Increasing the efficiency of science and mathematics instruction: Report of a national quality development program

Manfred Prenzel and Reinders Duit

IPN - Institute for Science Education at the University of Kiel
Olshausenstr. 62
24098 Kiel Germany
prenzel@ipn.uni-kiel.de duit@ipn.uni-kiel.de

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Abstract

German students did not do as well as expected in the TIMS studies. Their results in science and mathematics were just mediocre (Baumert, Lehmann, Lehrke, et al., 1997). What was even more worrying, however, was the fact that relatively large numbers of German students had problems solving the more demanding tasks, especially those requiring conceptual understanding. The heterogenity of achievement is high. From a longitudinal point of view there are relatively limited increases in competency in the course of compulsory education in Germany. These results clearly indicate that science and mathematics education in Germany is far less successful than expected and than necessary to guarantee a minimum of scientific and mathematics literacy. The deficiencies of German students have been hotly debated not only among the educational specialists and those responsible for science and mathematics education in the ministries of education, but also by the broader public. As a reaction to the insufficient results of German students in the TIMS-studies a nation-wide program to increase the efficiency of mathematics and science teaching started in the autumn of 1998. The goal of the program is to stimulate, promote and scientifically guide processes ensuring quality and optimizing teaching and learning in science and mathematics in an interstate network of schools. The conception of the program is based on an expertise worked out by a national group of science and mathematics educators on the one hand and educational psychologists on the other (BLK, 1997). Thirty pilot schools, connected with another 150 network schools, have worked on selected modules which concern key problem areas in science and mathematics teaching as identified by the expertise.

The TIMSS shock

In order to avoid misunderstanding, we would like to point out that the major problems of German science and mathematics instruction were familiar to researchers as well as a number of teachers and teacher educators before the results of TIMSS became known (for science education see the reviews of research findings by Häußler, Bünder, Duit, Gräber & Mayer, 1998). However, the TIMSS finding that German students were only mediocre alarmed the decision makers and the broader public. The low ranking of Germany just near the mean of the international science and mathematics tests (Beaton et al., 1996a, 1996b; Mullis et al., 1998) came as a shock to those holding the common view that the German school system is efficient and among the leading in the world. Fine grained analyses of the German results (Baumert et al., 1997; Baumert, Bos & Watermann, 1998; Baumert, in press) revealed particular deficiencies that turned out to be even more worrying than the mere low ranking. It appears that German students in science and mathematics have a certain strength when solving tasks that require routine procedures. They fail, however, to solve the more demanding and complex tasks requiring conceptual understanding or flexible application of knowledge. Considerable weaknesses also become apparent when scientific and mathematical thinking and argumentation is needed. The knowledge gains in science and mathematics, for instance within a year, turned out to be much smaller in Germany than in the higher ranking countries. The TIMSS results also support findings of large scale studies on the development of students' interests in science and science instruction (Häußler, 1987; Hoffmann, Häußler & Lehrke, 1998) which revealed a significant decrease of interests from grade 5 to grade 10, especially in physics and chemistry. This is true in particular for the girls. They also do less well in the TIMSS science and mathematics tests than the boys. The decrease in interest concerning mathematics, physics and chemistry leads to a rather limited participation in such courses in the upper secondary level of school and - what is also alarming - to a rather low enrolment in science and mathematics courses at the university. It is likely that Germany will fall short of science and mathematics expertise in the near future. It also appears that German students will not be able to appropriately meet the demands of life in a society that will be even more dominated by science and technology than now as their understanding of basic ideas of science and mathematics is rather limited.

The above TIMSS findings show that these international monitoring studies have substantially contributed to research knowledge about students' strengths and deficiencies in learning, understanding and using science and mathematics knowledge. In other words, TIMSS has much more to offer than just an international ranking in the spirit of a "horse race evaluation". On the background of analyses taking into account research findings of TIMSS and the other available studies, it becomes evident that German schools do not meet the aims of science and mathematics instruction that are viewed as essential at the international (National Council of Teachers of Mathematics, NCTM, 1989, 1991, 1995; Freudenthal, 1991; American Association for the Advancement of Science, AAAS, 1993; National Research Council, NRC, 1995; Gräber & Bolte, 1997; PISA, 1999) and at the national (Riquarts & Wadewitz, 1999) level. Therefore, the German "Interstate Commission for Educational Planning and Research" (Bund-Länder-Kommission für Bildungsplanung und Forschungsförderung) initiated an immediate action towards more effective science and mathematics instruction in German schools. A group of experts (Chair: Jürgen Baumert) was asked to develop the framework for a program on "Increasing the efficiency of science and mathematics instruction" (BLK, 1997). The group included educational psychologist and science and mathematics educators.

