Pupils, teachers and schools as mathematics learners

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Abstract

The paper focuses on the question how instructional and school development might be productively interrelated. In an exemplary way, it describes two secondary mathematics teachers' activities aiming at improving their teaching within the context of a nation-wide reform initiative in Austria. The teachers, supported by a mathematics educator, each investigated their own teaching practices. They not only improved their teaching, but sharing their experiences with other colleagues at (and partially outside) their school also contributed to their school's further development at different levels. The paper describes and explains this developmental process and reflects conducive and hindering aspects of linking individuals' growth and organizational learning.

1 Introduction

Research in mathematics teacher education has made considerable progress in describing and understanding *individual* mathematics teachers' growth and development (see e.g. Loucks-Horsley, Hewson, Love & Stiles 1998, Jaworski, Wood & Dawson 1999, Krainer, Goffree & Berger 1999, Lin & Cooney 2001, Peter-Koop, Begg, Breen & Santos-Wagner 2003, Adler, Ball, Krainer, Lin & Novotna 2005). We have learned, for example, how long-term professional development programs, collaborative research projects, etc. support mathematics teachers' efforts to bring about change.

However, it is often argued that teachers who participate in such intensive initiatives are "always the same," and those who really do need improvement do not come (see e.g. Krainer 1999). Furthermore, the growth of a single teacher does not necessarily have an impact on other colleagues at his or her school. Experience shows that it is neither easy for individual teachers to find colleagues who really want to join in their efforts to improve teaching, nor it is easy to sustain enough motivation and perseverance to realise changes in the short or long run. Furthermore, innovative action at a school is often regarded rather critically by non-participating teachers, a situation that can lead to open or hidden resistance and opposition. Even a pair of colleagues co-operating successfully might not be enough to have an impact on other teachers. Similar experiences were reported in Borasi, Fonzi, Smith and Rose (1999, p. 75) who pointed out that their professional development program had additional benefits when not just pairs but a critical mass of teachers from the same school participated in the program. If professional communication among teachers is not an important feature of the school culture, innovations by individual teachers remain limited to them and their classrooms. Schools as organisations have their own rules, habits, general conditions, and power relations. These factors greatly influence the role that mathematics teaching can play at a school.

In reaction to that increased knowledge and experience, more and more alternative approaches to promoting mathematics teachers' growth are carried out, taking into

account the *social and organisational* aspects that determine teachers' work. More than in the past, recent research papers in mathematics teacher education report about initiatives where teams of teachers, communities of practice, networks, or even whole departments of mathematics in schools learn together. We can state an increasing awareness of the social dimension in mathematics teacher education (Krainer 2003a).

There are expectations that working with entire mathematics departments (see e.g. Krainer 2001) can give birth to whole school development activities and that mathematics teaching could be more visible and could play a greater role at that school. However, it is not realistic that such organisational development processes can be carried out and can externally be supported at each school. Nevertheless, even in professional development programs with single teachers from different schools it should be possible to put an emphasis on the question how these teachers might bring about change not only in their own classrooms but might influence the further development of their mathematics department and eventually their whole school.

In the following, the paper describes the Austrian nation-wide reform initiative IMST² which was the context for the professional development process of two secondary mathematics teachers which will be analyzed later on.

2 The Austrian reform initiative IMST²

Following the poor results of Austrian high school students in the TIMSS achievement test, a research project was set up in which the results were analysed and additional investigations into the situation of mathematics and science teaching in Austria were started. As a consequence, the reform initiative *IMST² - Innovations in Mathematics, Science and Technology Teaching* was launched in order to support teachers' efforts in raising the quality of learning and teaching in mathematics and science (for further details see e.g. Krainer, Dörfler, Jungwirth, Kühnelt, Rauch & Stern 2002, or Krainer 2004).

