

## Quality Development: Challenges to Physics Education

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### **Abstract**<sup>1</sup>

Physics education is in a critical state. As international studies reveal, in many countries the level of scientific literacy is mediocre or even less and students are considered poorly prepared to meet the challenges of the future. The need for quality development has been recognized on the political level. The article focuses on the role of experiments and practical experiences in the teaching and learning of physics. Evidence from video-analyses of physics lessons points out the shortcomings of traditional teaching scripts but also the potential of learning by experiments. Additionally, information from informal learning shows that a positive development of students' interest can be fostered by adequately designed learning environments that focus on authenticity and practical experience. The outline of a new program "piko-Physik im Kontext" (physics in context) is sketched. "piko" aims at enhancing the quality of teaching and learning in physics by focusing on various context factors and by trying to change the teachers' views of learning.

### **1. The emerging knowledge society: challenges of global change**

On the verge of the new millennium, science, technology and society are undergoing dramatic changes. The rapid increase of knowledge in a wide range of disciplines is triggering off scientific and technological developments that deeply affect our lives and transform our culture. Innovations in many fields, for instance, in information and communication technology have led to profound changes, and an end of this process is not yet in sight. The post-industrial society is amidst a transition process towards what is called the "knowledge society". Knowledge is becoming the key resource in our societies and a central factor in political decision making.

The change is driven by the development of science in various areas, and its pace is even increasing. If we compare the situation of today with technological transitions of the past, many similarities but also qualitative and quantitative differences become evident. The evolution of knowledge in the past occurred at moderate rates with time scales in the order of one human generation. However, at the cutting edge of today's technologies, half-life cycles of 5 years and less are quite common.

On the one hand, scientific and technological developments offer promising new opportunities to improve the conditions of human life on a global scale. Not only in communication, but also in nutrition and healthcare do we have a realistic chance for significant improvements. We are developing a deeper understanding of the complex dynamics and interdependencies on various spheres and scales of the earth system. We have realistic expectations to create new technologies that contribute to a sustainable development. We are beginning to use tools and to implement processes on the nanometer scale that come close to what the fabric of nature has developed during evolution. We are beginning to understand more comprehensively the secrets of life and the functioning of the human brain. Scientific knowledge is profoundly reshaping our views of the world.

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On the other hand, the rate of innovation and knowledge explosion poses a great challenge not only to society as a whole but also to each individual, who is forced to question old wisdoms and to adapt to new developments. We are all aware of subtle interplay of global cooperation and competition. Change has become the main invariant, at least in our professional lives. The resulting uncertainty and the requirement to react rapidly can deeply disturb individuals and societies as well. We need knowledge and orientation to prevent such irritations. Successful innovations require the prepared individual and the susceptible society. Ideally, the community of competent and literate citizens decides upon the directions of future developments, but, in reality, the average level of scientific literacy does not keep pace with these rapid developments.

In view of these profound processes of change, the quality of science education has become a central issue in many countries. Well-educated students as future citizens are considered to be society's most important resource for shaping our future. There is a general fear that science education, scientific literacy and the public awareness of science do not comply satisfactorily with this transformation process and the needs of an emerging knowledge society.

## ***2. Problems of communicating the innovative role of physics***

Physics as an academic subject has a long and successful record of creating new knowledge that applies to a broad range of scales of human experience and that drives technological development. The program of physics resulted in creating a new world view that challenges naive beliefs as well as long-held philosophical convictions.

Physics is at the heart of new information and communication technologies that have deeply changed our lives in recent decades. Physicists work at the leading edge of new technologies that will probably trigger off even more profound changes. The intriguing development of nanotechnology is a key area for promising innovations not only in physics but also in the bio-sciences. Physically inspired model building has promoted a deeper understanding of complex processes in many fields. Physicists, as typical universalists, are successful in various professional careers ranging from medical and life sciences to engineering and computer science, from the geo- and environmental sciences to economy, just to mention a few fields. The professional openness and universal orientation of a training in physics covers a wide spectrum of knowledge and skills, extremely useful not only within science fields closely related to physics but also in a broad range of subject areas, even in fields with a very "unphysical" appeal, like, for instance, the analysis of stock market data or risk assessment in insurance companies (cf. [1]).

The diversification of jobs for physicists will probably even increase in the future, a development which is in line with other trends of our global, rapidly changing knowledge society, which transforms structures in traditional jobs and requires the readiness for lifelong learning. The spectrum of scientific disciplines and the technological work fields undergoes reorientations: Apart from probing "vertically" in depth in one area, science establishes "horizontal" links, connecting theoretical and experimental approaches and transferring knowledge between different disciplines. Often, hot spots in scientific and technological change connect several domains of knowledge.

From a global and historical perspective, physics, as an academic subject is extremely successful in a number of areas, providing, for instance, rather generic methods in analyzing and solving complex problems. Physical models bridge the gap between the macro- and the micro-level. They contribute to a deeper understanding of complex phenomena like emergence and evolution and offer a coherent view of universality in complexity. However, physicists have immense problems in making the meaning and the fascination of their subject tangible to young people. The public image of physics and physicists is not in accord with the

above optimistic view of the discipline either. Obviously, the potential of the subject and the new world view that intrigues our own minds as physicists is difficult to convey to the public. In spite of all the success physical methods had in the past and still have, we need to work harder and continuously to make them a vital part of the public understanding of our discipline.