Key problem areas in German science and mathematics education

The above framework developed by the expert group (BLK, 1997) is based on a review of research findings from various sources. Where results of TIMSS are concerned, the mere international ranking was of limited significance. Much more important were the findings of additional interpretations of the TIMSS data in Germany and Switzerland (Baumert & Köller, 1998; Moser et al., 1997; Ramseier, 1999). The results of a comparative video-study on mathematics teaching in Japan, the United States of America and Germany (Stigler et al., 1996; Baumert et al, 1997; Stigler & Hibert, 1997) were of particular significance. Research on variables of students' performance in general (Fraser, Walberg, Welch, & Hattie, 1987; Wang, Haertel & Walberg, 1993; Helmke & Weinert, 1997), on instructional quality (Einsiedler, 1997), teacher competencies (Bromme, 1997) and on teaching and learning in science and mathematics instruction (Gabel, 1994; Fraser & Walberg, 1995; DeCorte, Greer & Verschaffel, 1996; Linn, Songer & Eylon, 1996; Duit & Häußler, 1997; Stern, 1997; Häußler et al., 1998) were also carefully reviewed.

It appears that not only the way science and mathematics are taught in German schools is responsible for the deficiencies of German students as revealed by TIMSS, but also the image of these school subjects in the broader public. Science and mathematics as well as learning of these subjects are not highly valued in the public and accordingly in the families and the students' peer groups. Hence, learning science and mathematics is not sufficiently supported in society as a whole. There is also the common belief that the ability of learning science and mathematics is mainly a matter of being gifted. It, therefore, appears not to be worth the effort when students' think they are not among the gifted.

Another reason for limited efficiency of science and mathematics instruction in Germany is apparently the emphases of teacher pre-service and in-service education. German teachers are apparently not well prepared to improve the quality of instruction as, for instance, co-operation among teachers and critical reflection about instruction are not well developed and are only insufficiently supported by teacher training programs (Terhart, 2000).

As it will be very difficult to alter the beliefs regarding learning science and mathematics in the broader public, the focus of the present quality development program is on improvement of the way science and mathematics is taught in school. By means of a teacher based program the development and evaluation of new teaching and learning methods will also improve teachers' professionalism to be the driving force of quality development.

The science and mathematics knowledge of German teachers usually is quite solid. This holds especially for the Grammar School teachers. The major problems of science and mathematics instruction in Germany concern educational and pedagogical issues.

The TIMSS-video study on comparing mathematics instruction in Japan, the United States of America and Germany revealed significant differences in the scripts that guide instruction in these countries (Baumert et al, 1997; Stigler & Hibert, 1997). Whereas in Japan mathematics instruction includes major features of constructivist teaching and learning perspectives by providing students, for instance, with the opportunity to follow their own paths while solving problems and constructing meaning German mathematics instruction follows a much more narrow script. Typical for German science and mathematics lessons is a very limited interplay of teachers' questions and students' answers called the "questioning-developing-approach" (fragend-entwickelnder-Unterricht; Baumert, et al., 1997; Reusser, Pauli & Zollinger, 1998). The basic idea of this approach is to realize a Socratic dialogue at the whole class interaction level. In principle, this approach may lead to fruitful learning processes. However, it is very demanding and rather sensitive with regard to small disturbances. Therefore, in practice this approach usually narrows down to a verbal interplay which is nearly totally directed by the teacher who guides instruction towards the aims set by her or him. There is no time to carefully listen to the students' answers and to try to find out what students may mean. Hence, it is not possible to orient instruction towards students' pre-instructional conceptions which has proven essential for effective teaching in research on conceptual change (Treagust, Duit & Fraser, 1996). The attempt to engage students in developing knowledge is obviously not compatible with the teacher's wish to cover as much content as possible in the small amount of time available. Learning and assessment issues are also often merged in an inappropriate manner (Weinert, 1998). A fruitful instructional approach in the spirit of the Socratic dialogue would require students having time to deal with problems, think about relationships, tentatively use analogies, and develop hypotheses. However, their answers have to fit the expectations of the teacher. They are valued by the teacher in a positive (if they are accepted) or a negative (if they are explicitly rejected or ignored) way. The learning situation then easily turns into an assessment situation. A learning situation needs a climate in which it is allowed to make mistakes and to develop "wrong" conceptions (Oser, 1994). The assessment issue, however, supports a climate in which it is not wise for students to display wrong ideas.