In the years 2000-2004, each school-year about 50 innovation projects at Austrian upper secondary schools (and partially at other organisations, e.g. teacher education institutions) were supported by teacher educators in four priority programs (S1 – S4) according to the challenges sifted out in the above mentioned research project. The rationale of the four *priority programs* was the following:

Basic education (S1) reacted to the unclear expectations concerning qualifications, knowledge and contents that students need when leaving secondary school; the four S1-teams (biology, chemistry, mathematics and physics) supported initiatives at schools that planned and evaluated corresponding teaching units and worked out (inter-disciplinarily interconnected) concepts for basic education at the upper secondary level for the four subjects.

School development (S2) reacted to the relatively low status of the subjects biology, chemistry, mathematics and physics at schools, in comparison to their importance in society and the economy; the S2-team supported schools that set a focal point on mathematics and science teaching, and they tried to establish a network of such schools and to foster exchange of experience among them.

Teaching and learning processes (S3) reacted to the dominance of relatively passive forms of learning, not sufficiently taking into account the individual needs of students in general, and the low interest and the poor results of Austrian girls in the TIMSS-achievement test in particular; the S3-team both supported innovations at schools focusing on situation-appropriate teaching and learning processes and aimed at

working out a concept for generating, analysing and evaluating such processes (see e.g. the CD-Rom with video-clips developed by Jungwirth & Stadler 2003).

Practice-oriented research (S4) reacted to the lack of well-developed practice-relevant research and development in mathematics education and in science education in particular; the S4-team initiated, financed and supported teams of teachers or teacher educators (or mixed teams) who carried out investigations into their own teaching in order to promote students' (or student teachers') autonomous learning.

In general, teachers in all four priority programs (and later on also in a specific gender program) got support by staff members of IMST². On average, teachers within a priority program and their staff members met two times a year. In addition, communication also happened via phone or e-mail, partially (as done, for example, in S3) staff members organised individual meetings with their teachers (e.g. at their school in order to collect or discuss data). In many cases, the first meeting focused on working out the goals of the innovation and/or the research question of teachers' projects. Then the teachers refined their individual plans, carried out and analysed their investigations, supported by a staff member of IMST² or another critical friend. In many cases, one meeting dealt with provisional versions of teachers' innovation reports which were discussed in the whole group, in sub-groups or individually between a teacher and a teacher educator. The priority programs can be regarded as small *professional communities* that not only supported each participant to proceed with his or her own project but that also generated a deeper understanding of critical reflection of one's own teaching, of formulating research questions, of looking for evidence based on viable data, and on methods that help to gather that data.

Writing down the experiences is for many teachers a real challenge. It means not only an additional step of reflection but also a way of formulating the process and the results in a way that others can benefit from it. It is a major goal of IMST² to publish teachers' innovation reports on the web. It is intended to make reflective knowledge of mathematics teachers visible and accessible to a wider public and thus to contribute to the further development of the teaching profession.

Innovations played a key role within IMST². The corresponding basic assumptions were:

- Starting from *strengths*: Innovations are initiated, supported and made visible, thus motivating others to join in, stimulating "attraction" instead of generating "pressure".
- Innovations are not regarded as singular events that replace an ineffective practice but as *continuous processes* that lead to a further development.
- Participation is *voluntary*, teachers and schools have the *ownership* of their innovations.
- There is no "best practice" which might be defined by an external authority. For each learning and teaching context *different approaches to „good practice"* exist. Innovations are planned steps towards a "good practice".
- Through innovations and reflections *teachers construct their own professional growth* (likewise the students are seen as active learners).

- *Writing down* the experiences in a systematic way means a second step of reflection and opens the opportunity for more people to learn from those experiences.
- The dissemination of innovations passes along *personal relationships and experiences*, however, the existence of *clear and supportive organisational structures* is an essential conducive factor.
- One powerful strategy for wide-spreading innovations at schools is to *look for critical friends* in one's own mathematics and science teacher group, to inform other colleagues, the principal and other important administrators about the innovations and eventually to involve them into the innovation project.
- One powerful strategy for wide-spreading innovations to a whole system is to initiate *regional networks* and to promote their communication with other networks.