With respect to the aforementioned progress in nanotechnology, one might say, that physicists can touch and move even single atoms but they have serious problems in touching the hearts and moving the minds of our students. We all are aware of the negative consequences for the profession since physics no longer attracts the most talented young people. Additionally, we must worry about the status of science literacy and the attitudes of future citizens towards science.

### **3. Problems of physics education**

Physics, as a school subject, suffers from a bad reputation. Fewer students choose physics for their career. An explorative survey, carried out recently in Germany, investigated the preference for certain subject areas among high school graduates entering university [2]. The students were asked to name 4 school subjects, two favorite ones and two they disliked most. No subject other than physics had more negative nominations (30%), unbalanced by only 10% positive reactions. Only the negative image of chemistry came close to that. Mathematics, on the other hand, also stimulated a considerable amount of dislike, balanced by at least an equal amount of positive reactions. Biology ranged among the favorite subjects like arts, English and music, only superseded by sports. Latin, which is no longer compulsory, stimulated a similar negative/positive ratio of 3/1. Somehow, even in spite of all the good will of many physics educators, physics has become the Latin of modern times. Will the subject suffer the same fate as an extinct language and shrink to a discipline for specialists, not suited for the general audience? The situation comes close to being absurd. New technologies pervade our lives. Young people are attracted by the technologies, but the underlying basic science is widely ignored.

#### *3.1 Between fortress and ivory tower: the image of physics*

Although the data represent snapshot only from one country, the findings are probably quite generic. In the heads of many students, physics resembles a fortress. It is difficult to conquer, and, what is worse, many students do not even regard this a worthwhile endeavor. Physics is considered abstract, difficult, boring, unattractive, not very meaningful to and detached from everyday life. Only few students will find the key to unlock the fortress. Many students who begin their physics lessons with a certain level of enthusiasm and eagerness soon change their attitude and consider the subject uninteresting and even develop aversions. Something is terribly wrong with the teaching of the subject. Especially girls develop a negative attitude.

There are many reasons for this development. Physicists tend to tackle the problem on a rational level but the emotional experience is equally important. The image of people engaging in physics is bad. Another survey carried out among German high school students has focused on how students active and interested in physics are rated by their peers [3]. Students who are good at physics and mathematics are considered more intelligent and work-oriented, but fellow students rate them less attractive, socially competent, socially integrated and creative. The typical physicist comes close to the following stereotype: male, shy, unattractive, lonesome worker, not socially engaged. Such an image does not develop out of the blue and it will turn out to be fatal in the long run if physics only attracts a selection of students that conforms with the image of hard workers but that does not conform with the attributes of creative persons. Moreover, it is more than an image problem, that shows up in these views.

In this context one cannot evade a discussion of the “two cultures” phenomenon, a splitting up in a rational-technical and in an aesthetic, literary, humanitarian culture [4]. The gap between these subcultures exists and it develops much earlier and much more pronounced than one might expect. The above study [2] investigates the motives for selecting university subjects from science, engineering and the cultural sciences. It seeks to isolate relevant determinants, e.g. parents and peers, that influence subject preference and the socialization towards science, technology and the humanities.

At the end of high-school, a splitting up in two camps is already very clearly pronounced:

- The domain of natural sciences and engineering, dominated by male students
- The domain of language and cultural sciences, where female students are over represented.

Primarily, the subject preference is determined by a person’s interest in the subject areas, by the self-concept and by the experience of the own abilities. These results are in accord with the expectations. However, including further variables in a predictive model of subject preference reveals surprising results. Apart from the individual interest and the experienced strengths and weaknesses, the engagement towards a certain professional orientation is determined by other motives like "engaging in shaping the future of society" or "interacting with other people". Generally, these motives also have a high predictive power in explaining variance in subject preference. However, in order to explain a preference in science and mathematics, these factors discriminate in the negative sense! Compared to other disciplines, such motives are rare among mathematics and science students.

This finding comes as a surprise. It runs contrary to the optimistic view that mathematics and science students are bright, creative and highly active, not only in their specific fields. These motives come close to the stereotype of the ivory-tower scientist, an introverted person, working on his or her own, not interacting much with other people. The wish to actively shape the future is more common among engineering students. This motive appears to be one of the discriminating variables between future scientists and engineers. We have to digest these findings and we have to work on the issue, given the fact that co-operation and engaging in central problems of our society are crucial factors to shape the future. We have to stop complaining and to become active.

### *3.2 Effectiveness of physics education in view of international comparisons of school systems*

There is a broad consensus about the diagnosis of the deficits, but what is the best leverage to improve the situation? Are isolated actions within the domain of physics successful or do the mentioned problems refer to more general systemic deficiencies? It is useful to review these questions in the context of international efforts to monitor scientific literacy. The OECD Program for International Student Assessment (PISA) has addressed these problems which are considered vital in view of the rapid global changes [5]:

- Are students well prepared to meet the challenges of the future?
- Are they able to analyze, reason and communicate their ideas effectively?
- Do they have the capacity to continue learning throughout life?

The term “literacy” is used in a metaphoric way to describe a broad conception of knowledge and skills for life, which are broken down to various processes in the design of the actual tests, including, among many other aspects, the ability to apply knowledge from science in more or less authentic real world situations. Due to the comprehensive approach of assessing student performance and of collecting ample context information, PISA provides the empirical framework for a better understanding of the causes and possible consequences of

observed deficiencies in science literacy. It shows where we can make necessary improvements in schooling and in preparing young people better for the challenges of an adult life in a world of rapid change as well as global interdependence.