The limited standard teaching method in German science and mathematics classes that narrows down instruction in various ways also appears to be reflected in the following findings from TIMSS. Students had to provide their opinion about emphasis given to different teaching and learning settings. According to these data more open forms of instruction like group work and students' experiments occur significantly less often in Germany than in other European countries like Austria or the German speaking part of Switzerland (Schlömerkemper, 2000).

The above mentioned findings of TIMSS, i.e. that German students have a certain strength in solving routine tasks but fail in more demanding tasks, is certainly due to the way tasks and problems are solved in class and the kinds of tasks used. First, the dominating "questioning-developing-approach" leads to favoring one single solution only. Students do not have the chance to follow alternative solutions. It is interesting to point to major features of mathematics instruction in Japan as revealed by the TIMS-video-study. In Japan alternative solutions are not only tolerated but explicitly supported by the teacher. Different solutions are also discussed with the whole class. The tasks given are not routine tasks but are somewhat complex in order to allow solutions at different levels. It is further important that Japanese teachers do not follow the German script of questioning and developing but prefer a direct teaching way of presenting the mathematics point of view. Second, the tasks used in German science and mathematics instruction are only seldom of the type called "true" problems by Schoenfeld (1991, 1992). Only a small number call for applications in situations that are of significance for the students (Reusser & Stebler, 1997). Most of them may be solved by routines; usually they are not cognitively demanding and hence do not support understanding (Renkl, 1997). Tasks and problems that allow solutions on different levels are the rare exception.

A further key problem of German science and mathematics instruction is the additive sequencing of the topics. They follow one after the other without serious attempts to link them appropriately (Baumert, Bos & Watermann, 1998). Therefore, the single topics are not sufficiently linked in the students' knowledge base gained. The limited cumulative instruction hinders students in experiencing growth in competency and disturbs the development of subject-oriented learning motivation and interest (Prenzel, 1997).

The above identification of key problem areas of German science and mathematics instruction and the program to increase the efficiency of science and mathematics instruction outlined in the following are theoretically grounded in a script concept. Observed instructional patterns are interpreted within the framework of a choreography (Oser & Patry, 1990) or a script (Lambiotte et al., 1987). The script guides teachers' and students' activities. This script concept not only includes the observable behavior of the actors but also the beliefs, so to speak, behind this behavior. This is in accordance with major ideas of social-cultural perspectives of interpreting teaching and learning processes (Greeno, Collins & Resnick, 1997). International monitoring studies like TIMSS, for instance, provide convincing evidence that scripts in the above sense develop within a particular culture and are shared by this culture (Baumert et al., 1997; Stigler & Hiebert, 1997; Reusser, Pauli & Zollinger, 1998). These scripts provide the frameworks for teachers' and students' individual actions and interactions. A rather stable pattern of behavior and beliefs result which is very difficult to change. Metaphorically speaking, students', teachers' and also parents' scripts have to be re-written; a new shared script has to be developed. Increasing the efficiency of science and mathematics instruction therefore is a long-term endeavor where tacit routines and beliefs of students and teachers have to be altered step by step.

An outline of the program on increasing the efficiency of science and mathematics instruction

The expertise (BKL, 1997) mentioned above includes the conception of a large intervention program to improve science and mathematics teaching and learning in German schools. The program addresses the key problem areas of science and mathematics instruction outlined previously. The aim is science and mathematics literacy in a broad sense, including (a) solid basic knowledge which may be applied in a flexible way in various situations, (b) insights that allow the students to deal with the various demands of a complex world dominated by science, mathematics and technology, (c) awareness of science and mathematics' significance for understanding the world and for participating in decisions of society, and (d) the willingness to further follow developments in science, mathematics and technology and to a readiness for life-long learning in general.

The program's basic view of teaching and learning is constructivist in a broad sense (Steffe & Gale, 1995; Duit & Treagust, 1998). On the teacher side, the aim is the reflective practitioner (as described, for instance, by Schoen, 1987; s. also Tobin, 1998). Making teachers aware of the problems outlined above and later familiar with ideas of solving the problems (based on the findings of research) is seen as the key to the success of the program (cf. Munby & Russel, 1998). On the student side, the constructivist view of an active and self-reflective learner is adopted.

The program is teacher based. On the school level, quality development processes are initiated and further supported. It is expected that the changes within the schools in the program will be a model for changes in general. The conception of quality development of the program meets the major features of the international discussion (Close, 1996; Black & Atkin, 1996; Baker, 1997; Black & Williams, 1997; Fend, 1998). Research findings on school innovation are taken into consideration, claiming that changes of professional actions may be only set into practice if they are (a) accepted by the teachers (Brown, 1997; Knapp, 1997; Stake et al., 1997) and (b) may be successfully developed towards new routines (Wahl, 1991; Brockmeyer & Edelstein, 1997). The aim is an evolutionary development of teachers' views and routines.

