or several parotiti and familiarise yourself with the way they are set in motion so that you will be able to give the children tips and assistance.

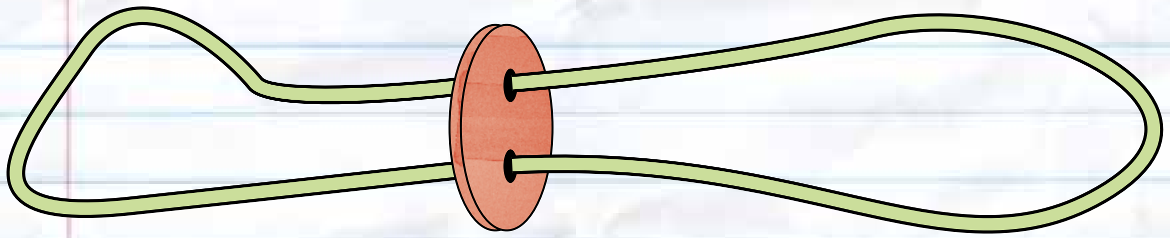
Have the children try out the parotiti and make their own ones. It doesn’t take long when you use buttons. Once the children have found out how to play with the toy, ask them which version works best, in their opinion. What might be the reason for this? Could it be due to the distance between the holes, to the size of the button or the cardboard disc, or to the length of the thread or string? Because all the children naturally want to make a perfect parotiti, the properties that the button/disk and the thread/string loop should ideally have will now be investigated.

A cardboard disc is suitable for this experiment. First, the children concentrate on the distance between the two holes in the disk. All the other parameters – that is, the size of the disk and the characteristics of the thread or string – remain unchanged. Have each child cut out a disk with a diameter of 8 centimetres and make two holes in it. However, the distance between the holes should vary – from very close to each other to very far away from each other. Now have the children thread their string or thread through the holes and carefully test which distance between the holes yields the best results.

Result: The perfect distance between the holes and the next technical experiment

Is there a clear winner among the disks with different distances between the holes? If so, the winning distance is written down and this value is implemented in all subsequent models.

If the children would like to improve their parotiti even further, they can conduct another experiment, this time changing a different parameter. For example, they could investigate whether a larger or smaller disk rotates better; whether the disk rotates faster with elastic cord or sewing elastic; or whether a triangular or a square-shaped piece of cardboard rotates in a more stable way. What is important is that only one variable is changed each time because only then can a technical experiment provide the most unequivocal answer possible to the question regarding the perfect component.



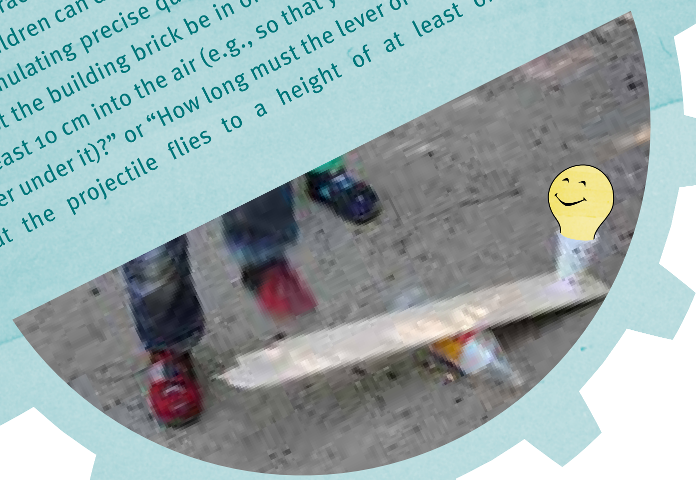
Ideas for further technical experiments

Technical experiments are called for in the context of a technical project whenever a decision must be made between different possible solutions or an answer must be found to a design-related (sub-)question. In the set of cards for teachers and educators and the set of cards for primary school students on the subject of “Technology – Forces and Effects” you will find numerous examples of such experiments. Here is a small selection:

Using the card “Friction – Resistance Permitted,” the children investigate how they can make different objects – for example, shoes or books – with smooth, rough, or structured surfaces slide down a sloping surface better. Instead of making the base of the objects the focus of their experiments, they can also focus on the incline of the slope or the weight of the objects, and they can explore the conditions under which the objects slide best.

On the card entitled “Spring Force – Stretched, Twisted, Twirled,” rubber bands are used to make catapults. The children can carry out technical experiments to determine which type of rubber band is most suitable for making paper projectiles fly farthest. They can also investigate whether there is a particularly good method for holding the rubber bands with their fingers – for example, winding them around their fingers once or several times, or tying them in a clever knot.

The card “Lever Force – Long and Short” presents several practical ideas for simple lever designs. The children can develop lots of experiments on this by formulating precise questions, for example: “How high must the building brick be in order to be able to lift the box at least 10 cm into the air (e.g., so that you can push a furniture roller under it)?” or “How long must the lever of the catapult be so that the projectile flies to a height of at least one metre?”.



On the exploration cards for primary school students, the children will also find ideas for technical experiments – for example, to investigate the conditions under which car passengers are flung farthest when the vehicle comes to an abrupt stop (“*Notbremsung*” [Emergency Braking] card); to explore how the length of the catapult arm and the position and height of the support point (fulcrum) effect the range of the shot (“*Gummibärchen-Katapult*” [Gummy Bear Catapult] card); and to find out how and where they can attach weights to a wobbly clothes peg (“*Wackelkammer*”) so that it remains balanced in a stable way (“*Wackelklammer*” [Wobbly Clothes Peg] card).

The production task

Why carry out a production task?

A production task involves producing a product for which a design already exists. In other words, the children have to be given either a model that they can study in order to understand how the object is constructed or step-by-step instructions that they can follow when carrying out the task.

If the children want to produce their own products, the challenges of the production task lie mainly in planning and implementing the production process. Before they start, the children should have a clear idea of the necessary sub-steps and whether they must be executed in a particular order.

One possible approach to determining the order in which the sub-steps should be executed is to have the children represent each sub-step on a separate sheet of paper – either by means of a sketch, a photo, or a brief description – and to shift the sheets of paper around until they have jointly agreed on the sequence of the sub-steps and have given reasons for their opinions in this regard. Whether the children can independently work out the sub-steps and the order in which they are to be executed, or whether the teacher or educator must give them a lot of support, depends on their age and the complexity of the product to be produced.

Suitable products for a production task include all products that the children are able to construct at their age and with the materials and tools at their disposal. Regardless of whether the product is a simple paper boat, an elaborate wooden bird-feeder house, or a prefabricated self-assembly kit: What matters is that (a) the children have the opportunity to identify the production sub-steps beforehand, (b) they are significantly involved in the planning and organisation of the entire process, and (c) they can judge for themselves on the basis of easily verifiable criteria whether the finished product has turned out "well".

When all the products have been produced, they undergo acceptance testing: Each product is presented, admired, and examined to see whether it satisfies the quality requirements; a little "topping out" ceremony could perhaps be held in honour of the young manufacturers. The production process itself must also be critically assessed in retrospect: What went well? What should have been organised differently? This critical reflection helps the children to plan and organise future production tasks even better.

Producing paper decorations

Pretty decorations with interesting symmetries can be made from paper folds and cuts. The task can be very simple or somewhat more complex and is therefore suitable for all age groups.

Materials: Paper in different formats and colours; scissors; glue and, perhaps, other aids such as a bone folders and staplers; a model, or instructions, e.g., from a book

Off you go: What is to be produced?

First of all, the children familiarise themselves with the product that they are to produce. If you have prepared a model, for example a paper garland, then the children should not only be allowed to take a look at it but also to pick it up, fold it, and examine it closely.

If the children are to follow a set of instructions, have them jointly clarify what these instructions mean. Do they all agree on what the work instructions and symbols mean and what the end product is supposed to be?

Now, further points should be discussed. How many products are the children to produce in total? Should the products have a minimum or maximum height – in order to fit a certain window, for example? Should they have other properties, for example should they be able to stand upright?

Next step: How do we proceed and what do we need?

The production is now prepared and planned: What kind of paper do we need? How much do we need? What do the individual work steps look like in detail? For which work step do we need a scissors? When do we need a bone folder or the glue? Is one pair of scissors enough for everyone, or will work get held up if we have only one pair? How will we divide up the work? Should everyone make a product of their own or should we take a production-line approach? Where should we best place the scissors, bone folders, and glue so that everything runs as smoothly as possible?

The younger the children are, the shorter and more simple this phase should be. Perhaps it suffices to ask whether thick or thin paper is needed. The more previous experience the children have, the more they are able to estimate in advance what is important during the production process and to assume responsibility for large parts of the planning themselves.

Once agreement has been reached on all production-related questions, the children can start to produce their paper products. Does everything go as planned? Do some decisions turn out to be impractical? Was anything important forgotten? Make a note of things like this in order to be able to discuss them afterwards.

Results: Did we do it well?

The finished paper decorations are now presented and admired. The children test whether they turned out as desired – for example, whether they fit well into the window for which they were made.

Depending on the children's age and experience, the production process is also assessed in retrospect. What worked really well? What could be done better next time? Perhaps it would have been helpful, for example, to place a wastepaper basket at each table so that there would be less tidying up to do later? What else bothered or hampered the children during the production process and what solutions do they propose?

At the end, the group room is of course decorated with all the lovely decorations so that all the children can enjoy their successfully produced products.

Ideas for further production tasks

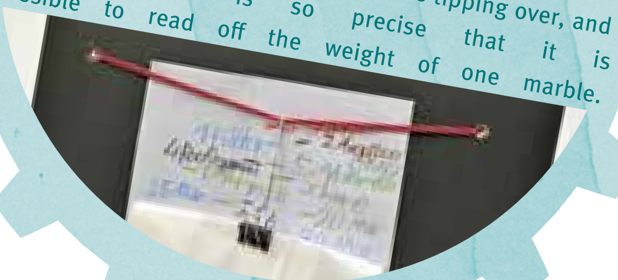
The exploration cards for teachers and educators and the set of cards for primary school students on the subject of “Technology – Forces and Effects” contain lots of ideas that are also suitable for use as production tasks. Here are a few examples :

The card entitled “Spring Force – Stretched, Twisted, and Twirled” features a carousel with a rubber-band motor. The carousel can easily be produced in series. One possible quality criterion could be that the “rotor” rotates the plastic cup at least three times without faltering, and that it can be used three times in a row without having to be readjusted.

Using the card entitled “Gravity – Everything Is in Balance,” the children build mobiles. In what order must they proceed when they hang the individual objects onto the mobile or incorporate the different levels? Here, it is advisable to consider in advance the individual sub-steps of the construction process.

On the discovery card for children "Dreh dich Teller, dreh dich" (Turn, plate, turn), the children will find instructions for making a rotary table with ball bearings. The quality criterion here could be that the plate can rotate at least ten times.

On the exploration card for primary school children entitled “Die beste Waage der Welt” (The best balance in the world) you will find instructions for building a simple balance with a measuring scale. Possible test criteria could be that the weight of between one and ten marbles can be measured without the rubber band breaking or the balance tipping over, and that the scale is so precise that it is possible to read off the weight of one marble.



The construction task

Why invent something or carry out a construction task?

If no technological solution to a particular problem exists, an invention is called for. A so-called construction task is recommended if a completely new invention is to be developed or if existing solutions are to be adapted for another purpose.

A design and construction task fosters, in particular, the children’s general and technical creativity and the application of knowledge and experience to new situations.