Among other findings, PISA confirms the results of earlier studies like TIMSS (Third International Mathematics and Science Study [6,7]). With respect to the consequences, I can speak only for my country: The TIMSS results have shattered the long-held beliefs about the high standards of physics education [8,9]. The learning progress in physics (and science lessons in general) is slow. Time is used inefficiently. Science education is more or less efficient only with respect to imparting the knowledge of facts. However, extensive deficits exist on the level of more demanding science processes, e.g. applying knowledge to new situations.

Broadly speaking, physics teaching focuses on conveying factual knowledge ("know what"). Approaching the "know how" and the "know why" poses big problems. Physics education falls short of attaining more challenging goals like flexible application of knowledge in new contexts. It fails in promoting conceptual understanding.

The PISA-approach adds more background knowledge that helps to interpret these findings by embedding them in a broader systemic context [10]. PISA shows surprisingly close connections between reading literacy, mathematics and science literacy. So the tendency among some countries to support early specialization certainly has a negative effect. Wide systemic differences and considerable variations in levels of performance between students, schools and countries become evident. Most importantly, the PISA-results show enormous differences in the impact of the socio-economic background of students and schools. Notably, some of the countries which have been most successful in balancing out the effects of social disadvantage are among those with the best levels of students' performance. This poses a great challenge to other countries (like my own) with a highly selective system which fails in supporting the lower performing students. But the system also has a problem at the upper end: it falls short of creating top performers.

The PISA results demonstrate convincingly that the problems of physics education cannot be discussed separately. The performance of the school system as a whole has to be taken into account. The enormous systemic differences indicate that human resources and human capital are activated in highly different ways, even when one compares two countries which are culturally not so very different. Isolated programs to improve physics education have only a limited impact as long as the system does not improve the learning culture in general.

### *3.3 Patterns of knowledge: Do systematic and problem-oriented approaches matter?*

A comparison of TIMSS and PISA results gives some advice on what to teach and how to teach because both tests approach the construct "science literacy" in complementary ways:

- The TIMSS-test sought, in the main, to measure students' understanding of the facts contained in the school curricula. The test has a high curricular validity and is constructed according to the contents and the systematic knowledge of the respective science disciplines.
- PISA, on the contrary, seeks to measure more generic process skills, especially the ability to apply knowledge. Science processes are in the foreground, such as communicating ideas, finding relevant information, drawing conclusions, evaluating evidence. All these processes depend on high level skills with a strong (mostly qualitative) problem solving component.

A comparison of these two different international surveys convincingly demonstrates that there are specific differences between countries in attaining these more demanding goals.

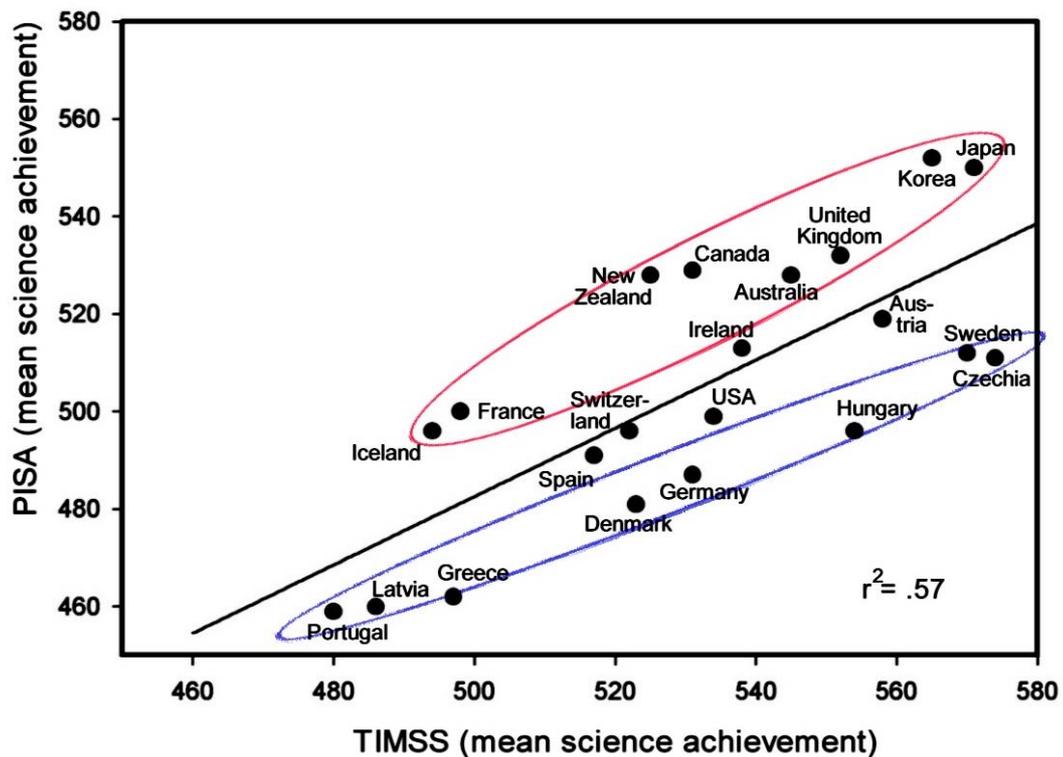


Fig. 1: A comparison of international comparison studies. The average science scores of countries in the TIMSS and PISA test are compiled. The line shows the linear regression (data from [8,10]).