A significant feature of the program is to support cooperation among teachers (Terhart, 1987; Terhart et al., 1994) as such cooperation in Germany is not very common. Cooperation includes collaboration within schools and the whole network of schools in which every school is embedded. It concerns joint development of new ideas and materials as well as collaborative evaluation and documentation of results.

180 schools in 15 of the 16 states Germany is composed of have participated in the program. The educational administrations of the individual states decided on participation. There were different procedures for selecting the schools. In a number of states, schools could apply to participate. The 180 schools are organized in 30 school sets, each composed of a *pilot school* as the center of activities and 5 additional *network schools.* Every school set is organized by a coordinator. This person is released from half of his or her normal teaching duties. The necessary funds to balance this are provided by the project. Some states also provide a coordinator who is responsible for the work of all school sets in that state.

Participation of the other teachers is funded by grants for the additional work done. However, the amount of money is rather small compared to the large effort expected from the participating teachers. In total around 25.000.000 DEM are available for the 5 years the program runs. Most of this amount of money is necessary for the mentioned funding of teachers and for the organization of the program. Around 10 % is dedicated to evaluation and additional research studies (see below).

The Institute for Science Education at the University of Kiel (IPN), the central institute for research on science education in Germany, is in charge of the organization of the whole program and its evaluation (responsible: Manfred Prenzel). The Bavarian Institute for Teacher Education and Curriculum Development (ISB) in Munich and the mathematics educator Peter Baptist (University of Bayreuth) are responsible for development and research in the domain of mathematics. Several institutes for science and mathematics education are also involved in the program at local levels. The program organizers provide various means of support including seminars to introduce teachers to the philosophy of the program and papers comprising summaries of research findings as well as examples of how the actual situation may be improved. These materials are available to all participants of the program on an internet server. This part of the server is also available to everybody interested (http://blk.mat.uni-bayreuth.de/blk/blk/). For the participating teachers, the server is also available as a tool to exchange ideas and materials.

The funds for the program are provided by the German Interstate Commission for Educational Planning and Research (Bund-Länder-Kommission für Bildungsplanung und Forschungsförderung), who also initiated the program, and the participating states. The state of Schleswig-Holstein is in charge of the program on behalf of the Interstate Commission (responsible: Bernhardt Brackhahn). An advisory board (Chair: Jürgen Baumert) composed of science and mathematics educators and educational psychologists is responsible for supervising research and evaluation within the program.

The 11 modules of the program

At the core of the program there are eleven modules (Figure 1) which address the major deficiencies of science and mathematics instruction in Germany. In a programmatic manner they indicate which direction instruction take. The modules concern the methods of teaching and learning. However, the particular views expressed in the modules also significantly influence the selection of certain topics and the contexts in which teaching these topics should be embedded. In brief, it is the aim to support active and self-responsible learning and to take into consideration students' pre-instructional conceptions, their interests and preferences.

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Figure 1: The 11 modules of the program
(the figures provide the number of schools dealing with the modules)

The school sets had the opportunity to select the subjects and the modules according to the particular needs identified by the groups of teachers. 154 schools chose mathematics, 89 physics, 69 biology, and 60 chemistry. The number of schools choosing the modules is given in figure 1. Clearly, module 1 is the favorite. In fact, it is the central module for the program.

Module 1: Further development of the task culture

Science and mathematics instruction in Germany is characterized by certain mono-cultures regarding the tasks and problems used and the instructional methods. As outlined above, the standard "questioning-developing-approach" leads to a kind of instruction that is strictly oriented to the aim set by the teacher. Tasks given, problems discussed, and experiments carried out are oriented to that aim only. Students are merely superficially engaged in this kind of instruction. Tasks, problems and experiments used are somewhat narrow or used in a narrow way in order to allow a smooth flow of instruction to the "right" target solution. Module 1 first aims at a larger variety of tasks and problems that also allow different ways to solve them at various levels. Second, the emphasis is on a larger variety of teaching methods and strategies beyond the standard method when a new concept, principle, or phenomenon is introduced and elaborated, when the new knowledge and insights are practiced by applying them to new cases or situations, and when content already taught is repeated. The focus in the schools at the moment is on developing tasks and problems that allow fostering learning and understanding (Lampert, 1990; Renkl, 1997; Reusser & Stebler, 1997). A particular emphasis is given more challenging tasks to apply science and mathematics knowledge in various contexts and situations, as well as tasks that allow more than one way to the solution and to effectively and systematically repeat content previously learned (Baptist, 1997). Module 1 is linked in various ways with most of the subsequent modules as will become evident in the following.