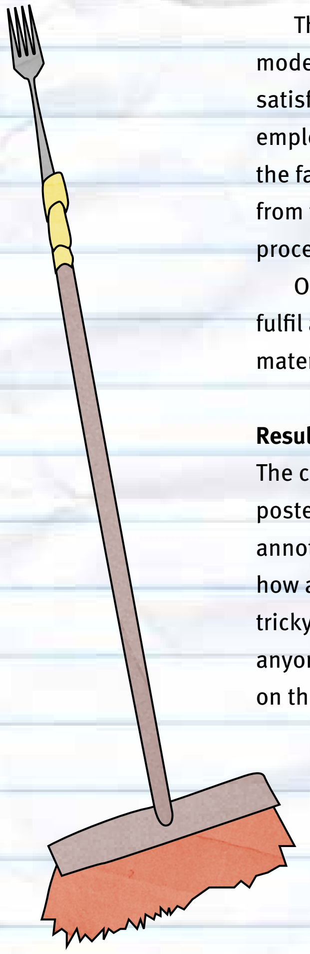
Inventing and constructing are typical technical actions. At the same time, however, it is a real challenge to formulate a construction task in such a way that the children are able to independently develop and implement ideas and, when so doing, achieve success within a reasonable period of time and with reasonable effort. For this reason, components are a very suitable subject of construction tasks. For example, you could give the children the task of constructing an extension for the lever of a tap so that it is easier to use. A construction project in which the children are allowed to use existing solutions can be a good starting point as it can facilitate the children’s progress towards finding their own construction solutions. A detailed example of this is presented on the methods card “Develop your own catapult”.

At the beginning of every construction process, the purpose must be clarified. What object is to be developed and what properties should it have? If, for example, the need consists in crossing a stream, then it makes a big difference whether (a) a few agile children want to cross the stream now and then and they could, if necessary, gladly hop along a row of suitably arranged large stepping-stones, or (b) lots of people regularly want to get to the other side safe and dry – sometimes with walking aids or baggage. In that case, the stepping stones would not be a good solution. Instead, a stable bridge would better fulfil the purpose.

Once the need has been clarified, ideas must be collected: What solutions are conceivable? Can the children implement them with the materials and tools at their disposal? After the brainstorming session, the children build their first models and prototypes. They should be given plenty of time for this because, as a rule, unexpected barriers and difficulties crop up when ideas are implemented. When the models and prototypes are completed, they are presented to the group and, of course, tested. The children check very carefully whether, and how well, their constructions fulfil the requirements. Here, it is also essential to discuss how they arrived at their ideas, where the greatest implementation difficulties lay, and how they solved the problems that occurred.

At the end, the results and the construction process are documented, for example by means of sketches or photos. The documentation should be presented in such a way that even persons who are not involved could understand the main aspects and, in principle, copy the construction.

Materials:
Broom handles; long sticks, rulers or narrow wooden strips; objects that could be suitable for use as grabbers (e.g., a tea strainer with a handle, a soup ladle, a hook, a paper cup; materials to make self-made grabbers and connecting parts (e.g., bendy drinking straws, wire, vegetable nets, jam jar lids, play dough, plastic bags, wooden skewers, matchboxes, rubber band, string, adhesive tape



Constructing a reaching aid ("grabber")

There is sure to be a cupboard, a sofa, or another piece of furniture in your institution under which little objects such as marbles or toy cars disappear and are very hard to retrieve. Have the children construct a reaching aid ("grabber") that is especially suitable for retrieving such hard-to-reach objects.

Off we go: What do we want to achieve?

First, the children clarify what the grabber will be used for and what properties it should therefore have. What is the piece of furniture in question? If, for example, the distance from the floor is very small, the grabber should not be too big. And what objects have to be "caught" most frequently? For round, rolling marbles you naturally need a different grabber than for flat snippets of paper. Discuss with the children the requirements that the grabber should fulfil. The children can, of course, invent several different grabbers for different purposes.

Next step: Collect ideas and build models

Now, the children develop their own ideas. Some children derive inspiration from the materials at their disposal; others perhaps make a small sketch; and many of them simply get started straight away and try things out while their ideas gradually become more concrete. As a rule, a lot of discussion takes place, many assumptions are made and questions asked, and numerous small and large barriers have to be overcome. For example, how can a hook made out of a bendy straw be stabilised so that it can successfully pull a marble? For paper snippets, double-sided adhesive tape at the end of the broom handle may perhaps suffice completely, but what do you do if it is full of fluff after you use it and it is not sticky any more?

The children should be given enough time for this phase. They will probably alter their models a number of times or supplement them with several parts before they are finally satisfied with them. When doing so, new ideas arise and existing plans are discarded or are employed in a different place than originally intended. This process is also very exciting for the facilitator of learning, especially when the finished model looks completely different from the original plan. How did that happen? What experiences during the construction process prompted the children to change their approach?

Once the children are satisfied with their grabbers, they test them thoroughly. Do they fulfil all requirements? What could still be improved or supplemented if more time or material was available?

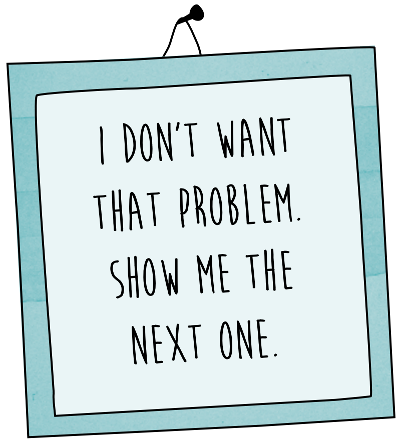
Result: My grabber – This is the way it is made

The children produce a documentation for each grabber – for example, in the form of a poster with sketches or photos, which the young designers can supplement with brief annotations, symbols, arrows, or numbering. What are the components of the grabber and how are they connected to each other? What aspect of the construction is particularly tricky? Should a certain order be observed when assembling the components? Ideally, anyone should be easily able to copy the grabber on the basis of the information provided on this poster.

Further ideas for construction tasks

Inventions can relate either to a narrowly delimited problem, such as a way of opening a rubbish bin although your hands are full, or to a more open-ended desire, for example to have a place of retreat for yourself and your friends. Of course, any other problem that occupies the children's minds can be made the subject of a technical experiment. For example: "What can I invent so that my pet doesn't get bored when it's home alone?" or "How can I prevent myself slipping on the shiny wooden floor all the time?"

Taking as the starting point the need or desire that the children wish to fulfil, ideas are developed and products planned. To fulfil their desire for a place of retreat, the children could design a bolt for the door or develop an alarm system made out of string and little bells. However, it would also be conceivable to construct a tree house where the ladder can be pulled up once you are in it. The following section on problem-based learning contains numerous other ideas from which construction tasks can be derived.

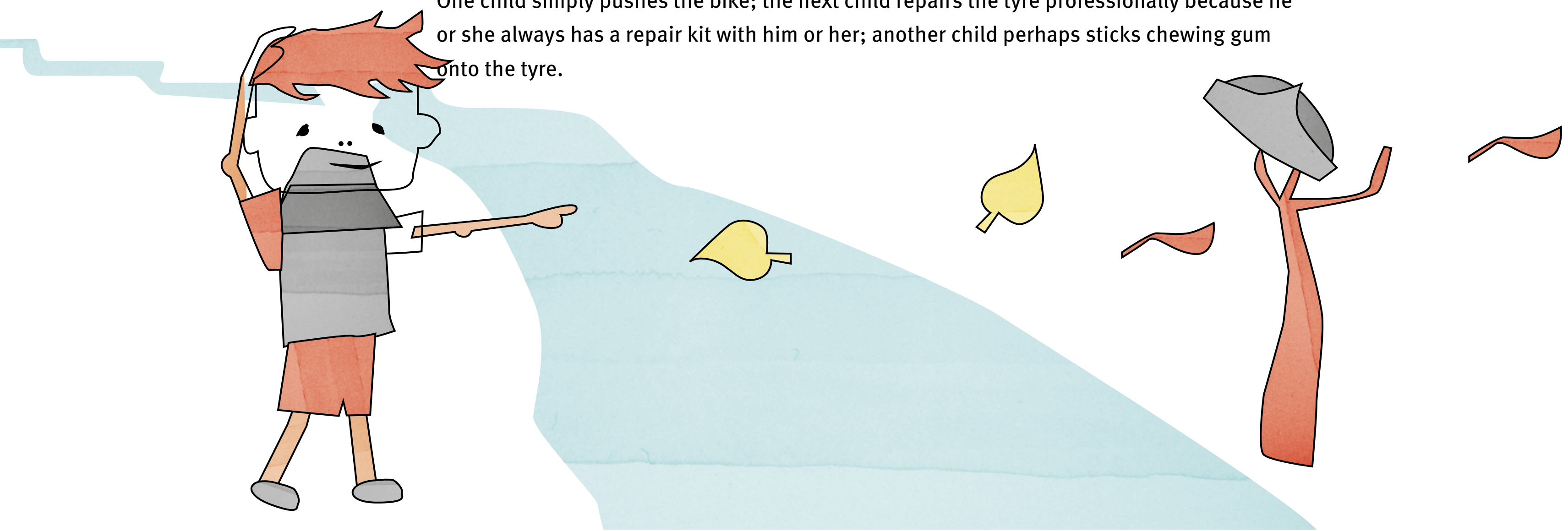


Solving problems

The children will find different things exciting. So how do you best present a problem that all the children will willingly participate in solving? In this section, we present possible ways of introducing the children to problem-based learning and we supplement them with methodological information. The suggestions have been comprehensively tested by the "Haus der kleinen Forscher" Foundation within the framework of the development of *Forscherzeiten*,[11] and they proved very suitable for inspiring children to develop and implement their own ideas.

Problems from the children's life-world

We are constantly faced with problems. And we are constantly solving them – each in our own individual way and with the possibilities we have. Take a flat bicycle tyre, for example: One child simply pushes the bike; the next child repairs the tyre professionally because he or she always has a repair kit with him or her; another child perhaps sticks chewing gum onto the tyre.



Offer a problem you have chosen

A simple and quick way of confronting children with a problem is to present them with one that you have chosen yourself and ask them to solve it. In this case, you should make sure that the children are allowed to decide for themselves what aspect of the problem they want to focus on in particular. For example, if the children are to develop an alarm system for their room, one of them might be especially interested in how they can "prime" it when they are not in the room themselves. Another child may prefer to focus on designing the alarm system in such a way that the intruder does not notice that he has been discovered. So give the children the opportunity to make the general problem into their "own personal problem".

Ask the children to come up with a problem themselves

Another option is to ask the children about possible problems. Many of them will already have ideas that they want to implement; others must first be "sensitised". Are there things that they have always wanted to invent? Something that would be great to have? And what might it look like?

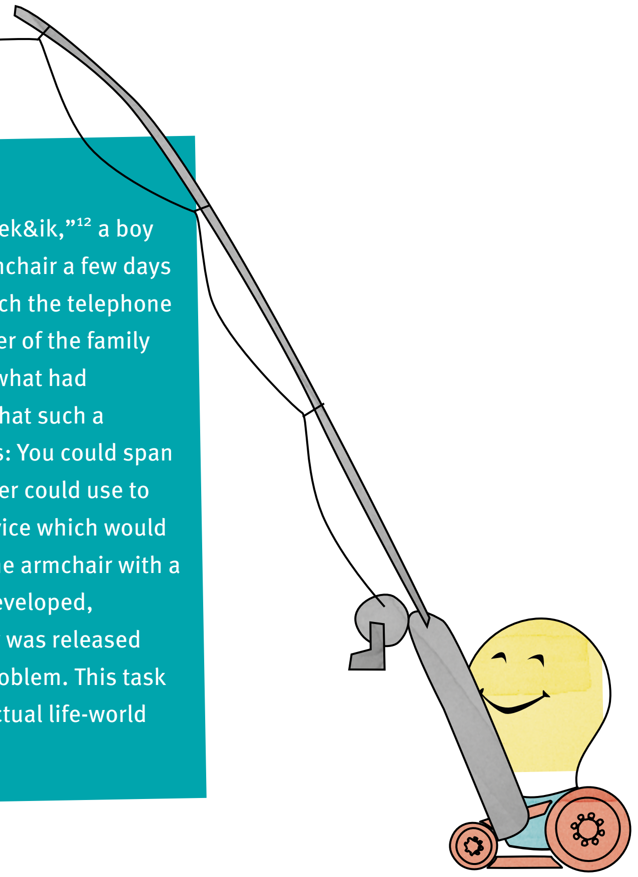
In these deliberations, it's not that important that the inventions can actually be built. Have the children draw their ideas and explain to you the way they work.