Fig. 1 shows a compilation of the science test scores from countries which took part both in TIMSS and PISA. The scales do not represent raw test scores. The data have been transformed according to item response theory. Both tests are normalized to an average of 500 and a standard deviation of 100; i.e. roughly 2/3 of the distribution score between 400 to 600. The standard error bars are not shown in the figure and range roughly from 2-5.

In spite of a five-year-time difference between both tests (1995 and 2000), such a comparison is useful for explorative purposes. Certainly, some efforts have been under way in various countries to improve science education after the publication of the TIMSS-results. In view of the long time constants in the educational systems, these effects should be of minor importance, however. As one would expect, the TIMSS and PISA results are correlated. Roughly 60% of the variation of the PISA achievement can be predicted on the basis of TIMSS performance.

The PISA results challenge the teaching tradition of many countries even of those doing well in TIMSS. Two groups of countries can be found above and below the regression line which perform differently on both tests. There is one group of countries below the regression line, which might be called the "PISA losers". They do worse in the PISA test than one would expect from the TIMSS results. Another group of countries (the "PISA winners") shows much better achievements that one could expect from their TIMSS results.

In trying to understand this specific pattern of achievements one might be tempted to resort to explanations like the statement: "International comparison studies are not culturally fair". As countries taking a leading role in designing the PISA test (e.g. Australia) are among the "winners", such an assumption might be justified indeed. However, in my view, this is only a

superficial explanation. We have to explain why some countries (e.g. Sweden and the Czech Republic), which showed an excellent performance in the TIMSS test, cannot use their potential to do better in the PISA science test. Obviously, it is not sufficient to learn science in a systematic context. Something essential is lacking.

A more plausible assumption is that the gap between the PISA winners and losers might reflect the specific curricular orientation in the different countries and the ways in which physics and the other science subjects are taught. Primarily, the gap appears to stand for two different approaches to physics teaching and learning:

- the traditional approach, where the systematic teaching of the subject is in the foreground.
- the more "progressive" approach, with problem- and process-orientation as guiding lines.

Such a view of a gap between content knowledge and procedural knowledge can be supported by observations from the German PISA results. In addition to the international test a national supplementary test was administered, which was constructed in the curriculum-oriented and systematic TIMSS-tradition. A comparison of both test parts gives rise to a pattern similar to fig. 1, depending on the teaching tradition of the various states [11]. Again, the results show a clear indication of a gap between the kind of science literacy addressed by the PISA-framework and approaches to systematic scientific knowledge which accord with the TIMSS test approach. A good achievement on the systematic side is not sufficient to solve the process-oriented tasks of the PISA-test. The systematic, content-oriented approach falls short of providing adequate contexts for applying knowledge in real world situations.

#### ***4. The role of experiments, cognitive activation of students, and authentic learning experiences***

As teaching and learning are culturally dependent, programs to induce change necessarily have to reflect the specific experience of the respective culture and generic recommendations are difficult. From the perspective of the teaching tradition of the countries that belong to the group of "PISA-losers" in fig. 1 there is the challenge to shift the balance from the more conventional, systematic approaches to physics teaching towards the more progressive, problem- and process-oriented ways.

Probably, we all would subscribe to the following vision: "The ultimate aim of our didactics is to find methods of teaching, where the teachers need to teach less, but where the students nevertheless learn more; where there is less noise, frustration and useless effort, and where freedom, pleasure and true progress prevail." This is a quote from Comenius' first grand didactical opus, dating back to 1628 [12]. Today's teaching is still way off this general goal. This can be seen from a number of recent video studies of physics lessons that focus on the quality of physics instruction.

##### *4.1 How matters are: information from video analyses of physics lessons*

In order to obtain research based evidence on contexts which are relevant to improve the quality of school a research program has been launched in Germany [13]. Several studies within this program focus on physics teaching, trying to identify central factors in teacher expertise and behavior that facilitate students' learning [14-16]. These studies take into account prior experiences from a transcultural comparison of instruction in mathematics by off-line analysis of videos from lessons in Japan, USA, and Germany [17]. The video-analysis provides strong indications for linking students' performance in mathematics with teacher expertise and their instructional patterns. Although rather resource consuming, video-analyses represent a useful method to get evidence of what to focus on in quality development.

The IPN Physics Video Study investigates early physics instruction in the 8th grade, analyzing lessons from two subject areas, the introduction to mechanics and to electricity. The method is based on combining video-analyses of physics lessons, student questionnaires on how they perceive teaching, and tests on how they actually perform. Additionally, teacher questionnaires and interviews provide information on the teachers' background, their intentions and beliefs. The study tries to identify patterns in elementary physics instruction and their relation to learning outcomes [18]. From this perspective, research questions are generic to the problems of teaching any school subject. Additionally, the research focuses on specific problems of physics instruction which refer to the role of experiments. How do teachers actually use experiments to activate students and to engage them in meaningful physics inquiry processes? Is the specific role that the cycle of experiments and model building plays adequately reflected in the teaching method? Does the nature of physics as an empirical science become evident?

The following factors relevant to successful physics instruction have been found:

- students' perception of cognitive engagement
- students' perception of instructional quality
- self-determined learning motivation
- supportive teaching and learning conditions.

The findings indicate that certain patterns of teaching behavior and of organizing classroom activities are already dominant in the early stage of teaching introductory physics lessons that set severe limitations to students' motivation and their individual learning processes.