For these reasons, IMST² aimed at working with least two teachers from one school in each innovation project. Yet, at the very beginning of IMST², this was not possible for many projects. It was one challenge of the teacher educators to support teachers in developing strategies for enlarging the project group. The support of the principal was regarded of great importance. Therefore, in IMST², the priority programs signed contracts with (single or teams of) teachers, and these documents (defining the goals and content of the collaboration) were also signed by the principal.

In the school-year 2000/01, 34 innovations at schools (and partially universities or other institutions) were promoted within the context of IMST². This number continually increased till the last year of the project (2003/04) in which 62 innovations were supported. The outcome of the project was evaluated from different perspectives (students' and teachers' learning, development at the school and at the regional and national level). The main emphasis was put on looking at the professional growth of teachers and on how IMST² generated the basis for a sustainable support system for mathematics and science teaching in Austria (in a next step extending the initiative to the whole secondary schooling, and also integrating new subjects like geography and information science).

For example, an external evaluation using a questionnaire for teachers and principals (Specht 2004) investigated the effects of IMST² at schools after two years. It concludes that the initiative mostly reached active schools and teachers. The project is regarded as an *"important, helpful and effective support for instructional and school development"*. The evaluator stresses that positive changes dominate and indicates that they refer, for example, to more readiness for innovations in teaching, increased ability to reflection and self-evaluation and intensified collaboration. Only a few problematic aspects were articulated by teachers and principals, for example, indicating too much work (e.g. for those who are engaged in many activities) or conflicts among teachers (e.g. because some teachers resist to take responsibility). Other evaluation data included, for example, teachers' own written reports, meta-analyses of those reports by the IMST² staff, some exemplary case studies on teachers' professional development, and case studies on some development of schools (e.g. carrying out interviews with participants and principals) supported in the context of IMST².

In the following, the paper sketches the struggle of two teachers [1] to improve their teaching within the *priority program "Teaching and learning processes"* (S3). Data

include teachers' innovation reports, papers by the supporting mathematics teacher educator in S3 (Helga Jungwirth), interviews of the author (project director of IMST²) with one teacher, a conference report of this teacher together with the author, a case-study on the school's development process including interviews with teachers and the principal by a member of the evaluation staff (Gertraud Benke).

Both teachers, *Gottfried Dangl and Maria Scharizer* (real names), are experienced mathematics and physics teachers at a secondary school (Schule der Kreuzschwestern**)** in Linz. Gottfried and Maria participated for the same two years in the mathematics strand of S3. However, they did not start their work in IMST² as a team but entered into the project with two totally different challenges and development perspectives. Only later, as the story will show, the interests of the two teachers came together and initiated a synergy, neither planned nor foreseen by any of them or other people. It is the story of a dynamics that emerged out the interesting focus of these teachers, the context of that school and the support by the project, in particular by the mathematics teacher educator.

3 Looking at two teachers' professional development

Case 1 - Gottfried's struggle for improving pupils' attitude towards working at the blackboard