11 The so-called *Forscherzeiten* (research times) are an extracurricular offering for children's groups between the ages of six and ten. They aim to awaken the children's interest in research, enhance their self-efficacy, and enable them to recognise their own approach.

Once the inventions have been drawn and their properties have been mentally and discursively formulated, the models can be built.

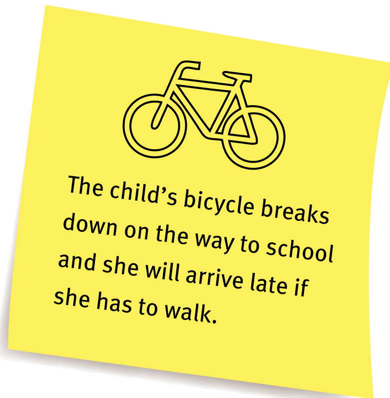
Take up children's current problems

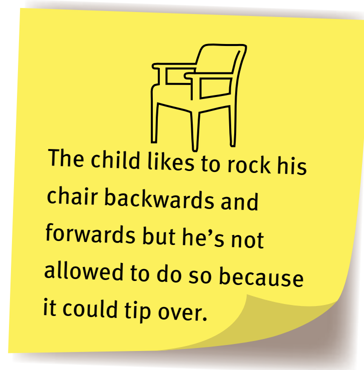
Identifying a current problem from observations of, or joint discussions with, the children, and broaching it, places high demands on the facilitator of learning. However, this kind of problem development is extremely significant because it stems from the children's life-world. The children experience a lot of self-affirmation when they are able to develop and present genuine solutions to real problems.

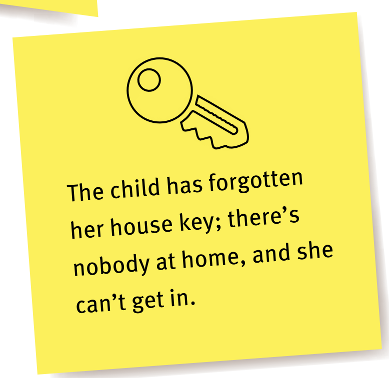


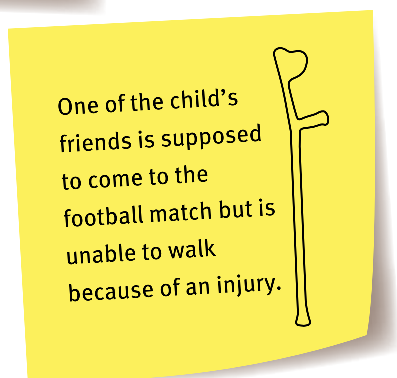
A safety system for Grandma: In the context of the Dutch initiative "Techniek&ik,"[12] a boy recounted that his grandmother, who lived alone, had fallen out of her armchair a few days before. Because she was unable to get to her feet again, she could not reach the telephone to call for help. She lay injured on the floor for several hours until a member of the family coincidentally called by. The boy's fellow classmates were very moved by what had happened to his grandmother. They tried to think of ways of making sure that such a situation never happened again. They came up with a broad range of ideas: You could span a network of cords on the ground and along the wall which the grandmother could use to pull herself up. These cords could also be used to trigger an electronic device which would then send a distress signal to the family. You could also fit both sides of the armchair with a support device so that the grandmother would not fall out. The children developed, planned, discussed, drew, and built models. When the boy's grandmother was released from hospital, the class visited her and presented their solutions to the problem. This task was especially significant for the children because a problem from their actual life-world provided an occasion for a construction task.

Examples of problems from the children's life-world could be:









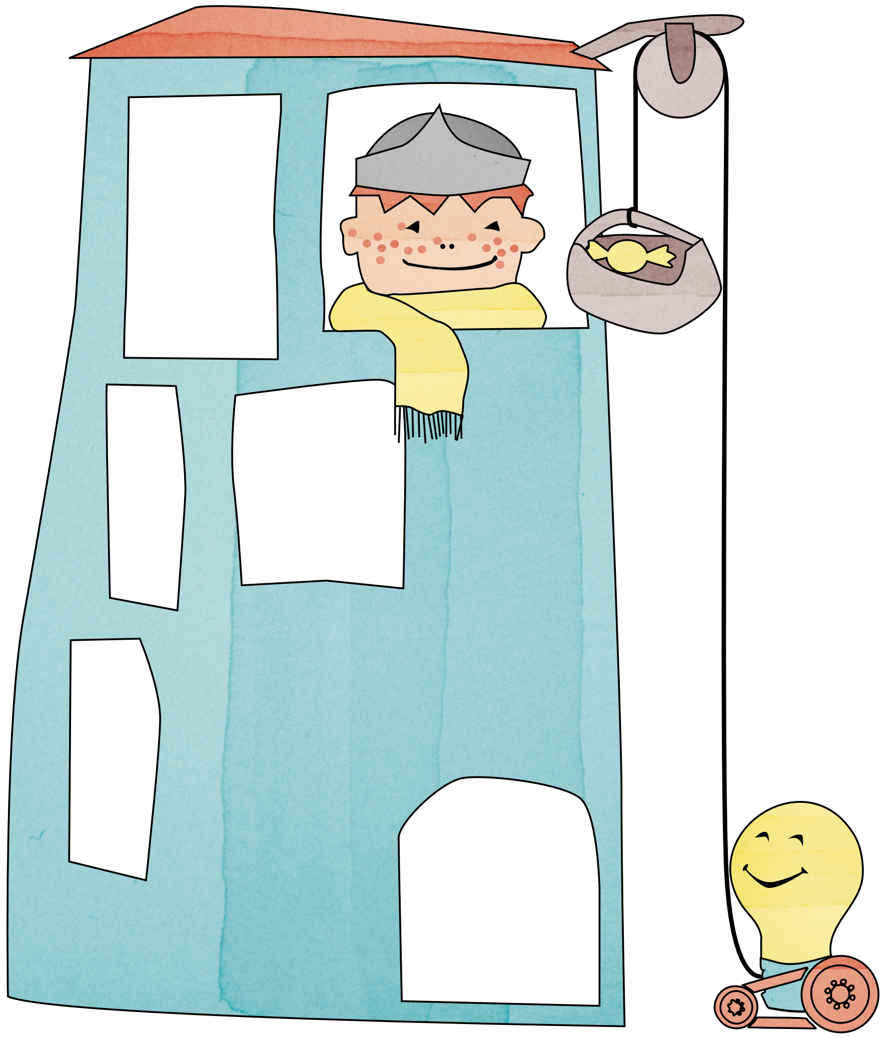
12 See Fontys School for Child Studies and Education – Partner of Techniek&ik, www.techniekenik.nl

Problems from real and fictional situations

Another possibility is to briefly sketch a problem situation, for example by means of a brief description or a cartoon. These problems can be real or fictional. All that matters is that – as in the case of the above-mentioned examples from the children's life-world – they can be grasped quickly without having to take into a account a complex system of prevailing conditions. Developing solutions in this way is both inspirational and a lot of fun because the ideas do not have to prove themselves in the real world.

Suggestions for this kind of problem can be found in the cartoon below and in the following list:

- Two children want to communicate with each other between two houses that are five metres apart. However, they are not able, or not allowed, to use the normal telephone. What can they do? (paper cup telephone, wire rope hoist to exchange messages ...)
- Rapunzel cut her hair off. How can she climb down to the prince or help him to come up to her?
- While the king's daughter is playing with her golden ball, it falls into the well. However, there is no frog around to fetch it for her. How can she get the ball back?
- The well is at the bottom of the hill. The plants are growing on the hill. How can we get the water from the well up the hill?
- A little elephant has to carry a big heavy box into the house. Can you invent something that helps the elephant to transport the box?



Problems from a fantasy story

Besides ideas from the real world, you can tell the children stories that feature problems. This gives them the chance to choose from the many problems addressed in the story the one that interests them most. Just like the story itself, the solutions that the children come up with can be fictional. In this way, it is possible to help learners with little practical experience and (supposedly) few technical skills to overcome their fear that they might not be up to the construction task.

What conditions should a problem story fulfil?

In order for the children to be able to visualise the situation, the story must be very vivid. It should be told in as much detail as possible so that a large number of problems are touched on. Moreover, the problems should encourage tangible, practical action.

The topic of the story may gladly be far removed from the children's everyday reality. In fact, this even has great advantages because, from the children's perspective, there are already technical solutions for all the problems in this world. A story that is replete with completely unrealistic situations offers the children the possibility of linking it to their own experiential life-world and of developing solutions that no longer have to be found on earth. In literature, stories for problem-solving approaches are often set in outer space or children's dream world. In a dream story or a story set in outer space, you can make up situations that do not exist on earth – for example, zero gravity, cosmic rays that prevent the transmission of radio waves, or a vacuum through which sound is not transmitted. Situations that are so dramatic that a solution just has to be found are an exciting challenge. They include, for example, a place where you forget everything after two minutes, or where such loud sounds ring out that you can neither concentrate nor conduct a conversation, or where vital things can be found only under water.

On the next page you will find a fantasy story about other planets, which confronts the children with a multitude of problems.

Fantasy story – Inventors needed!

“Tim, Tim,” Juli cries as she runs towards her friend.
“What’s wrong? You’re all out of breath!” says Tim.
“Yes,” Juli gasps, “I’ve got to tell you something. The space researchers need us!”
“What? I can’t believe that. Why would they need us? And how do they know who we are, anyway?” Tim asks.
Juli sits down and explains everything to him in detail.
“Well, space researchers from all over the world have been searching for a long time for new planets on which humans could live. One professor has just come up with a good idea. He wants to ask children what things they would invent for a new planet.”
Tim looks a big sceptical and says: “But Juli, what would we be able to invent? We don’t know anything!”
“Yes, we do!” Juli exclaims. “The professor says that children have really good ideas. Ones that grown-ups would never think of. And that’s why all children can participate. You and me and all the children in the world.”
“Really?” asks Tim. But then he ponders and says: “Well, space researchers have been trying for years to find planets on which humans can live. Those planets must have oxygen in the air so that we can breathe; there must be water there; and it can’t be too hot or too cold. Everything else is not that important. But we don’t know exactly what such a planet looks like.”
“Yes, exactly,” Julia replies, “But they have an idea of what it might be like there. For example, the force of gravity might be very weak. When you throw things up into the air, they remain there for a really long time. There might be plants that have leaves that look like coil springs – and work like coil springs, too. The planet might consist only of mountains and look like a porcupine ball. And all the mountains are so smooth that you always slip down when you try to climb them. All that might be possible. Nobody knows what such a planet looks like exactly. But because it will definitely be different from here on Earth, every child can simply imagine what it looks like and what things they would invent for the people living there. And when such a planet is discovered one day, then thousands of children will already have given thought to the things that could be invented, to what these inventions might look like, and perhaps even to how they work.”
Tim’s face breaks into a broad smile: “That sounds pretty good. And logical. I think we should work together with all the children who feel like joining in.”
Juli now asks you, too: “So, who’s going to help us?” You can

- think up crazy planets and give them a name,
- invent and construct solutions for problems that exist on that planet. For example, Tim asked Juli:

→ “How can you play ball if the balls always go flying really far away?”
→ “How can I visit my friends if we all live on different mountains?”
→ “How can you get up the mountains if you always slip down?”
→ “What do houses, football fields, or roads look like on a planet that consists only of mountains?”

“We can’t wait to see what you invent. Why not upload pictures of your planets and inventions to our children’s website!”

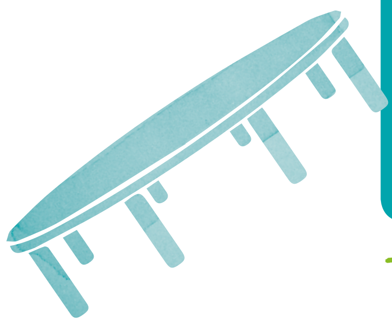
Yours,
Juli and Tim

www.meine-forscherwelt.de/#werkstatt

Presenting the story:
Read the story to the children. What action do they want to take afterwards?