Module 2: Towards more adequate views of scientific work and experiments

It is among the most important aims of science instruction to make students familiar not only with science concepts and principles but also with basic ways of thinking and operating in science. Science instruction should include learning science and *about* science. Driver, Asoko, Leach, Mortimer and Scott (1994) provided a comprehensive list of arguments in favor of including issues of learning about science in science teaching and learning. They claim, for instance, that such an orientation not only provides an adequate view of the nature of science, but is also a prerequisite for an adequate understanding of science concepts and principles. Much emphasis has been given the past decade issues of the "Nature of Science" (NOS) (see Abd-El-Khalick & Lederman, 1998) that supports the claims by Driver et al. (1994). However, there is not much research on the second claim by Driver et al. that an adequate view of the nature of science is essential for understanding science concepts and principles. Where research on the role of experiments is concerned, Harlen (1999) comes to the conclusion that the way experiments are carried out often leads to inappropriate views of scientific thinking and the scientific methods of inquiry.

As outlined above, in German schools the predominating script of teaching narrows down the role of experiments. Errors have to be avoided, hence "everything" is planned, how to carry out the experiment as well as how and what to observe and measure. Usually there is no or only little room for students' active engagement.

Quite often in science teaching and learning it is argued in favor of "hands on" experiments. What appears to be much more important, however, is "minds on". Module 2 therefore puts main emphasis on this issue. It is argued that the experiment should be viewed as an allurement to or challenge for thinking. Futhermore, there are the following characteristics of experimenting in science classes which are at the heart of the program (see also Lunetta, 1998; Harlen, 1999):

- Towards more open forms of experiments that allow active engagement of students;
- towards supporting discourse among students about planning and interpreting an experiment;
- towards encouraging students to generate "research" questions and hypotheses of their own;

- to bring different emphasis of scientific work in the different science subjects (biology, chemistry, physics) together.

Module 3: Learning from mistakes - Towards admitting that mistakes are not just impediments of learning

It is claimed that mistakes are constitutive in learning (Oser, 1994; Oser, Hascher & Spychinger, 1999; Weinert, 1999). They accordingly have to be viewed as opportunities for learning and not (only) as learning barriers. This view has been at the heart of research on students' alternative conceptions and conceptual change for the past two decades (Wandersee, Novak & Mintzes, 1994; Treagust, Duit & Fraser, 1996; Duit & Treagust, 1998). Students come into science classes with manifold alternative conceptions that may be viewed as false from the science perspectives. However, these conceptions provide stable and fruitful interpretation patterns in many everyday situations. Mainstream constructivist approaches on conceptual change have viewed these conceptions as both necessary building blocks of students' constructions and as interpretation patterns that hamper easy access to the science views. The manifold conceptual change strategies that are available provide powerful tools to address students' pre-instructional alternative frameworks as well as in dealing with the more general kind of mistakes that are also given attention in the present module.

Module 4: Towards securing basic knowledge - Meaningful learning at different levels

Pre-instructional knowledge has proven to be a key factor in learning. Pre-instructional knowledge and experiences are usually very different among the students in a class. Therefore, it is difficult to orient instruction to these differing starting conditions. Often this problem is addressed by building homogeneous subgroups of students. In the present program, within module 1, tasks and problems are developed that allow solutions on different levels. Further, different levels of understanding are elaborated for basic science and mathematics content according to differing pre-instructional knowledge and experiences (Prawat, 1989; Reusser & Reusser-Weyeneth, 1994).

Module 5: Making students aware of their increase of competence - Cumulative learning

Students need to know the status of the actual learning task within the whole sequence from the first step to the final state. This issue is often disregarding in science and mathematics instruction (see above). A change from *additive* learning to *cumulative* learning is necessary. What is learned has to be linked to the already learned and to the issues to be learned in future (principle of vertical linking). Instruction gains coherence by the vertical linking (Messner, 1978; Baptist, 1997; Jost, 1999). Conceptual knowledge may be differentiated and partly revised, understanding of qualitatively higher levels may develop (Baumert, 1998). Instructional sequencing has to take this into consideration in order to allow successive increase in competence (Prenzel, 1997).

Module 6: Making students aware of the limited view of a particular subject - Towards integrative features of instruction

Phenomena in nature, technology, society, and culture are usually multi-perspective and complex. In order to understand them, contributions of various domains are necessary. Horizontal linking of perspectives provided by the different sciences, mathematics and other school subjects (e.g. social sciences) are necessary. This kind of linking provides applications of subject oriented knowledge that are more meaningful for the students than applications which remain within the borders of the particular subject (Baumert, 1998). It is also possible to make students aware that different perspectives provide a deeper understanding as the particular advantages and limitations of the single perspectives may be identified. This deeper understanding allows problem solving at an advanced level (DeCorte, Greer & Verschaffel, 1996; Häußler et al., 1998; Ruf & Gallin, 1998).