At the beginning, Gottfried's main interest in IMST² (Dangl 2002) was to get a general feedback about his teaching. In particular, he was interested to understand pupils' view of problematic aspects of his teaching. Like in many other cases, including Maria, the support process by the mathematics teacher educator started with individual conversations with the teacher. Very essential was to work out the specific needs and problems that should be investigated more deeply. Gottfried and Maria decided to focus on the lowest classes of their school's upper secondary stream (9th grade). Together with Helga (Jungwirth 2002 and 2005), they further developed an existing questionnaire, and in addition, their mentor also carried out interviews with two pupils from each class (nominated by the teachers). These data were separately discussed with Helga who intensively contributed to the generation and analysis of the instruments. Gottfried got a real positive feedback to his teaching; however, one aspect of the feedback challenged him: he realized that pupils' view of working at the blackboard did not match his own view. As a consequence of that, Gottfried decided to go deeper into that aspect and to gather additional data. A more detailed questionnaire was developed; he made field notes concerning pupils' and his own behaviour during pupils' work at the blackboard. In addition, Helga – a specialist in ethnography of teaching – video-taped a classroom unit where pupils worked at the blackboard. The teaching analysis revealed that the teacher and the students constructed different frames of these situations. Whereas he aimed at generating an open learning environment for the pupils, some of them felt like of fool with regard to their class-mates when working lonely at the blackboard. Among others, Gottfried realized the importance of clearly articulating his expectations, for example, indicating whether in a specific teaching situation errors are welcome (as a starting point for learning) or should better not happen (because it is an examination and leads to a bad mark).

The positive experience with the feedback from his mentor woke his interest to get also collegial feedback from other teachers. He initiated mutual classroom visits among a group of three teachers at that school. The continuation of that collaboration at this school will be described within the case of Maria (who also took part in that

group). In an interview two years after his participation in the project (Benke 2005), Gottfried indicated that he is pleased both with the larger number of pupils who voluntarily chose mathematics in their final exam, as well as with these pupils' better achievement, in the written and the oral part of this exam. Concerning his own professional growth, he stressed that *"for each participant the project was a personal enrichment"* which brought a *"broadening of perspectives"* and a *"strengthening of one's self-confidence"*. He highlighted that he feels now better able *"to argue more clearly his viewpoint"* in conferences or other professional meetings.

Case 2 – Maria's struggle for promoting pupils' autonomous work

Maria's major insight from her IMST²-participation in the first year was that her pupils experienced open learning as very positive, nevertheless, a lot of pupils articulated that this approach asked too much of them (Scharizer 2002, see also Jungwirth 2002 and 2005, and Krainer 2003b). Therefore, she decided to use open learning in the same class (in the meantime at grade 10) again, but also to look critically at pupils' difficulties when working autonomously. Maria aimed at promoting pupils' taking responsibility for their learning and at enabling them as far as possible to check their working results by themselves.

She planned nine teaching units in trigonometry. The pupils worked in pairs and got working sheets for elaborating new contents (where all items had to be solved) as well as file-cards for stabilizing and practicing the learnt (where the pupils were free to choose). Maria paid much attention on checking pupils' learning progress. The working sheets were controlled by her, the pupils were expected to check the file-cards themselves.

For data gathering Maria used two methods: she audio-taped some pairs of pupils when elaborating the definition of goniometric functions, and she gathered pupils' written feedback (asking for positive and negative aspects of open learning). Pupils' answers showed that they liked this approach very much, indicating, for example: *"I appreciate open learning very much, because I can work on my own pace"*; *„With open learning I need a little bit more time, but then I really understood it"*; *„I like open learning, because I get help without being forced to ask in the presence of the whole class"*; *"Open learning makes more fun"*. (Scharizer 2002, p. 6)

Maria found listening to the audio-tape really revealing. In her innovation report, above all, she reflected on the problems the pairs of pupils had and which kind of help she gave them. She tried to avoid direct answers to pupils' questions. Instead, she tried to intensify pupils' autonomous learning by small hints like „read carefully", or by playing questions back to them (e.g. asking „What does it mean that …?"). She was really pleased by a section of the audio-tape where a pupil was successful in explaining a mathematical theorem to another pupil with convincing arguments.

Maria resumed *„that several pupils came out of their shell and contributed to solutions in a more intensive way as they usually did when elaborating things with the whole class."* (Scharizer 2002, p.7). In addition, she found that working with that approach, even weaker pupils had a sense of achievement and got motivated by that fact. She stressed that autonomous work needs to be practised; however, after a phase of getting used to it, this kind of work does not cause exceptional difficulties to pupils. Maria highlighted that her changed role in the classroom enabled her to observe students' learning and thus having more time to reflect on her teaching. She found that she is now more aware of the importance of supporting pupils' autonomous learning, and she is willing to invest time. She concluded that taking that approach it is possible

to increase self-confidence of pupils, and even quick thinkers and very talented pupils can be supported adequately.