On a general level, one could state that mostly the teachers are active – but not students. A central problem refers to the teachers' role. Primarily, teachers see their role in the transmission of knowledge and not in arranging a learning environment that allows for a high level of students' participation and mental engagement. A certain script or a pattern of instruction prevails which is called, in the German pedagogical tradition, the questioning-developing-style of teaching. It represents a form of teaching which is strongly guided by the teacher, who develops knowledge in small pieces, by asking questions. It is a ping-pong like game of questions and answers. Although it is guided by the teacher, this style of teaching should not be mixed up with instruction.

Some students appear to be active, they respond to questions, present ideas etc. But closer inspection shows, that this occurs only at a superficial level. Detailed analyses of response times reveal that the teachers often do not give the students enough time to become immersed in the problems and to reflect more intensively on them. As a result, the students are only superficially engaged. If the teachers allot the students more time to reflect and if they provide the opportunity for longer periods of group work, their instructional quality and the learning support is rated much higher. The quality of instruction as measured by the learning gain is mainly connected with the degree of active involvement of students and the goal-orientation of the teacher [18].

The actual teachers' scripts also set limitations to an adequate use of experiments. Experiments serve a wide spectrum of functions in physics as well as in physics instruction. Theoretically, teachers assign a crucial role to experiments in the teaching and learning of physics. Teachers' beliefs mainly reflect the following function of experiments (cf. also. [19]):

- The learners should have a practical experience with the phenomenon in question.
- Experiments have a high motivational value.

- Experiments are important to develop practical skills (observation, thorough working, use of tools and instruments).
- Experiments are an important source of knowledge.
- Experiments make abstract concepts visible.
- Naive beliefs can be challenged by experiments.
- Experiments serve a methodological function: the testing of theories and ideas by confronting them with reality.
- Experiments promote scientific inquiry methods.

Physics teachers use experiments quite often, although the actual use of experiments in the teaching process is not in full accord with the above aims. Most of the teaching is arranged around experiments with various phases of preparing the experiment, of actually carrying it out and of discussing the results and the implications [20]. Two main ways of “orchestrating” experiments have been found:

- Embedding demonstration experiments mostly done by the teacher in teacher-centered questioning-developing style.
- Carrying out experiments by students working in small groups. The group work is embedded in phases of discussions guided by the teacher.

Although learning gains differ significantly between classes, there is no systematic difference between these two learning situations. Other factors appear to be more relevant. In both cases, students have only little opportunity to engage in planning, in formulating hypothesis about possible outcomes and in reflections about the function of the experiment. Even in the case of students doing experiments in groups, there is hardly any opportunity for openness in the activity, of responsibility and commitment transferred to the students. Students follow a fixed program of experimental manipulations and observations set up by the teacher. Narrow guidance provides only little space for students to develop their ideas or to follow their own approaches.

It is difficult to draw generalizations from observations within a single learning culture. One has to keep in mind that what is considered good teaching and learning has a strong cultural bias, and the variability in the actual use of different teaching methods is rather limited. Even within these limitations, positive indications on the role of experiments can be found. Classes, where the teacher devotes a high amount of time to preparing, carrying out and discussing the results of experiments have a higher learning gain, indicating that doing experiments in physics has a positive effect on learning [20]. However, not the experiment per se appears as the relevant factor, but appropriate measures on the part of the teacher that facilitate learning. These teacher activities co-vary with other relevant teacher-related factors like the above goal orientation and the degree of student engagement.

At present, the available database is not sufficient to allow for multivariate analyses in order to single out the influence of doing experiments. To tackle this problem, an investigation using more classes and comparing two different systems with the same language but with different pedagogical traditions is being carried out (physics lessons in Germany and in German-speaking Swiss schools).

Watching the videos often leaves the impression that many opportunities are left out which could enhance meaningful engagement and learning by a proper combination of hands-on and minds-on activities. The general style of teaching prevents exploiting the full potential of experiments in stronger inquiry-oriented learning settings of planning, of doing practical work and of modeling the observations. Often, the experiments are done in a linear and additive

fashion, with the systematic structure of the subject area serving as a guiding principle to arrange their sequence in the learning process. There is a general lack of building up adequate mental models and of linking the experiences from different experiments in order to get a coherent view of the subject area. The systematic approach prevails and a problem-oriented way of arranging experiments is rather rare. Also, experiments using everyday material are not very common. Experiments get the flavor of something very artificially set up, which is only done in physics lessons, not very relevant to daily life.

Our present findings on the practices of using experiments in actual physics teaching echo the complaints and the diagnosis of deficits that have been around in the didactical literature for decades. Wagenschein commented on the limited success of physics teaching and attributes it to the prevalent way of knowledge presentation [21]. In his view, an exaggerated emphasis is laid in the systematic order, arranging the subject matter in a linear way, starting with the simple and proceeding to the complex. Such a procedure requires learning and piling up unrelated facts before being able to link them in a meaningful way. Especially, teachers from the hard sciences will favor such a way as it appears the natural order and reflects the logical structure of the domain. Although such a systematic way of additive knowledge presentation is in accord with the logical structure of the subject matter, it is by no means psychologically and pedagogically adequate. The view implicit to such a type of teaching is a transmission model of knowledge.

Wagenschein's critique (written in 1963) is still valid today. Physics teachers, as seen in the videos, are often driven by the idea to achieve systematic completeness. Their pedagogy is guided by what they consider an appropriately simplified elementary approach, which cuts knowledge into pieces, into small chunks of information that they present. Consequently, problem- and context-based approaches to physics teaching are very rare. Additionally, many teachers are very reluctant in giving those approaches a try; their thinking and their ways of teaching are fixed rather rigidly within the systematic structure of the discipline. However, the logic of the discipline and the logic of pedagogy are different. In order to improve the students' engagement in knowledge acquisition more diverse approaches are necessary.