“For my planet I’m going to invent a rocket with a warp drive so that I can fly to my family on Earth within a day. Furthermore, there will be a water-pressing machine with which you can press water and nutrients for a year into one small tablet. That’s important because otherwise you have nothing else to eat on the planet. In addition, there is a water catcher that catches water from other planets, and a stopping place for spaceships. To generate power, I will invent a solar belt that will encircle the planet. Then we will always have solar energy because, like the Earth, the planet rotates around the Sun.”

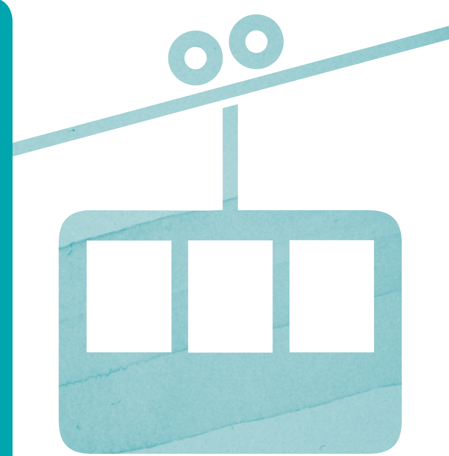
→ Possible construction projects: Rocket, press, solar belt that can rotate, for example as a model



“I thought up a double planet. You get from one to the other through the volcanoes. There are buttons on them. If you press one, you are catapulted to another planet. There, you land on a trampoline – very softly. The clover leaves are full of energy – you can use them as batteries. There are also playgrounds on the planet. What is more, you never have to take a ball with you because there are always some lying in the rivers.”

→ Possible construction projects: Catapults that shoot something away, trigger buttons for catapults, landing trampoline, models of play equipment

“My planet has round houses because they’re modern. The power supply lines are in the clouds because they don’t look so nice. There are buttons that you can press to make the power supply lines descend in order to repair them. There is a school. A railway to school runs from every house. In addition, my planet has a winter side and a summer side. Depending on whether you want winter or summer, you can simply change where you live. There is a railway between the winter and the summer house so that the children can travel on their own. Furthermore, there are hybrid animals in the zoo. But the animals are allowed to roam around freely and they go into the zoo only when they want to. For the refuse, there are robots who scrap it and build new houses out of it.”



→ Possible construction projects: Railways (e.g., cable railway), masts and power supply lines across a large surface area, refuse-handling robots, waste compactor

Tips and suggestions for further handling the children's inventions

1. Discuss the need:
What is the invention capable of?
What "problem" does it solve?

Leander simply wants to build his rocket. He needs it in order to visit his parents. Although it's not possible in reality, he still wants to build a cool rocket – as a model, as it were.

Simon wants to build the landing trampoline. After a long flight, you should have a soft landing and not jump too far away.

Leticia would like to build the connecting railways because she would like to be able to switch quickly between the winter house and the summer house.

2. Specify the need:
What properties should the inventions have?
Are they practical?
Or what would be even more practical?

Leander's rocket is optimally thought out, as is Simon's landing trampoline. They want to start building their models right away.

Leticia's facilitator of learning likes the idea of connecting the houses very much, but she says that she would not find it practical if there were railway lines running everywhere because then the place would be full of them. Without further ado, Leticia relocates her railways into the air.

3. Gather implementation ideas:
How could a model of the invention be built?
What materials do you need?
What does it look like exactly?
Can the children draw their ideas?

Leander discusses with his friend what his rocket should look like,exactly.
What material should the model be made of? What shape must the model be to be able to fly well? To decide how big it should be and what it should look like inside: How many people will be travelling and how long will the journey take? In other words, will sleeping facilities and food for the journey be needed? The boys draw their rockets.

Simon has no idea how to build a trampoline. His facilitator of learning shows him a drawing. He likes it and immediately selects building material from the cupboard.

What should Leticia's railway look like, exactly? How many people should it transport? What does the construction look like and what material should it be made of? Leticia makes a list of all the things she needs.

4. Continue to accompany the children in their construction process:
Depending on the children's perseverance and interest, this phase can last for a very long time and contain several "optimisation loops".
Are the children satisfied with their models?
Can they do everything that they are supposed to do? Why not discuss the challenges at a researchers' meeting.

Leander and his friend each built a paper model of their rockets. Leander's rocket has four seats – one for each family member. The journey lasts one day. The armchairs are very comfortable; he made them out of cotton wool. In reply to a question from the facilitator of learning, he says he does not want to do any more work on this model but rather, first, to let the rockets fly, and second, to build a model rocket out of wood. Only the exterior model, not the seats inside ...

Simon's trampoline is finished. He thinks it's so good that he plays with it for a while. Then he decides that he wants to build a bigger model. He explains this decision to the facilitator of learning by saying that then his little man would not jump so far away. Together they consider how this could be made possible. Simon wants to comparatively test two ideas:
(1) bigger and (2) just as big, but with a loosely stretched balloon.

Letitia has a problem with her wooden cable railway. The stands are always tipping over. At a small meeting with three other children, they jointly consider how the stands could be stabilised...

5. Celebrate an inventors festival:
What things did the children invent? What problems do their inventions solve? And what tips can the children give to others who also want to build something similar?

6. Document the planets and the inventions:
Would the children like to present their planets and inventions on the children's website?[13] That would be fantastic! The children can add notes or use little symbols to indicate what is particularly important in the case of individual components or construction steps. In this way, everyone can understand all the essential aspects of the inventions and perhaps even copy them.

13 www.meine-forscherwelt.de

Chain reaction

A chain reaction is always exciting to observe: Once set in motion, the marble rolls away and knocks over a building brick, which then causes a row of upright dominoes to topple over, one by one; the last domino hits a fork, causing it to shoot upwards, thereby setting a second marble in motion. The motion goes on and on, around the corner, up and down, on rails, with ropes, sometimes hopping, sometimes moving in circles, until finally, with great entertainment value, a balloon bursts, a light is switched on, or paint in a paint pot is splashed onto a sheet of white paper.

It takes a lot of skill and perseverance to build such a chain reaction contraption. Even many grown-ups reach their limits when they attempt this task. However, most children have great fun developing ideas and thinking up chains of effects. Simply standing a row of dominoes upright or connecting two different motion elements is often enough for them.

Where do we find chain reactions?

Children are familiar with the principle of the chain reaction from many other games – for example, marble runs, in which one or more marbles roll down tubes, chutes and slopes, are caught in cups, cause bells to ring, or hop down steps. On the Internet you can find lots of videos of elaborate chain reactions in which liquids, candles, and many unusual components are involved; a number of links are listed on page 62 of this brochure.

However, chain reactions are not only a fun way of passing the time. In fact, many technical devices comprise several individual systems that together form a kind of chain reaction: The forces and movements are transmitted from one element to the next until the desired effect is achieved at the end. For example, a toilet flush comprises a lever in the flushing tank that is moved when you press the button or handle to flush: The lever pulls on a chain inside the cistern to which a stopper is attached, thereby opening the outlet hole and allowing the water in the tank to flow into the toilet, When you release the button/handle the lever in the flushing tank is lowered again, the chain goes down, and the stopper closes the outlet hole once again. Some flushing tanks can be opened and inspected. If possible, have a look inside a flushing tank with the children and jointly investigate which parts move when you press the flush button.

Build your own chain reaction contraption

Build your own chain reaction contraption with the children. Start small, and don't be too ambitious. When you proceed in small steps, the children gradually gain experience and will thus be able to extend their contraption by adding suitable and fully functional parts.

Look at a chain reaction with the children – for example, the image on the following double spread – and try to jointly find out what is happening, for example by asking the following questions:

- Where might the beginning be? And the end?
- What happens when you press/push/pull here?
- What might flow or trickle through the blue funnel at the top?
- What task might the spoons have? And what movement might they make?
- Shall we copy parts of it?
- What ideas do you have yourselves? And what materials will we need to implement them?

What should the endpoint of the chain reaction be?

Jointly gather ideas about what should happen at the endpoint of the chain reaction. Should a light switch be pressed or should a stone fall into a bowl of paint, thereby covering the sheet of paper underneath with colourful splashes? Or should a little bell ring or a balloon burst? Agree on a goal.

Now jointly consider the mechanisms with which you could reach this goal. For example, a toy car could drive down a slope and strike a bell. The children will undoubtedly have lots of ideas. Write them all down because even if the chain reaction has only one endpoint, the other ideas can probably be incorporated at different interim stages.

Have the children gradually attach further elements to the chain reaction contraption. How must the slope be positioned so that the toy car strikes the bell head on? And how could you set the toy car in motion? A good way would be to use a row of dominoes that topple over one by one and finally set the toy car in motion. One thing is very important: Test the contraption again each time a new element has been attached. Does it really work? Can it be repeated?

After every extension, test whether it works

One of the greatest challenges when building such a chain reaction contraption is to tolerate the fact that something always goes wrong. Sometimes the toy car rolls past the bell; sometimes not all the dominoes topple as planned; and sometimes something simply gets stuck or collapses. Time and again, the contraption has to be built up again. Experience shows that a lot of patience and dexterity is needed and not all children have the same level of perseverance. However, these setbacks spur many children on to try again because next time it is sure to work.

Don't give up: Next time it's sure to work!

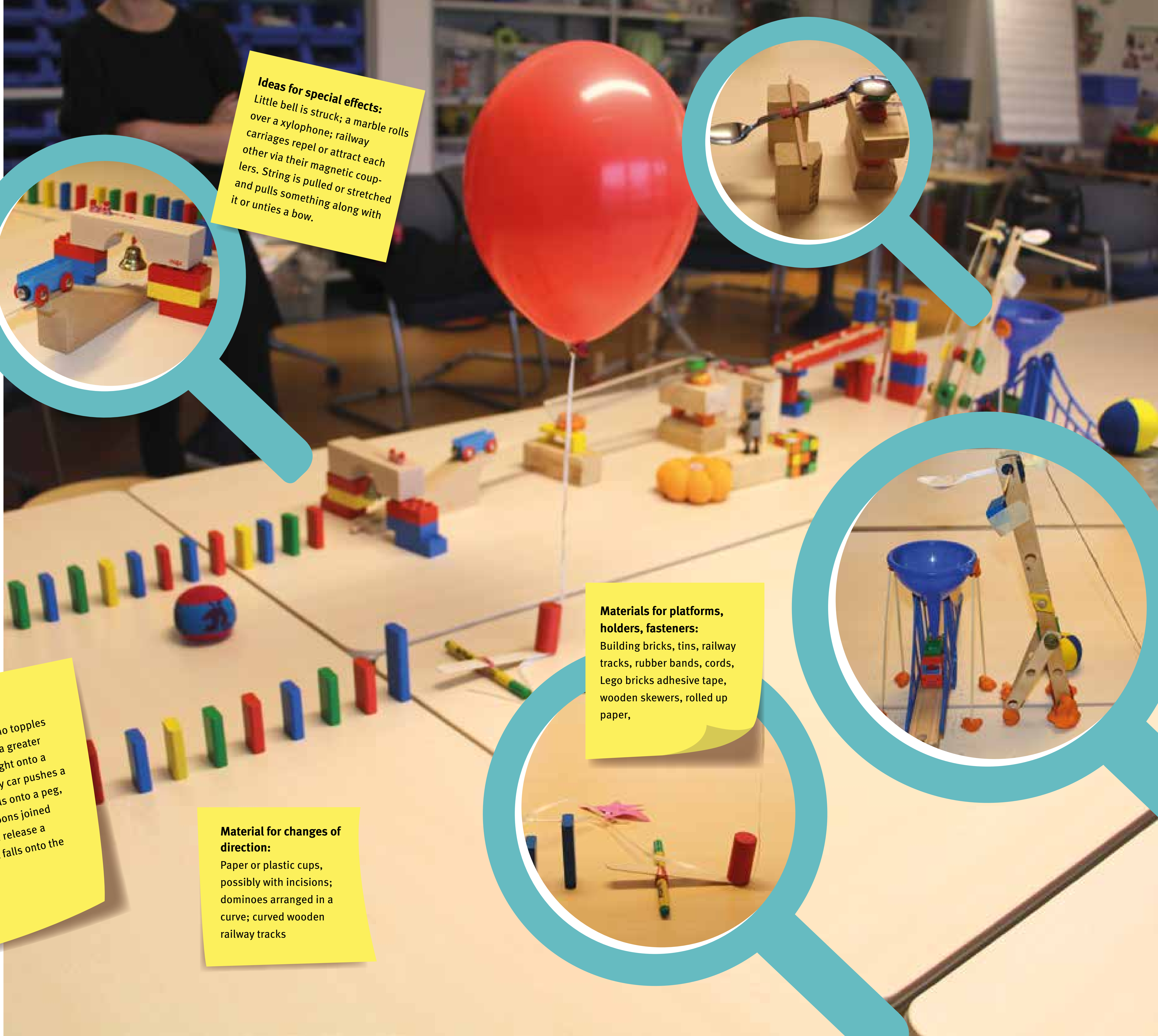
The children can also divide up into groups, each of which works on different aspects of the overall contraption. For example, some of the children can continue working on an idea for the start at another table. When they are finished, they can integrate their part into the chain reaction contraption. Other children can mull over a weak point and try out ways of making it more stable and reliable. Another group can search for building materials, for example, or sketch their ideas. Let the children decide for themselves when their device is finished – even if it consists only of a row of dominoes that fall over one after the other.