Module 7: Promoting girls and boys - Towards gender equity

It is well known that girls and boys differ in several regards in learning science (Kahle & Meece, 1994). Most research has been carried out on the different interests of boys and girls. A large longitudinal study in Germany, for instance, clearly showed that girls' interest in physics is far behind the interest of boys and significantly decreases during grades 5 to 10. Intervention studies however revealed that it is possible to increase girls' and boys' interests by embedding the content to be learned in appropriate contexts (Hoffmann, Häußler & Peters-Haft; Hannover, 1998). Powerful contexts are the relevance of the particular content in daily life or regarding the public discussion of the risks and advantages of certain modern technologies, the possibility to understand features of the (human) body, and phenomena that touch emotions and feelings.

Module 8: Development of tasks for cooperative learning

Cooperative learning has been given particular attention in attempts to improve learning in general. This kind of learning not only supports social learning, it also results in deeper cognitive gains (Huber, 1993). Cooperative work allows students to verbalize what they think, to argue and to deal with discrepant views and opinions (Slavin, 1990). Tasks and problems have to be developed for cooperation to lead to the outlined positive effects. Clearly, science and mathematics instruction needs domain specific scripts for effective variants of cooperative learning (Linn, Songer & Eylon, 1996; Renkl, 1997; Huber, 1999).

Module 9: Strengthening students' responsibility for their learning

It is a key insight of constructivist approaches that students are responsible for their learning. To learn the demanding science and mathematics concepts and principles requires substantial effort on the side of the learners. Students' readiness and ability for self-responsible and self-regulated learning has to be developed within the context of the particular subject (Baumert, 1993; Wild, 1996). Instruction may contribute to these forms of competency for effective learning by providing various problems and tasks to be solved independently and various means of repeating previously learned knowledge as well as by supporting strategies for self-structuring and self-monitoring of learning (Hollenstein & Eggenberg, 1998). Support of autonomy and social relations within the learning culture are proven key variables for the development of motivational self-regulation (Prenzel, 1995; Krapp, 1998).

Module 10: Assessment: Measuring and feedback of progress of competencies

What you test you get. Assessment is of utmost significance for the success of instruction in general and for programs like the one presented here in particular (Crooks, 1988; Black, 1998; Black & Wiliam, 1998). The aim is to develop methods that allow support of students' learning by providing feedback about progress of understanding (Rheinberg & Fries, 1998). A particular focus is given the development of manifold assessment tasks and problems that allow evaluating students' progress beyond routine knowledge, including linking the newly acquired with the already known and application of the understanding gained in new contexts and situations (Shavelson & Ruiz-Primo, 1999; White & Gunstone, 1992).

Module 11: Quality development within and across schools

Quality development of schools has been an issue for a long time - in Europe as well as in the United States of America. However, more recently this issue appears to be given increasing attention (Close, 1996; Black & Atkin, 1996; Baker, 1997; Black & Wiliams, 1998; Fend, 1998). The final module, module 11 of the program under inspection here, functions on a meta-level in attempting to develop the conditions and cultures in the participating schools that are necessary for the success of the program. The aim is to develop standards of science and mathematics instruction that are valid beyond the participating schools. Quality development programs have to start from a "stock-taking" of the present state in the participating schools (NCTM, 1995). Criteria have to be developed, discussed and further elaborated to be suited to evaluate the state of students' knowledge and abilities in science and mathematics (Tucker & Coding, 1998). For that purpose, the school sets develop subject specific tasks to evaluate the actual state and its further development (Black & Wiliam, 1998). Criteria developed within the single schools and the single school sets are the starting point of negotiation on standards that are valid on a more general level.

Research and evaluation

The program aims at a long-term, and - finally - a professional process of optimizing science and mathematics instruction using stimulation and support by providing the actual state of research on teaching and learning. This process is carefully evaluated and there are several research projects integrated into the process. Part of these research and evaluation studies is centrally organized by the program organizers, others are being carried out by institutes for science and mathematics education involved in the program on the local level. The following activities are centrally organized and critically supervised by an advisory board.