#### *4.2 How matters could be: the role of experiments in informal learning environments*

Teacher behavior hardly reflects pedagogical developments of the last decades, which give the learner an active role in constructing her or his knowledge. From the perspective of situated cognition and moderate constructivism, learning environments should conform to a set of certain criteria to enable meaningful learning processes [22]:

- They should be authentic, allowing the learner to deal with problems in realistic and not in artificially arranged situations.
- A problem should be presented and analyzed from multiple perspectives, using different approaches and methods of problem-solving.
- The experience of a problem in multiple contexts is prerequisite for a flexible use of knowledge that transcends the context of knowledge acquisition and that allows a flexible transfer of knowledge to more distant problems.
- Knowledge construction takes place in and is facilitated by an appropriate social context that allows for cooperative and collaborative problem solving.
- The learning arrangement should leave sufficient freedom for the development of the students' own ideas and for following his or her own approaches. To explore one's own ideas is a prerequisite for successful knowledge construction.

While these ideas permeate the formal education system extremely slowly, there is another active new field of development outside the traditional system, which implements many of

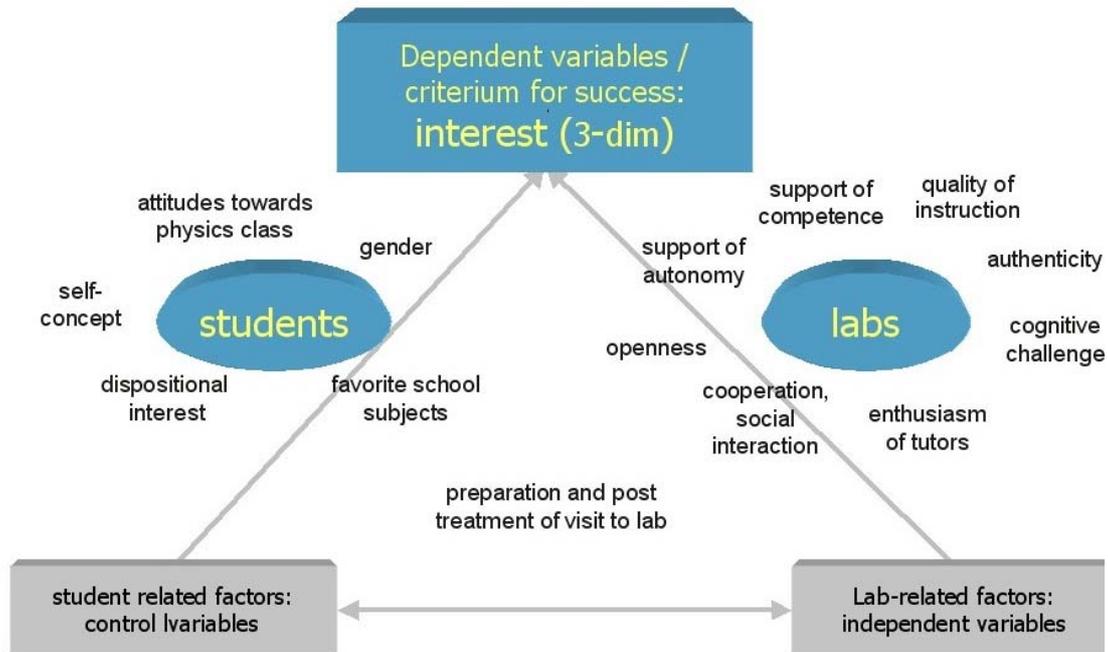


Fig. 2: Factors contributing to the success of science labs

these approaches. Science labs have been established during the last decade in several countries as a consequence of the crisis of science education and to counteract the imminent lack of qualified workforce in science and technology. Various initiatives from research sites, industry, universities and science-centers offer opportunities for laboratory experience and learning to school-students of different age groups. To put it briefly, these out-of-school learning experiences are called informal learning.

Compared to science museums these labs fulfill a somewhat different function. They intend to give insight into „the real thing“ instead of strongly pedagogically reduced versions of school physics. They offer various possibilities of experiencing the working environment of scientists in authentic ways and of getting into personal contact with researchers in science and technology. Carrying out experiments and engaging the students in practical, hands-on activities is considered essential. Primarily, the labs intend to convey the fascination of science and technology by presenting authentic insights into the missions and the workings of institutions that play an important role in shaping our future. Stated more generally, these labs implement approaches of cognitive apprenticeship by working in highly authentic situations.

Although the individual origins and purposes of the science labs differ, most informal learning labs agree upon the following general goals:

- Getting school students an authentic feeling for the scientific endeavor
- Getting in touch with science and technology in the work place
- Get in personal contact with students and scientists
- Creating opportunities and stimulating environments to interact with authentic problems from science and technology that pose a certain degree of challenge
- Working on problems that show cooperative and collaborative aspects of projects in science and technology

- Providing an adequate framework to get first hand experience of the role of science and technology in our society.