Materials to cover large distances:
Marbles, little wooden balls, other balls of different sizes (e.g., tennis balls, footballs), cardboard tubes, washing machine hose, tracks of a marble run, boards, wooden strips or rulers, wooden railway tracks and wooden trains, dominoes

Suggested materials

In principle, you can use almost anything: building bricks, cardboard tubes, play figures, cutlery, office supplies, empty packaging and containers, “rubbish”, etc. What is important is to have elements with which large distances can be covered, changes of direction can be executed, and transitions from one section to the next can be created. Moreover, you need material for platforms, holders, and fasteners. Furthermore, elements that produce special effects or enable a spectacular “finale” are particularly nice.

Ideas for transitions from one element to the next:
Marble pushes domino; small domino topples larger building block, which exerts a greater force as it falls with its heavier weight onto a fork or a spoon; wooden ball or toy car pushes a heavy weight off a platform; it falls onto a peg, which opens as a result; two spoons joined together function as a lever and release a wooden ball when another ball falls onto the oppposite side of the lever.



Ideas for special effects:
Little bell is struck; a marble rolls over a xylophone; railway carriages repel or attract each other via their magnetic couplers. String is pulled or stretched and pulls something along with it or unties a bow.

Materials for platforms, holders, fasteners:
Building bricks, tins, railway tracks, rubber bands, cords, Lego bricks adhesive tape, wooden skewers, rolled up paper,

Material for changes of direction:
Paper or plastic cups, possibly with incisions; dominoes arranged in a curve; curved wooden railway tracks

Tips, tricks, and first aid

The whole thing is wobbly and unsteady; even the slightest movement makes it tip over

You can achieve greater stability when the tables are on a horizontal surface; or build the contraption on the floor in the first place. With regard to the individual components: Create broad supporting surfaces below and build more narrowly above. Moreover, use stable materials (e.g., a paper cup instead of plastic cup; solid wood instead of pliable plastic). Play dough is also very useful: You can use it to prevent things from slipping or to stabilise very wobbly connections between the parts.

The transition works, in principle, but the force of the motion is not sufficient

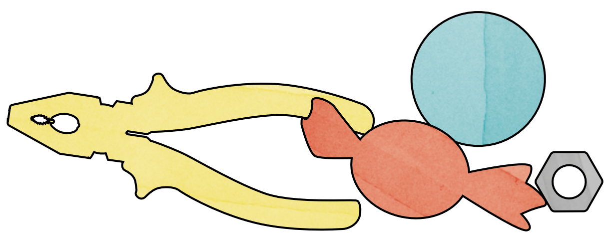
If you make the ball tracks or ramps steeper, the balls or toy cars will move faster. Use a heavier trigger – for example a tennis ball rather than a ping-pong ball or a building brick instead of a domino. In the case of levers, you can a use a longer lever arm or increase the height of the fulcrum in order to achieve a greater effect.

Why doesn't it work?

Just now it worked twice in a row and now it's not working again. Sometimes it's difficult to find out what exactly is causing the problem. With the children, carefully examine the whole apparatus several times. Is something wobbling? Is something disrupting the functioning of the apparatus? You could call an emergency meeting and invite other children and also the parents. Pin a notice on the noticeboard of your institution: "Who would like to come by and take a look at the problem we're having with our chain reaction contraption? Suggestions for solving the problem are welcome!" The chain reaction is a good opportunity to discuss things with other children, or even with adults, and to exchange assumptions and ideas. You can also write to the "Haus der kleinen Forscher" Foundation, for example via the children's website www.meineforscherwelt.de. There you will find a *Treffpunkt* (meeting point) where children can ask questions. We welcome all contributions – not only about chain reactions!

The children are close to giving up

If the construction does not succeed as the children intended, it can be quite frustrating. It is a good idea to exclude as many external disruptive factors as possible. Sometimes the mechanisms can be triggered or disrupted simply because somebody walks by and this causes a gust of air or makes the ground vibrate. Also make sure that the scale of the children's project is not too large. Experience shows that a lot of time is needed to successfully combine even two or three elements. At first, simple combinations are perfectly suitable and, with a bit of practice, quickly ready for use again. They include, for example, rows of falling dominoes that perhaps even turn a corner. Sophisticated effects can best be introduced when the basic construction functions reliably.



What experiences do the children gain in the process?

What happens then?

When they build a chain reaction contraption or observe a chain reaction, the children address cause and effect relationships: "What happens if ...?" The children discover that they must think and plan in advance so that the apparatus functions as desired. How can they achieve the desired effect? What cause produces what effect? These deliberations require a lot of concentration and proactive thinking – which is something that everyone must first learn and practise.

Apply experience and knowledge

f you want to build a chain reaction contraption, you need ideas. What should happen? What should move? May sounds be produced in the process? Should the apparatus look pretty? The more things we have already built and tried out ourselves or copied from others, the more ideas we develop ourselves. It is therefore helpful if the children deal in advance with the way certain forces can be used to achieve certain effects. "With a seesaw, I can can raise one side when the ball falls on the other side." This suggestion could come from a child who has recently dealt with the lever effect. "You have to hang more weight on the other side so that it is balanced". This statement could come from a child who has just dealt with the topic of "balance". If the children have already made discoveries on the subject of forces and effects, then planning and building a chain reaction contraption is a good way of applying these new experiences.

Strengthening fine motor skills and patience

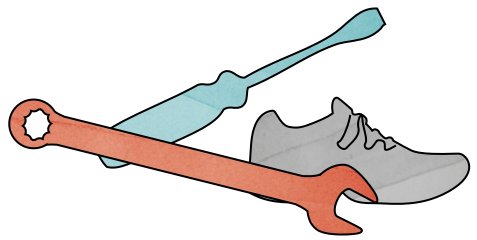
If you want a large chain reaction apparatus to function smoothly, each individual component must be in exactly the right place. For example, if one domino is standing too far to the left, it may not be hit by the one in front of it and the whole motion sequence may be stopped. Or if the marble rolls too fast, it flies off the track and cannot transmit its motion as planned. Therefore, building a chain reaction contraption requires a lot of patience and dexterity. If something goes wrong, it has to be modified – perhaps several times. The children have to find out what components they must incorporate and where, so that their chain reaction proceeds without a hitch

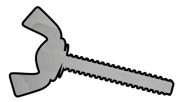
Describe things exactly

When jointly building the chain reaction contraption and observing the chain reaction, the children will discuss a lot among themselves. When doing so, they can extend their vocabulary, for example by learning different verbs of motion: to fall, to topple, to hop, to roll, to slip, to slide, etc. The same applies to the various objects that are used or to the function that they will have in the chain reaction apparatus – for example, ramp, lever, track, guide, etc. And, last but not least, the description of causal relationships calls for very complex sentence constructions, for example: "If the railway engine rolls down the sloping ramp, then it will knock the building brick over, and then all the other bricks will fall over, and the last brick will fall onto the wooden spatula, and the wooden spatual will shoot up and release the balloon, and the balloon will rise up into the air.

"Let's do it together"

Building a chain reaction apparatus is lots of fun, especially when it's a joint project. Who will do what? How will we organise ourselves? How will we reach a consensus when there are different desires and ideas? Here, the children practise making compromises and coming to an arrangement. Tasks can also be distributed according to special skills: Who is good at building particularly stable high structures? Who has good ideas for ball tracks? Who has a steady hand and can stand the dominoes upright? Who has ideas for pretty decoration elements? In this way, all the children can be involved and contribute their individual skills and abilities.





LEARNING WITH A DRINKING STRAW

A contribution by Dr Hermann Krekeler

How to grasp the laws of mechanics

About the author

Dr Hermann Krekeler (born 1951) is a journalist and educationalist. He worked for many years as editor of various journals. He is also the author of non-fiction books, school books, and children's books, and he runs training courses for teachers, educators, and parents.

Dr Krekeler and the "Haus der kleinen Forscher" Foundation have engaged in a continuous and intensive dialogue since 2011, the results of which can be found in exciting contributions to various thematic brochures.

I ask the twelve participants in the technology workshop to balance the drinking straw on one finger. The neon-coloured straws are about 75 centimetres long. On party islands, tourists use them to drink sangria from large plastic buckets. With the twelve early childhood educators on this course, I am going to try out what else these straws are good for. Let's go!

"Balance the drinking straw on one finger"

Most of the participants interpret the request to mean that they should stand the straw vertically on their finger and, with the help of more or less hectic movements of the arm and the body, try to prevent the straw from falling over. It falls over nonetheless – in most cases after just a few seconds. Try again – and make sure you don't bump into each other. Nobody manages more than ten seconds!

Some of the participants do something completely different. Either they understood the request differently or they don't feel like engaging in hectic movement activities. They simply lay the straw horizontally on their index finger, shift it around a bit until it remains straight, and that was that.

Now, I distribute clothes pegs to everyone. Once again, we try out the first variant with the upright drinking straw. "Attach the peg anywhere you like to the drinking straw. Is it easier to balance the straw with the peg attached?" Ten lively minutes later, we take stock: What do the participants say about the peg? The straw is easier to balance:

- when the peg is at the bottom (between one and two participants).
- when the peg is in the middle (between one and two participants).
- when the peg is at the top (between eight and ten participants).

And some of them do not notice any difference at all.

Preconcepts about balancing:

- It is easier to balance the straw when the weight (peg) is at the bottom. This corresponds to the experience that things are more stable when their centre of gravity is as low as possible. Top-heavy things fall over easily. No one would place a Christmas tree on its head.
- It is easier to balance the straw when the weight (peg) is in the middle. This echoes the experience that the middle often has something to do with equilibrium and balance.
- It is easier to balance the straw when the peg is at the top. Only someone who has experience of balancing light and heavy objects and who has tested, for example, how a broom can be successfully balanced – with the brush upwards or downwards – would assume this.

The best thing is to try it out yourself straight away!

The more time you have to try things out, the clearer it becomes that it really is easier when the peg is located near the top of the straw. This experience is completely in line with the strict laws of mechanics with which the movements of bodies – be they as huge as the Earth or as tiny as a grain of sand – are described in physics.

So much for the theory. In practice, however, this is not much help to us because the laws of mechanics are formulated in such an abstract and remote way that we do not immediately recognise them in our balancing experiments with the drinking straws. Conversely, we would not be able to readily express our experiences with the drinking straws in the formula language of physical laws. Luckily, we don't have to.

Nonetheless, the following experiments give us lots of opportunities to explore and use the effects of these laws. The main focus here is on gravity, inertia, friction, and the lever effect.