Maria also further developed the working sheets, in particular sharpening the working instructions for the pupils. She presented the outcomes of her investigations in a meeting of the school-internal working group of mathematics teachers (and later even in a school board meeting – led by the principal – with representatives of teachers, students and parents). These inputs had a stimulating effect on the whole group of mathematics teachers: her colleagues were interested to use that material and to report back to her about their experiences.

The merging of the cases: Gottfried and Maria as active contributors to the school's development process

Maria also joined the peer-group consisting of three mathematics teachers which Gottfried initiated in order to install mutual classroom visits. This activity was highly supported by the principal (who also was a science teacher) and became a part of the school's evaluation culture. Also the use of a questionnaire for evaluating teaching became a model for the whole school. The school's teaching staff unanimously decided to integrate these two activities into their two-year development program ("Schulprogramm"): each teacher should either participate in a peer-group (carrying out mutual classroom visits) or evaluate his or her teaching with a questionnaire. In a recent interview, Gottfried stressed: *"And I regard that as a sensational success, since it began with a small questionnaire … and it ended up with a school development program where 120 teachers enthusiastically work on that, and now these two years are gone … We are working now on a school development program 2, where it is considered to retain certain elements like the peer-groups and to support it. In particular, young colleagues regard that as a chance to observe senior ones and to ask for further information."* (Benke, 2005).

Within IMST², Gottfried and Maria met several times with the group of mathematics and science teachers that participated in priority program 3. Through that participation they became increasingly interested in laboratory teaching ("Laborunterricht"), thus showing that the project not only effected mathematics but also science teaching. With regard to that, for example, Gottfried highlighted: *"In particular, this laboratory teaching was pointed out over and over … one can see a primer detonation that slowly becomes an extending movement"*. As a consequence, a new subject putting an emphasis on laboratory teaching in science was introduced at the school. Gottfried stressed that *"due to the participation in IMST, the ground for science-related work has improved generally … Through that participation also others got somehow more open, we try out something new …"*. Maria saw a kind of *"leaping over"* from innovations in mathematics teaching to science teaching, as well (Benke 2005).

The principal, when also recently being interviewed, stressed that the mathematics teachers of that school have a long tradition of engagement for a good quality of teaching. She regards the focus on evaluation which started in the mathematics group as a *"sustainable development"* for the whole school, among others caused by a *"stronger awareness of the science teachers"* (Benke 2005). The fact that Gottfried and Maria were (apart from being mathematics teachers) also physics teachers, fostered that process.

In the following, the he paper introduces the four dimensions *action*, *reflection*, *autonomy*, and *networking*, and later uses them as a framework to explain this developmental process.

4 The theoretical perspective: action, reflection, autonomy, and networking as dimensions of "learning systems"

The following considerations are based on the assumption that social systems (society, educational system, school, teacher education institute, mathematics department, classroom, family, teacher, student, etc.) can be very different, but can nevertheless be regarded through the lens of some general dimensions that are fundamental for their further development. Social systems can be seen as "*learning systems"* when the interaction of the actor(s) within the system or with relevant environments (other systems, e.g. sub-systems and higher-systems) are characterized by the following four dimensions [2]:

- Attitude towards and competence in experimental, constructive and goal-directed work (*action*).
- Attitude towards and competence in reflective, (self-)critical and systematically based work (*reflection*).
- Attitude towards, and competence in, autonomous, self-initiative and self-determined work (*autonomy*).
- Attitude towards and competence in communicative and cooperative work with increasing public relevance (*networking*).