In terms of the number of participating classes, most of these science labs work extremely successfully. In Germany, for instance, about 50 science labs have been created in the recent years, and more initiatives are planned. The existing labs are booked for many months and the increasing demands have created waiting lists. Thus from the perspective of demand, these labs can be considered a great success. However, a thorough theoretical basis of learning in labs is still lacking. Many labs have been established in the naïve belief that carrying out experiments guarantees an increased level of motivation and better understanding. As several meta-analyses on the role of lab work in schools have shown, successful learning in labs is not an automatism. Creating stimulating learning environments, that adapt to the various interests and cognitive abilities of students is far from trivial [24,23]. Additionally, the strong claims of cognitive apprenticeship and the situated cognition approach have been questioned [25].

Do the labs work in the expected way? Is it possible to create interest by confronting school students with authentic problems from research? What design factors are relevant? Do school students appreciate the labs and do visits to science-labs change the image of science in the long run? An evaluation study carried out with five science labs in Germany with a focus on physics sought to isolate factors in the design of labs that are relevant for cognitive activation of students and for creating situational interest [26]. 15 different school classes (3 per lab, 9th and 10th grade) visiting the labs once (~3h lab session) were investigated. Information was collected using two questionnaires, one at the end of the lab and the second one 3 months later in the regular physics class. Creating situational interest was considered the relevant success criterion of visit to the lab. Situational interest was broken down into three subcategories, emotional interest, value orientation and epistemic interest. This in accord to the person-object theory of interest, defining interest as a special relation of a person to an object characterised by positive feeling, personal significance and the desire to know more [27].

On a descriptive level, the lab visits are rated very positively by the visiting students. Roughly 75% rate the labs as interesting or very interesting. They would come back for another visit. Especially, the contact with “real” scientists and the insight in their research institution is highly appreciated by the visiting school students. No gender differences are detectable with respect to the three aspects of situational interest. In sharp contrast to most science classes in school, both the boys and the girls rate the labs equally positive. The possibility of conducting experiments and the learning environment of the science labs addresses both genders in a positive way. In this respect, labs do something that regular classes do not achieve. Obviously, the authentic and problem-oriented approaches meet the girls’ interest much better than the systematic approaches of school physics. This interpretation of the positive result is in line with findings from research on students’ interests [28,29].

A closer analysis has to take into account how the labs work for different groups of students depending on their dispositional interests and on their self-concept with respect to physics. The study investigated the interactions among student-related variables and lab-related variables (fig. 2). In the analysis, creating situational interest was considered the dependent variable with the student-related variables as control variables and lab-related variables as independent variables. Out of the collected lab variables the following factors account for variation of the situational interest of the students:

- competence / quality of instruction
- cognitive challenge
- authenticity.

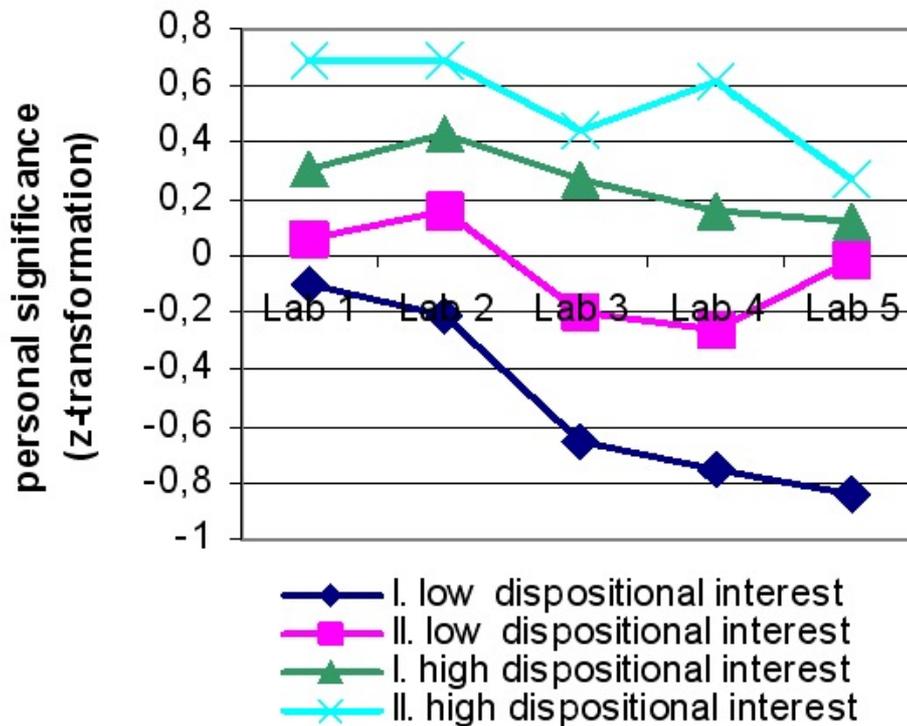


Fig. 3: Students' ratings of the personal significance of the visit to the science lab, measured immediately after the visit (I) and 12 weeks later (II). Both the low and the high interest group show a significant improvement.

There are noticeable differences between the three components of interest discussed above (positive feeling, personal significance, desire to know more). The five investigated school labs fulfill their intended role in creating interest in modern science and technology, although the labs do this in very different ways. Accordingly, their ratings differ with respect to the three dimensions of situational interest. Some labs show remarkable differences concerning the personal significance of the visit as well as the desire to know more.

There are differential effects depending on the dispositional interest of the students. There is no significant difference between the lab ratings of students with a high interest, but the ratings of students with low initial interest in science differ significantly. Some labs address this group of students better. A very interesting long-term effect shows up and with a surprisingly strong effect-size. Fig. 3 shows how the labs are rated with respect to the value-oriented dimension of interest for the two measurements. There is a considerable improvement in the ratings after 10-12 weeks time have elapsed. The long term improvement tends to be even stronger for the students from the low interest group.