Module-specific research and development activities

The program organizers provide materials for every module in order to allow the participating teachers to take into account the actual state of research and development with regard to the different issues addressed by the modules. These materials aim at making teachers aware of the educational problems (like how to address students' pre-instructional ideas appropriately or how to set into practice methods of co-operative learning) and to provide means to critically observe and review what is going on in one's own teaching and in the other team members' instruction. The materials include examples of how to develop new tasks, new methods of teaching and learning, or new uses of experiments. The materials also provide the basis for research studies on the issues addressed by the modules that are carried out by the research organizers or on the local level. Three studies are integrated in the activities of the IPN that investigate issues of module 1 (task culture) and module 2 (views of the nature of scientific work) as well as implementation processes. Other studies are in progress in several other institutes all over Germany.

Research on the acceptance of the program

The participating teachers and local organizers are asked to report about the work done in their sets regularly. They are also requested to evaluate the materials, advice and seminars provided by the program organizers and to judge the key ideas and features of the program. Important issues include surface features (like layout and structure of the materials), whether materials and advises are understandable, and especially whether they may be set into practice and may change practice in a fruitful way. Not only the teachers but also the school directors, parents and students are asked to provide their views of the program. Data are collected by the program organizers. A comprehensive questionnaire on the participants' views of the key features of the program was sent to all teachers in early 2000. Results will be available by summer 2000.

Evaluation

The data gathered above may be viewed as part of the formative evaluation of the program. The activities in module 11 on securing quality development have to be seen as a significant part of formative evaluation of the changes within the school sets.

The formative evaluation is essential for the process of quality development. However, a summative evaluation of the program is also necessary. The modules outlined above indicate the kind of changes in science and mathematics instruction that are expected to occur as a result of the many activities running. At the end of the program, solid evidence should provide information on the success or failure of the attempts to improve the quality in the participating schools. The changes should not only occur in single classes but in the whole set of schools dealing with a certain problem.

In spring 2000 a baseline data collection will be carried out that allows investigation of a comprehensive set of the schools' "starting conditions" with regard to the characteristics of the school context and climate as well as science and mathematics performance. The research methods used for this baseline investigation draw on the instruments used in the OECD-PISA-Program (ACER, 1998) and on the additional instruments of the German part of the PISA data collection. In other words, the schools in the quality development program under review here will be integrated into the German PISA sample. Accordingly, manifold data will be available to identify the above characteristics of the schools in the program in comparison to the other participating German schools. In 2003 the schools on the program will also be integrated in the second round of PISA. Hence, a large-scale control group design is not necessary. There is also an option for a follow-up-study in 2006 when the third round of PISA will take place. The instruments employed in these studies are the following:

- A questionnaire on school characteristics (e.g. kind of student intake, level of equipment, kind of teachers, profile and program of the school);
- a student questionnaire on motivational issues (e.g. interest in the subject and in participating in instruction on the subject; subject specific self-concepts) and on science and mathematics specific activities in leisure time;
- student tests on science and mathematics performance.

Research on implementation

Investigations about the implementation of the new program in the schools, i.e. on conditions that support and hamper the process of setting the aims of the program into practice are an essential part of the evaluation (Euler & Sloane, 1998; Reinmann-Rothmeir & Mandl, 1998). Here formative and summative features may also be differentiated. The formative features include the implementation processes within the school sets. The summative features address the implementation of the ideas and results of the program into the other schools in Germany.

The studies outlined above also provide significant basic information on implementation processes. A study on implementation processes carried out in the IPN (see above) allows deeper insights. A key focus of studies on implementation processes is on activities that support the work in the participating groups and that help the participants to overcome conflicts and difficulties. From a theoretical perspective it is of interest which school characteristics and which kind of activities and support by the regional and central coordinators are essential (Fullan, 1991). Evaluation provides information on this. In addition, more qualitative data will be available from case studies on the implementation processes in selected schools. It is the aim of the implementation studies to gain information on the conditions for implementing the concept of quality development beyond the schools involved in the project.

A national focus program on research on science and mathematics education

As another reaction to the alarming results of German students in TIMSS, the German Science Foundation (Deutsche Forschungsgemeinschaft) initiated a "focus program" on studies on science and mathematics teaching and learning (Prenzel, Merkens, Noack, et al., 1999). This program will be funded for six years. About 20 individual projects will closely cooperate. A particular focus of this program are context factors of science and mathematics learning that go beyond the features of learning environments in science and mathematics lessons including the impact of the broader school context and out of school contexts like parents and peer groups. These projects address issues that are also at the heart of the quality development program presented here. A number of the projects are integrated into this program in using student and teacher samples. This is true, for instance, for video-studies on physics (Prenzel, Duit, Euler, & Lehrke, 1999) and mathematics (Klieme, 1999) instruction. In both studies teachers' and students' scripts of instruction and their interaction with learning processes will be investigated. In the first phase of the studies, classes involved in the quality development program will be the target group. In general, findings from research on the quality development program and from research within the focus program will provide a body of research knowledge that will be a powerful basis for improving science and mathematics instruction.