The omnipotence of gravity

I ask the participants: "What tells you where you have to move your hand to so that the drinking straw does not fall over? No, that is not just your feeling. You observe the direction in which the straw is tilting and you follow it in exactly that direction – until it stands still. And when it changes direction again, you follow it straight away. The tip of the straw is your compass: It acts as your guide. It's not magic; it's not intuition; it's just a little bit of mechanics.

Gravity acts on everything and everyone in the direction of the centre of the Earth

Mechanics? What forces are involved here? The main one is gravity. It acts on everything, and it always does so in the direction of the centre of the Earth. And that is exactly where the drinking straw would head if your finger (or the floor) was not in the way.

As long as the drinking straw is standing vertically on your finger, everything is OK. But what if it tilts to the side, even just slightly? Alarm! Now gravity can take hold again and unbalance everything. If you don't take action immediately, the straw will fall sideways faster and faster. Why? Because the point of application of gravity no longer lies directly above your finger but rather to the side, and the straw can thus fall freely to the floor."

The weighty centre of gravity

The point on which gravity acts is aptly called the "centre of gravity". The centre of gravity of a drinking straw is located exactly in the middle of the straw. To prevent the straw from falling over, we must always support it directly below its centre of gravity. The "compass" at the top of the straw acts as our guide.

The clothes peg compass at the top acts as our guide.

The question remains as to how a clothes peg can be of help to us during all these manoeuvres. At first glance, its weight offers gravity an additional point of application and shifts the centre of gravity upwards a little – towards precarious top-heaviness.

I ask the participants: "What effect do you suspect the peg will have?" Their answers reveal a certain perplexity. It is apparent that they lack certain relevant prior knowledge and experiences. Perhaps we will be wiser after the next two experiments.

The endless moment of shock

The first experiment is called "moment of shock" and, at first glance, it has little to do with our question. But let's wait and see. Conveniently, we can use our drinking straws with pegs attached for this reaction test.

And this is how it goes: Each participant chooses a partner. The first person holds the end of the drinking straw to which the peg is attached above the hand of the second person so that it hangs freely between the thumb and the index finger. Suddenly, the first person lets the straw go. The second person has to react quickly to catch the straw as soon as possible. By drawing a scale (numbered marks three centimetres apart) on the straw beforehand, the reaction times can be better compared with each other.

"Oops!" Almost all participants have the same problem: On the first try they have the feeling that they were not paying attention. But on their second and third tries, their reaction times do not improve. In fact, they are astonishingly long: By the time the hand reacts to what the eye perceives, between one-tenth and three-tenths of a second have passed.

Oops, I mustn't have been paying attention!

By the way: Our sense of touch is significantly quicker than our eyes: We attach a strip of paper to the peg and repeat the experiment. This time we close our eyes and rely completely on our sense of touch. As soon as we feel the paper strip on our thumb and index finger, we grasp the straw.

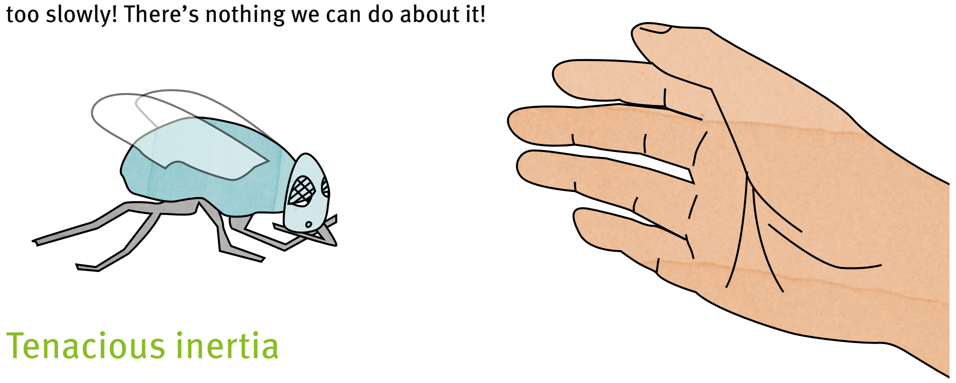
Long or short?

Beforehand, I ask a question: "What is easier to balance (without a clothes peg), a normal, short drinking straw or one of our long Sangria-type straws?" Before we try it out, I have the participants express their assumptions. About half of them are convinced that a short straw – or a pencil – is easier to balance. This assumption is probably based on the experience that small, light things are easier to handle than big, heavy ones. That is often correct – but not in this case.

We react too slowly

I can safely offer a prize of ten euros to the person who manages to balance the straw for longer than five seconds. All participants are soon convinced that that is quite hopeless, even when we apply what we have just learnt and try always to support the straw directly below the centre of gravity. The next thing we know, it's lying on the table. We simply react too slowly! There's nothing we can do about it!

By the way: The reaction time of a fly is ten times shorter than that of a human. It sees the straw toppling in slow motion, as it were, and could calmly take corrective measures. That is why it is so difficult to hit a fly with your hand.



Tenacious inertia

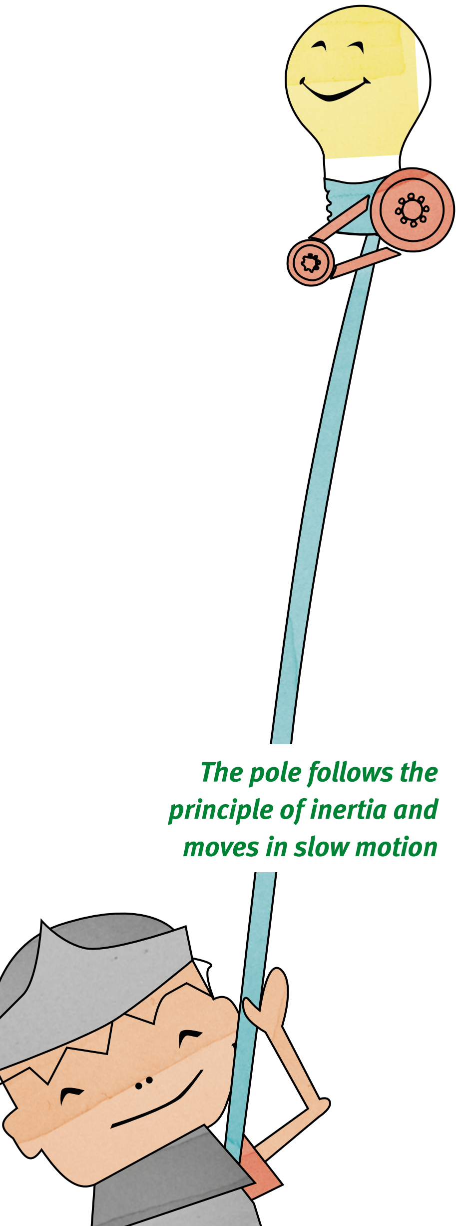
We cannot influence our reaction time. But, in contrast to the fly, we can get help from a clothes peg – and from inertia.

Inertia and gravity are similarly universal phenomena. Exceptionally, the term **inertia** has a very similar meaning in physics as it does in everyday parlance. **Inertia** refers to the tendency of physical bodies to maintain their current state of motion.

I want to stay just the way I am

A body at rest tends to remain at rest, a body in motion tends to continue moving at the same speed and in the same direction. The greater the mass of a body, the more force must be used to overcome its inertia. A bowling ball is harder to shift than a ping-pong ball, and it is also harder to stop once it is in motion.

That was a lot of physics, and, indeed, many centuries elapsed between antiquity and Newton's clear formulation of these laws. What elements of these laws are of importance for our balancing tricks?



Thought experiment

But first, yet another experiment. However, we won't conduct it physically but rather mentally: We are in the Chinese National Circus and we are watching two acrobats. The stronger of the two is balancing a five metre long pole on his shoulder. The lighter acrobat climbs nimbly up the pole and performs his gymnastic feats at the top.

"I bet that you could do that, too," I say. "I don't mean the acrobatic tricks at the top, but you could balance the pole at the bottom – provided you had the necessary physical build. For you now know what has to be done: As soon as the pole tilts sideways a little, you move a little in that direction, and so on. You see, it's quite easy. And if you take a close look, you will see why this is so easy: The pole moves very slowly, as if in slow motion, and not as hectically as our short drinking straw. You have all the time in the world to follow it.

The pole follows the principle of inertia and moves in slow motion

For it obediently follows the principle of inertia, which states: The larger the mass of a body is, the greater its inertia, the more ponderously it moves. Moreover, the length of the pole has the advantage that the movements at the top are much larger and easier for us to recognise than would be the case with a short pole with the same weight."

Mystery solved

Now we have gathered all the knowledge we need to understand what the clothes peg at the top of the drinking straw is all about:

- Gravity causes the straw to topple as soon as it is no longer supported directly below its centre of gravity.
- The inertia of the weight at the top. and the length of the drinking straw slow its movements down.
- Hence, despite our relatively long reaction time, we can act soon enough and prevent the straw from falling over.

The horizontal drinking straw

Let's go back to the beginning, to the "dissidents" who did not even join in the adventurous attempt to vertically balance a drinking straw. Instead, they laid the straw horizontally on their index finger and after a bit of balancing they relaxedly observed their colleagues' hectic actions.

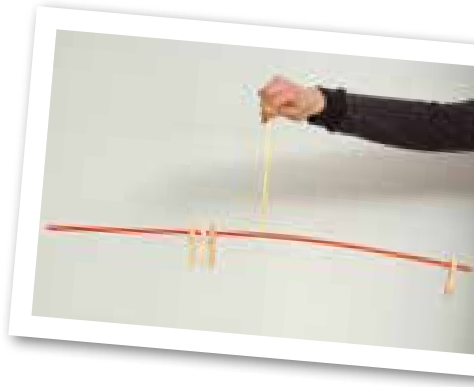
What exactly did these dissidents do? Basically, the same things as the others did: They supported the straw with their finger directly below its centre of gravity. The only difference was that, in their case, the centre of gravity was not thrashing around at a dizzy height (37.5 cm) but remained in one place just (3 mm) above the finger. That's no great feat!

And now do it with your eyes closed

"How did you find this fabulous point?" I ask the whole group. "That's not difficult, you look to see where the middle is, then you shift the straw a bit until it stops moving." "Can you also do that with your eyes closed?" I ask. That takes a little bit longer but it does not pose a problem: As soon as you see, or sense, that the straw is inclining to one side, you have to shift your finger in that direction. Quite similar to the way you do it in the case of the vertical straw. But more leisurely.

A drinking straw as a balance beam scale

We make a note of the centre of gravity of the drinking straw and suspend it at exactly that point with a piece of string or thread. Now we have something like a balance, or, to use the correct term, a balance beam scale. If the beam – that is, the drinking straw – is hanging exactly horizontally, this indicates that the same weight force is acting on both sides (this is the way it is put in technical language).



If we now attach a clothes peg to one side, that arm tilts to one side. In order to bring the straw into balance again, we have to attach a clothes peg to the other side as well. Nobody finds this surprising.

By contrast, however, it is not as self-evident for many people – children and adults – that it is by no means immaterial where we attach the second clothes peg to the free arm. We immediately notice that the more we move towards the middle, the more the other arm rises again.

Next task: "We attach a peg to the end of one arm of the scale. Can you attach two pegs to the other arm in such a way that the scale is in balance once again? Where must the pegs be placed to achieve this?" This is a trick question because there are countless possible solutions that have, however, one thing in common: The further from the suspension point the first peg is attached, the closer to the suspension point the second peg must be.

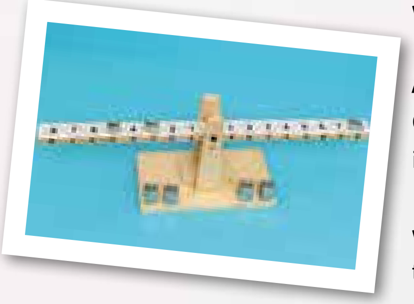
Where must the weights be placed?

Here, the law of the lever applies, to which, by the way, we owe the seesaw phenomenon: A light-weight child can let his heavy-weight friend starve in the air if he just moves out far enough on his side of the seesaw.