Obviously, the labs are effective – they have changed something in the heads of the students, and the change requires time. However, even more can be done. The results show that a visit to a lab is in many cases not well-prepared. In view of research on the effectiveness of science museums and interactive science centres [30], this is clearly an indicator that the present practice of the relatively new established science labs could be improved. Many labs offer only a single visit to a class. Only in very few cases special schemes are established in order

to prepare the visit and to maintain interest and activities after the visit, for instance by offering additional learning opportunities. Such measures could prove essential in enhancing the positive long term effect that shows up even after a single visit.

Due to their novelty, the function of the labs in the conventional formal educational framework is not yet settled. These labs could provide an additional pillar to the education system because they show the real work place and authentic science and technology instead of a didactical transformation. The informal learning activities can feed back on the formal education system in a beneficial way by providing more authentic and attractive ways of engaging students in learning and in doing authentic up-to-date science. Moreover, the labs could contribute to strengthening cooperative and collaborative project work, which is important in the workplace, but which plays only a marginal role in schools.

However, the function of informal learning has to be clarified and made explicit. Is it complementary or supplementary to learning in the formal education system. The question how teachers can be involved needs to be addressed. The science labs could play a more prominent role in the professional development of teachers by engaging them in different phases of their professional career.

In summing up the results from the empirically oriented view of this chapter, experiments and practical activities can play an essential role in learning physics, although in practice there are deficits. There is no automatism for experiments to stimulate interest and to enhance learning. Evidence from regular lessons and from informal learning environments points out that the proper arrangement of the learning environment is essential. A balancing of the sometimes conflicting views of systematic and problem-oriented approaches is necessary. In regular classes, too little effort is put in creating learning environment that activates the learners and allows for opportunities to raise meaningful questions and to provide an adequate level of challenge for students of diverse abilities.

### ***5. Physics in context: Linking meaningful physics and meaningful learning processes***

Physics education is challenged to prepare our students to cope with a world of increasing complexity. In overcoming the problems of teaching and learning physics we have to address both the rational and the emotional channel. We have to find more appropriate ways to make physics meaningful to the learners. This includes embedding the approach of physics more broadly in diverse contexts and to anchor it in our culture. Depending on the target group, meaningful contexts range from a better understanding of the natural and technical world to metacognitive and epistemic considerations that reflect upon our status in the universe and address the role of our own mental activities in building models of the world.

In communicating physics we have to respond to the challenges of the future like understanding and managing complex systems ranging from nanoscale science to the subtle global interdependencies in the earth system. We are challenged to create sustainable technologies that do less harm to the environment. In teaching physics, this requires shifting the focus and also contributing to the progress in other fields like, for instance, understanding life processes and brain function. Physics education has good chances of doing this. However, we have to become active and promote a future-oriented view.

Various programs throughout the world have been created that react to the more recent problems of teaching and learning physics and address the quality of physics education. For my outlook, I shall focus on a physics program in Germany, that is funded by the national ministry of science and education (BMBF). It is called “piko-Physik im Kontext” (physics in context). “piko” is a program to improve science literacy by improving the quality of physics teaching and learning. On a general level, it aims at raising the students’ interest in physics

and foster their open-mindedness and receptiveness towards science and technology, in order to be able to address problems of the natural and the technical world by the rational methods of science and to keep pace with the developments described in the introductory sections[31]. The program starts in October 2003.

Part of the project philosophy is based on positive experience from an earlier program on school quality development. A nation-wide model project funded by the German Board of Education (“BLK-Modellversuch”) aims at improving the quality of teaching and learning in science and mathematics (cf. [32]). The characteristics of this program is a bottom-up approach. Basically, networks of schools define their own goals. Each school set within the network consists of six schools. It selects focus areas according to the particular needs from a list of modules, which had been identified before by a group of experts. The program is considered a success by the participating schools and by school administration [33]. At present, the program is continued in a dissemination stage. One of the main success-factors relies on the networking-idea. As a result of that program, networks of teachers have been created and are still active that cooperate in promoting teaching and learning.

“piko” also relies upon school networks and the cooperation of teachers, but, furthermore, it combines bottom-up and top-down strategies. Further thematic and methodological input (i.e. subject specific training and coaching) is provided by external experts, who accompany and evaluate the process. Additionally, a summative evaluation of the project is planned. “piko” addresses three different conceptions of “context” that will be developed systematically:

- thematic contexts (everyday science, physics in the context of technology and society, inter- and trans-disciplinary contexts)
- learning environment as context (to overcome the shortcomings of conventional teaching described in section 4)
- out of school learning contexts (including authentic experiences and projects from the workplace, research institutes etc.).

Apart from raising the average level of science literacy, “piko” aims at the professional development of teachers in order to enable teachers to take a different role and foster active learning and inquiry processes. As physics teachers tend to be strongly subject-oriented, the project philosophy counts on getting the teachers involved by their interests in new physics subjects, and to commit teachers to implement these subjects by creating learning environments that do better in activating and stimulating students’ learning processes. Thus, “piko” seeks to combine innovative physics with innovative pedagogy. For more details about the piko-program, its approach, its philosophy and the networking strategy see [www.physik-im-kontext.de](http://www.physik-im-kontext.de). In the near future, we hope to present first results on the approach.

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