The actual state of the program and an outlook

The quality development program started in late 1998 and will last for five years. The first phase of activities focused on the organization of the whole project, on elaborating the major aims and on developing materials to explain the aims as well as to support the work in the school sets. At this time (spring 2000) there are only preliminary results of research and evaluation activities available. The main sources are the reports the teachers and local coordinators have to provide, reports that are published, for instance, in journals and more informal information available by interactions of the organizers with teachers involved in the program. By the end of the year 2000 more solid results of the above mentioned study on the acceptance of the program and the baseline investigation within the PISA study will be available. In the following we briefly provide an overview of the major insights about the program available so far.

First, we would like to refer to the focus given to the particular subjects and modules reported above. Most schools (154) deal with mathematics. This preference is due to the significance of mathematics instruction in the German syllabi and due also to the fact that German students did particularly poorly in mathematics. Among the sciences, physics is given preference (89 schools dealing with this subject), with biology (69) and chemistry (60) following. However, it should be taken into account that the program explicitly supports the close cooperation of the subjects, for instance, under the umbrella of cross curricula features like co-operative learning or learning from mistakes. Module 1 is the target of most (114) schools. It appears that especially mathematics teachers are of the opinion that the task culture in their instruction should be improved and that by this the educational spirit of the whole program may be effectively initiated. Where the school level addressed is concerned, most activities are focused at lower secondary, i.e. at grades 7 to 9 (about age 12 to 15).

The 11 modules merely provide a somewhat general frame for the work in the school sets that has to be specified and focused. Therefore, the participating teachers were asked by the program organizers to develop a plan of their work including describing and justifying the aims and developing plans for the work in detail. These documents were rated by two raters independently. The ratings reveal that about half of the schools provided documents that clearly state and elaborate the aims as well as describe the activities and products in detail. However, it became also clear that a number of schools only developed vague ideas about their work. With regard to the fit of the plans with the ideas of the program, the results of the ratings are quite encouraging. About 90 % of the rating indicated "strong" or "somewhat strong" orientation towards the ideas of the program (5 point Likert scale).

A local study on the school set in Bremen (Hauk, 2000) employing interviews and questionnaires provides some preliminary insight into these teachers' motivation and expectation in participating in the program. It appears that one strong motive is that teachers are not pleased with the present state of their teaching and that they expect instruction will become more pleasing for teachers and students when the ideas of the program are set into practice. A large number of teachers also expect the program will allow exchanging and discussing ideas with other colleagues - also beyond the own school. These findings are supported by the fact that the central server is used to exchange ideas and that several school sets started their own homepage which is also open for guests from outside the set.

Briefly summarized, the data available show that the program initiated valuable activities on improving science and mathematics instruction throughout Germany. There is much interest in the progress of the program by teachers outside the project. It appears that the initiative has been greeted by many teachers it is an attempt to change a situation that is no longer pleasing to them. The enthusiasm and the quality of products and ideas in many school sets is impressive as the already published reports reveal (Diefenbacher & Wurz, 1999; Henn, 1999; Hepp, 1999; Herbst, 1999; Heußer, 1999; Köhler, 1999; Maier, 1999; Schupp, 1999). For a number of teachers a particularly significant issue appears to be the close cooperation with their colleagues and especially the mutual visits to instruction. The wish of a number of teachers also appears to be worth mentioning, i.e. of documenting their actual teaching and their future teaching when changes are likely on video.

Of course, the optimistic preliminary picture painted earlier does not hold for all school sets. There are various problems in a number of the sets that even question the success of the program for these participants. However, a discussion on more effective and pleasing science and mathematics instruction started in Germany that will most probably change the awareness of a substantial number of teachers and decision makers outside the quality development project. Even if the results in a number of school sets are not totally pleasing (or not pleasing at all) from the perspective of the program organizers we are convinced that there will be a significant push to change science and mathematics instruction into a direction we are aiming at.

From the perspective of research in science and mathematics education we would like to add that the developments outlined in this paper are most promising. On the one hand, the large school based quality development project provides manifold opportunities for science and mathematics education research. The close interplay of research and practice will lead to research knowledge that allows information about practice in a more fruitful way than it is possible today. The above outlined focus program of research in science and mathematics education will substantially contribute to this research knowledge. Particularly important features of this program are: first, that there is a focus in all projects towards improving practice; and second, that science and mathematics educators on the one hand and psychologists and pedagogists on the other cooperate closely.

In closing we would therefore like to point out that there will be results from the program outlined in this paper that are of interest for improving science and mathematics instruction outside Germany. We hope to be able to report about major findings in the near future.

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