Using a balance beam scale as a calculator

I ask myself why this versatile device cannot be found in every primary school class. Many teachers have never even seen one before. They are amazed and incredulous when I demonstrate it to them and allow them to try it out.

It's called a *Rechenwaage* (balance beam scale calculator) and it deserves the name, at least as far as addition and multiplication is concerned. The numbers from 1 to 8 are inscribed on both arms of the beam scale. In addition, we need around 30 identical washers.



And this is how we do the maths:

On one arm of the scale we place one washer each on positions 3 and 4. The scale settles itself into equilibrium when we place a washer on position 7 on the other arm.

In the case of the calculation task: 2 x 3 + 4 (left arm: two washers on position 3 and one washer on position 4) we could bring the scale back into balance, for example by placing two washers on position 5 on the right arm.

The scale is a wonderful application of the law of the lever, which has been known since ancient times. In its simplest form, it is often formulated as follows: Weight x weight arm = force x force arm. The terms originate in a common technical application in which a (heavy) weight is moved with the help of a (long) lever. In our case, these terms do not play a role, but the statement, which we now formulate colloquially as follows, does: Equilibrium exists when the product of the distance from the pivot point (fulcrum) and the weight is the same on both sides. For example: On one side, a 2 kg weight is situated 30 centimetres away from the pivot point (2 x 30). Hence, a weight of only 1 kg situated 60 centimetres away from the pivot point on the other side could bring the scale back into balance.

I cannot think of a better illustration and application of the law of the lever as a calculation aid!

Magic or mechanics?

"Because you all shifted your straws so patiently, I will now show you an amazing experiment with which you can astonish children and grown-ups alike. The children, in turn, will use it to impress their parents.

Somehow we control it. Or don't we?

Let's go: Lay a straw (or a long pole, e.g., a broom handle) on top of your outstretched index fingers and slowly push them towards each other. I bet your fingers will meet exactly in the middle (at the centre of gravity, as we now expertly call it). Repeat the experiment a few times to exclude the possibility that this was a mere coincidence. Although your fingers slide a bit differently every time, and almost never simultaneously, the result is always the same.

"How can this be explained?" I ask. Almost all the initial assumptions come nowhere near solving the mystery and can be summed up as follow: " Somehow we intuitively control the way we have to move our hands." Let's see if there's some truth in that. "Close your eyes before the next experiment, then we can test whether the sense of sight is involved."

It isn't. It works just as well when one's eyes are closed. "Then it must be the sense of touch." Before we test this, I'll quickly show you a funny test to carry out in pairs: The partners stand beside each other. One uses her right index finger, the other uses her left index finger, and we repeat the experiment. It works, too! Only slowly does it dawn on the participants that it has nothing to do with our perception or our control.

However, many of the participants still doubt whether the whole thing works without any possibility of control on our part. So we lay the drinking straw across the backrests of two chairs and push the chairs towards each other. It looks almost spooky when we move only one chair and leave the other in its place. Unbelievable: At the end, the straw is balancing on the narrow point where the two backrests touch.

Friction is always present

It is now high time to get to the bottom of this! The amazing thing is that, from our everyday lives, we are very familiar with all the forces and phenomena that interact here. And yet we do not succeed in putting the puzzle together straight away. So let's get going.

The heavier the object, the greater the friction

- We have all experienced that it is harder to push or pull a heavy case across the floor than a light one. This is due to the friction forces acting between the bottom of the case and the ground. The heavier the case is, the greater is the resistance that we have to overcome. (Moreover, the smoothness of the floor and of the bottom of the case also plays a role.)
- It is this direct relationship between weight force and friction forces that makes us into conjurers in our drinking straw experiments.
- If you watch closely, you will see that the straw always rests alternately on one finger while the other finger can slide under the straw towards the middle. Before the two fingers meet in the middle, they swap roles several times.

The fingers alternately swap roles

- The adhesive friction is obviously greater at the point where the straw is resting at the beginning. However, this changes when the weight above the sliding finger increases as it slides towards the middle. However – as in the case of our piece of luggage – as the weight increases, so too does the sliding friction that the finger must overcome.
- On the other hand: The more weight the one finger has to carry, the lighter the weight above the other finger becomes. That means that the friction decreases there and the finger can slide. The finger on the other side remains immobile while the other finger is sliding.
- Now the game is repeated on the "light" side until the weight and the friction become so great again that the whole thing is reversed. And so on, back and forth until we reach the happy end.

Admittedly, this is not very easy to understand, especially if you are not familiar with the way forces act. And, of course, this is true, in particular, of children. Nonetheless, it is an interesting and worthwhile experience. It can be followed up with many further experiments that are suitable for providing children with a solid wealth of experience on the subject of "forces and effects".

And last, but not least

From our everyday lives, we are actually very familiar with the way mechanical forces work. We use them as a matter of course, not least because they accompany us everywhere we go. Every door handle, every nutcracker makes use of the law of the lever; every salad spinner makes use of centrifugal force. But we rarely go to the trouble of systematically investigating them. Considered individually, the experiments with the drinking straws do not constitute proof, nor do they lead to the discovery of the laws of mechanics. However, each experiment increases children's and adults' wealth of experience and can help them to explore these complicated laws with their own senses.

Can Fish Drown?

How our everyday experience hinders our understanding of formal laws of nature

For the book *Kinder antworten auf Kinderfragen* (Children Answer Children's Questions), one of the questions I asked pre-primary children was “Can fish drown?” One of the nicest answers I got was:
“No, they can’t drown, because they rest at the bottom of the sea when they can’t swim (*schwimmen*) any more.” (In German *schwimmen* can mean “to swim” or “to float”). This explanation is not only amusing, it also highlights very basic problems when teaching science topics. In what follows, I address some of these problems:

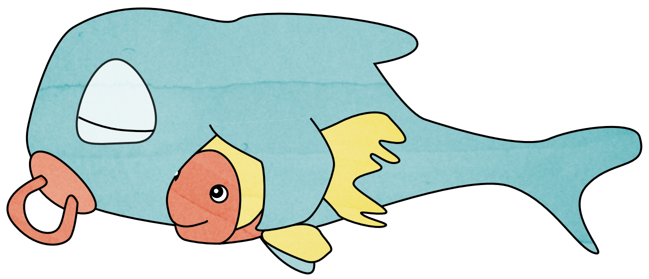
- Colloquial terms and expressions (e.g., *acceleration*) often have a completely different meaning in the terminology of physics.
- For children, the reference point when interpreting phenomena is their physical environment – often their own body with its lively qualities (e.g., *swimming*).
- Laws of nature apply, as a rule, only under ideal conditions that are rarely found in practice. There, disruptive conditions prevail that render it difficult to derive laws from the phenomena observed. For example, the law of falling bodies applies only in a vacuum.

For a German-speaking child, *schwimmen* means something different than for a scientist. For scientists, *schwimmen* means floating, that is, the buoyancy-dependent behaviour of an inanimate body in a liquid. By contrast, a child associates with *schwimmen* swimming, that is, the activity of a living being which involves effort on its part. In the child’s answer quoted above, you can hear the worried mother “Don’t swim out too far, otherwise you’ll get tired, and then you may drown because you no longer have the strength to swim back to shore.”

In mechanics, especially, the overlap with everyday terms may bring more confusion than clarity. When the term *body* is used in mechanics, it refers only in exceptional cases to something of flesh and blood but rather to a inanimate thing of any shape or form.

What is particularly confusing in mechanics is the term *acceleration*. Colloquially, we equate it to *getting faster*. It is difficult to grasp that in the sciences the term also refers to braking and to the change of direction of a body moving at constant speed.

A further example is *pressure*. Here, too, scientists associate it with something different than laypeople do. If pressure is exerted somewhere, then, in everyday parlance, it is, for example, pressure on a doorbell – a directed force. In scientific terminology, it is incorrect (albeit customary) to say that the pressure acts in a certain direction. It is more accurate to describe the pressure as “acting on all sides”. *Pressure* describes the state of a system.



We intuitively measure whether something is heavy or light on the basis of our physical strength. And we relate fast or slow to the speed at which we can move. All this is not surprising because the only way small children can “appropriate” the world is via their bodies and their senses. The sciences, on the other hand, span very different horizons. They operate in the microcosm of elementary particles just as dispassionately as in the macrocosm of the stars. No direct route leads from the sensory movement experiences of a baby to understanding abstract laws of nature. On the contrary, our everyday experience often even hinders our ability to understand laws of nature. “The greatest truths often, and indeed almost always, contradict the senses. The movement of the Earth around the Sun – what can, by all appearances, be more absurd? And yet it is the greatest, noblest, most momentous discovery ever made by Man – in my eyes more important than the whole Bible.” Thus spoke Goethe.

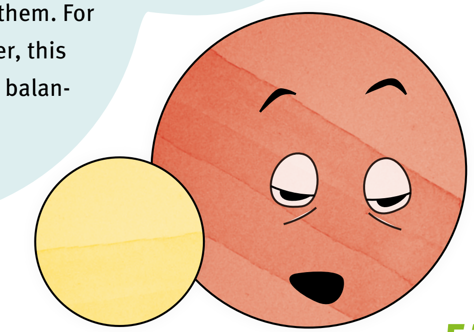
The tired cannonball

Since ancient times, scholars have pondered how the movements of bodies come about and how they can be explained. What happens when you throw a ball into the air? Or when you shoot a cannonball?

The interpretation of the phenomena that prevailed into the 18th century goes back to Aristotle, and is surprisingly similar to the naive explanations offered by children. This theory assumes that motion can be triggered and sustained only by a living force. A thrower or a canon imparts a strong impulse to the projectile, which enables it to move in the intended direction. Through the exertion of flight, however, it uses up its momentum and eventually tires and falls to the ground. This sounds plausible, and it is also approximately what we see when we observe ourselves or a ball in flight.

By contrast, the currently valid version of the laws of motion, which was formulated by Isaac Newton, requires us to “describe [the physical phenomena] in the way that we do not experience them” (Carl Friedrich von Weizsäcker). Following Newton, unless a braking force is applied to it, the cannonball will retain the direction and the speed that was initially imparted to it and will not tire. As soon as it escapes the Earth’s gravity, it will fly on indefinitely at the same speed without tiring. This is what Newton’s law of inertia demands, and it has long since been practically applied in space technology. The distance of the flight is no longer of any great relevance once a space ship has reached the vast expanses of the universe. Further force is needed only to travel faster or to brake and land the spacecraft.

And what now? Are the law of inertia and children’s everyday experiences and interpretations irreconcilable? And because these naive interpretations are not, after all, completely unusable – indeed, in most cases, they work wonderfully – children are loathe to give them up in favour of more abstract concepts. So there is no reason to prematurely force technical models on them. At best, that will make them into would-be Copernicans, as Wagenschein once said.[14] Only when children, acquaint themselves in the course of time with the indisputable advantages of scientific explanations, will they come to like them. For only then will the scientific models and technical terms be of help to them. However, this takes patience and extensive experience with the phenomenon, for example when balancing – and marvelling at the behaviour of – a drinking straw.



14 See Wagenschein, M. (2010).

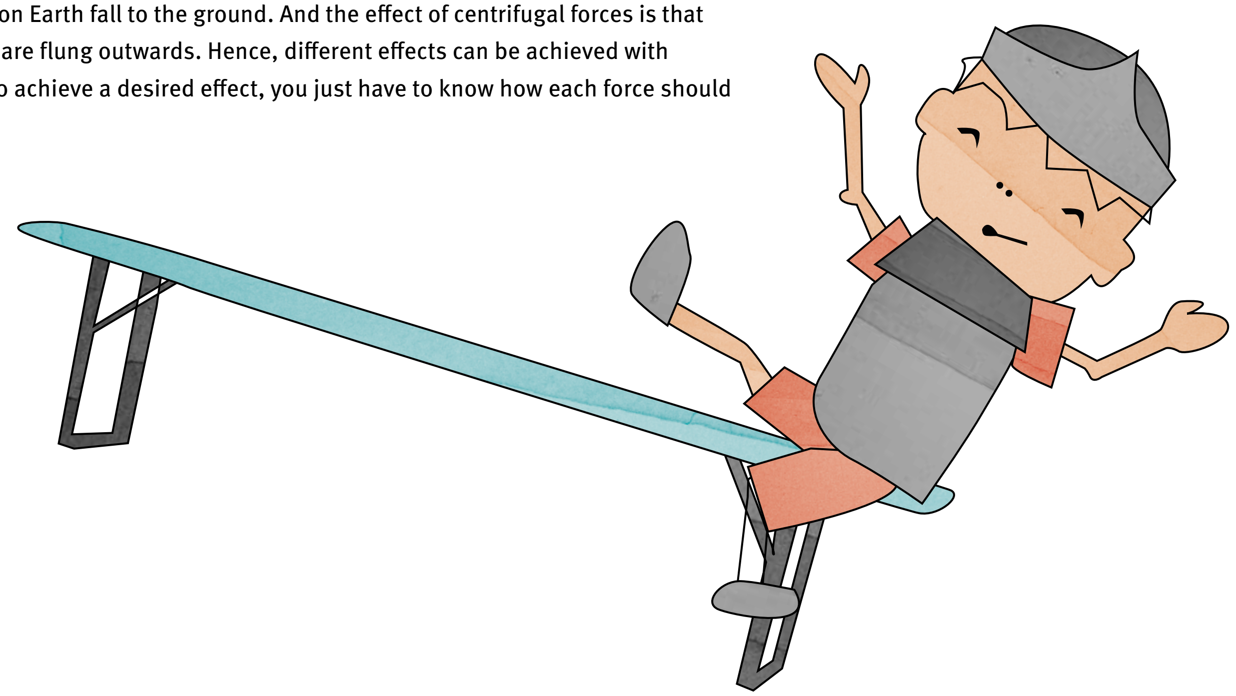
INTERESTED ADULTS MIGHT LIKE TO KNOW ...

What is force?

The term *force* often crops up in our everyday vocabulary in different contexts. The German word for force is *Kraft*, which also means strength or power. So it crops up in utterances such as “Daddy has so much strength (*Kraft*) that he can lift me and my brother up at the same time.” or “The car has a lot of power (*Kraft*); it can drive up the hill although it is fully laden.” or “The big boat is secured to the jetty with a strong (*kräftig*) rope.” From the perspective of physics, force is an external influence on an object. The object is set in motion or – if it is not movable – deformed by this force. Many different forces are constantly acting on us and our environment. First, gravity is ubiquitous and omnipresent and pulls everything towards the centre of the Earth. Moreover, the Earth is also responsible for another force that acts on us – namely, centrifugal force. Because the Earth rotates, we are flung outwards by this force. But we don’t notice it at all because the effect of gravity is much stronger: You could say that gravity “outdoes” centrifugal force. So when we are supposedly standing still on Earth, we are actually being simultaneously pulled towards the centre of the Earth by gravity and pushed upwards from the ground again and flung outwards by the centrifugal force caused by the Earth’s rotation. And we notice neither the one nor the other. But when we are standing at the edge of a swimming pool and somebody pushes us in, we feel the force that knocks us over. So there are very different kinds of forces. They can have very different causes, they can achieve different effects; they can be large (e.g., a Ferrari that accelerates from 0 to 100 kilometres per hour in eight seconds); they can be small (e.g., nudging a little pearl); or they can cancel each other out (e.g., in a tug of war when neither side moves because each team is pulling on the rope with equal force).

What is an effect?

The word *effect* can have different meanings, depending on the context. Generally speaking, however, an effect is the result of a cause. In the present context, it refers to the change that a force causes when it acts on something. For example, the effect of the spring force of the upholstery in a sofa is that the upholstery gives slightly when we sit down and returns to its original shape when we stand up. The effect of the lever force of a nutcracker is that we need only relatively little muscle power to crack a hard nut. And the effect of friction is that objects are prevented from moving or are slowed down. The effect of gravity is that all objects on Earth fall to the ground. And the effect of centrifugal forces is that things that rotate are flung outwards. Hence, different effects can be achieved with different forces. To achieve a desired effect, you just have to know how each force should be applied.



Spring force

The term *spring force* means the so-called restoring force, for example of a metal spring. If you compress or stretch a spring, then it exerts a force that brings the spring back to its original position. The magnitude of the restoring force depends greatly on the properties of the spring. The material, the shape of the spring, and the load direction determine this magnitude, which is called the spring constant. The spring constant of a spring can be calculated with a dynamometer. It shows the force (in newtons) needed to extend the spring to a certain length. The spring constant

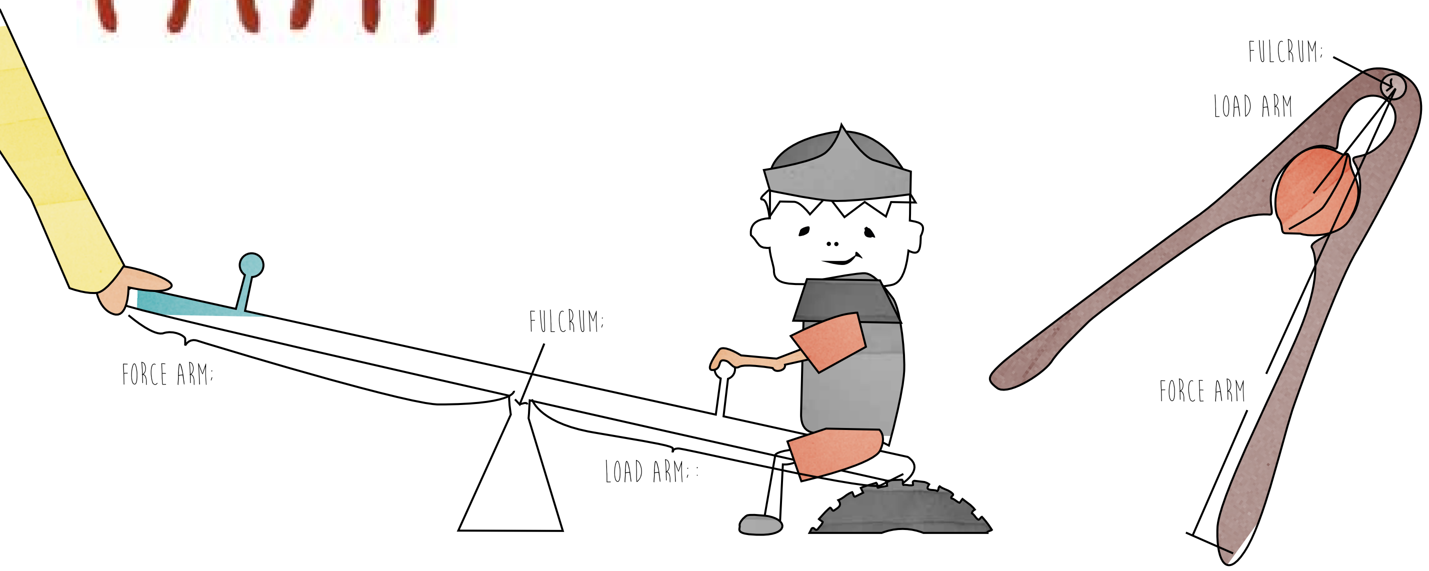
$$D = \frac{\text{force (F)}}{\text{deflection (d)}}$$

Springs are used whenever something is to be cushioned (e.g., a mattress), or when energy is to be stored for later release (e.g., in a trampoline or a catapult). Moreover, technical springs are useful in cases where devices or objects (e.g., the ink refill in a retractable ballpoint pen) are to deformed and then returned to their initial position or shape.

Lever force

“Give me but one firm spot on which to stand, and I will move the Earth.” Archimedes is said to have spoken these words in 200 B.C. while researching the laws of the lever. By this remark he meant that one can achieve a great effect with a lever even though one applies only a little force.

Important parts of a lever are the force arm, the load arm, and the pivot point, or fulcrum. The longer the force arm is, the less force we need to apply to lift the load (weight) on the load arm. Hence, the longer the lever, the less strenuous it is for us to lift the load.



Gravity

Gravity, or gravitational force, is one of the “four fundamental forces of physics”. The other three fundamental forces are electromagnetic force, to which electricity and magnetism belongs; weak nuclear force, which is responsible for the decay of atomic nuclei; and strong nuclear force, which holds atomic nuclei together.

Gravity is caused by the mass of the Earth and it is always attractive. Strictly speaking, every mass, or, to put it colloquially, every object that has a mass (i.e., also a human being), exerts an attractive force. However, in the case of small masses, this force is so small that we do not feel it in our everyday lives. Because the mass of the moon is smaller than that of the Earth, gravity on the moon is much lower than on Earth, which is why visitors to the moon can jump very high without any effort. On a big, massive planet like Jupiter, we humans would be pulled to the ground by a gravitational force that is three times greater than that on our Earth.

Friction force

When two objects roll or slide over, or adhere to, each other, an opposing force occurs, which opposes the motion of the two objects. This opposing force is known as friction. For example, if we shift a table on the floor, part of the energy that we expend is transformed into heat through *friction*. Technically, we cannot make further use of this heat – in other words, we lose some useable energy. For this reason, friction is sometimes an annoying problem.

Friction is a phenomenon that takes place at the microscopic level: The surfaces of the table legs and the floor, which come into contact with each other, have tiny irregularities which get interlocked. When shifting a table, the first push is the hardest (static friction) because you must first separate these tiny irregularities. After that it gets easier because atoms on the surface start to oscillate and become more mobile. On the one hand, the motion of the atoms creates heat. On the other hand, the contact between the table and the floor is briefly interrupted and it is easier to move the table further (sliding friction).

In order to increase friction (e.g., to avoid slipping on ice), you can make the surface rougher, for example. That is why we spread sand on the roads in winter. Alternatively, you can equip the smooth surface with profiles, for example by putting snow chains on car tyres or wearing shoes with deep-tread soles. To reduce friction, you can make the surface smoother or use intermediate layers, for example smooth cloths, soft scarves, or lubricants such as oil, water, or sand.

Inertial force

All bodies, that have a weight, or, more precisely, a mass, are inert. That means that, left to themselves, they would always remain in their current state of motion. A body at rest does not start to move of its own devices. A body in motion remains in motion until something stops it or changes its direction. Additional forces are required to effect all these changes in motion.

For example, if you want to pull a wooden hand cart with children seated inside, you must first overcome the inertia that makes it stay still. The more children are sitting in the cart, the more inert it is, and the harder it is to move it. However, once the cart has started moving, it rolls on easily. In order to stop the cart, further effort is needed, for, now, the inertia of the cart means that it continues rolling without further pulling. (The fact that it eventually stops, nonetheless, is due to the friction force that gradually slows it down and finally brings it to a halt.) As a general rule: the heavier an object, and the greater the change in speed and direction, the greater the inertial force.

Centrifugal force

Centrifugal force comes about through inertia. It occurs whenever a change in direction takes place. A body that is moving in a certain direction will not change this direction unless acted upon by an external force. A change in direction is thus also a change in motion, even if the speed remains constant. So if we want to drive around a bend or in circles we have to expend additional force, and the car (and all the passengers) will resist this circular motion; actually, it “wants” to continue driving straight ahead. The result is that the car and its passengers are pushed outwards – they “flee” from the centre of the curve. The faster the curve is taken, and the farther away the object is from the centre of the curve, the greater the centrifugal force that acts it.

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- ***Grundschule Sachunterricht,*** issue 65, 1st quarter 2015.

Links to chain reactions

- ***KiKaninchen, Jule baut eine Kettenreaktion,*** www.youtube.com/watch?v=mZPnYThTA8E
- ***Kettenreaktion der Katakombe – Offene Jugendarbeit,*** www.youtube.com/watch?v=e2sXs0DnPlk
- ***Kettenreaktion – Projektwoche bei der Wiener Kunstschule,*** www.youtube.com/watch?v=6OGegs1qvsk

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