The four dimensions are intentionally described in an *abstract* form in order to be able to apply them to different systems. For example, considering a "learning school", the dimension "autonomy" might refer to a team of mathematics teachers of that school. "Networking" then refers to their interactions with other relevant systems within or outside their school, e.g. other teachers, other departments, the principal, parents, a mathematics educator team at a university or the inspectors of the region. A joint relevant action of this team of teachers might be the development of a new curriculum, whereas reflection might refer to meetings of the team evaluating the progress of the implementation of the curriculum. Inviting experts (e.g. from university or teachers from other departments) in order to discuss their experiences can be regarded as actions that lead to more intensive reflection and networking, furthermore, it will probably result in the teams' improvement of the quality of its autonomous actions.

The concept of "learning systems" makes use of several theoretical backgrounds: The interplay between action und reflection, for example, is a prominent feature of *action research* (see e.g., Elliott 1991, or Altrichter, Posch & Somekh 1993), the interplay between autonomy and networking marks a link between *cognitive and social constructivism* (see e.g., von Glasersfeld 1991, or Ernest 1994). *System theory* (e.g., Willke 2000) puts an emphasis on considering different relevant environments. The importance of the interplay between the four dimensions action, reflection, autonomy and networking is supported by manifold considerations. For example, Stenhouse (1975, P. 144) defines teacher professionality as a *"capacity for autonomous professional self-development through systematic self-study, through the study of the work of other teachers and through the testing of ideas by classroom research procedures."* Schön (1983) refers in his notion of *"reflective practice"* to the crucial interplay between action and reflection and distinguishes *"tacit knowing-in-action"*, *"reflection-in-action" und "reflection-on-action"*. The importance of communication and networking in social systems is stressed in a variety of books, for example using

concepts like *„community of practice“* (Wenger 1998) or *„corporate systems“* (Willke, 1999).

In many cases, the weak point of social systems is that learning occurs isolated (and not jointly and supported, mutually and/or externally) and non- critical (taking existing routines as given): autonomous action predominates, lacking reflection and networking. Therefore, in order to get the system more balanced, an adequate intervention strategy is *to promote the system's focus on reflection and networking*. This is a central feature of the intervention strategy of IMST².

5 Explaining the progress: Gottfried's and Maria's classroom, their IMST-group and their school as "learning systems"

The case of Maria and Gottfried showed that progress occurred at different levels (exemplified by some selected indicators):

- *Pupils:* More pupils voluntarily chose mathematics in their final high-school exit exam, also showing better achievements (Gottfried); the teacher observed pupils' successful argumentations and problem solving, high motivation and satisfaction (Maria).
- *Individual teachers:* The teacher reported that he extended his perspectives for teaching and assessing, got a broader repertoire for dealing with specific teaching situations, and strengthened his self-confidence, thus being better able to argue more clearly his viewpoint in conferences or other professional meetings (Gottfried); she claimed that she became more aware of conducive and hindering general conditions for pupils' learning (in small groups), set the priorities concerning mathematical contents that pupils should learn more consciously, and created new ideas for improving instructional material (Maria); both teachers were invited to report at regional and national meetings in Austria and at conferences in Germany (Gottfried and Maria).
- *Team of teachers:* The teachers reported about experiences within the project and exchanged instructional material (mathematics teachers); a peer-group was formed (mutual classroom visits, starting with mathematics teachers); innovations leapt over to science teachers, laboratory teaching was introduced (science teachers).
- *School (as an organisation):* Teachers gave reports in conferences and at school board meetings; the questionnaire-evaluation and the mutual classroom visits in peer-groups were integrated as elements of the school development program; a new subject putting an emphasis on laboratory teaching in science was introduced.

How can this development be explained? In the following, the four dimensions will be used as a framework for explaining pupils', teachers' and the school's progress, primarily focusing on Maria's case.

Pupils' learning

Maria's teaching innovation shows a rich dynamism concerning the above-mentioned four dimensions. This can be visualized as follows (fig. 1):

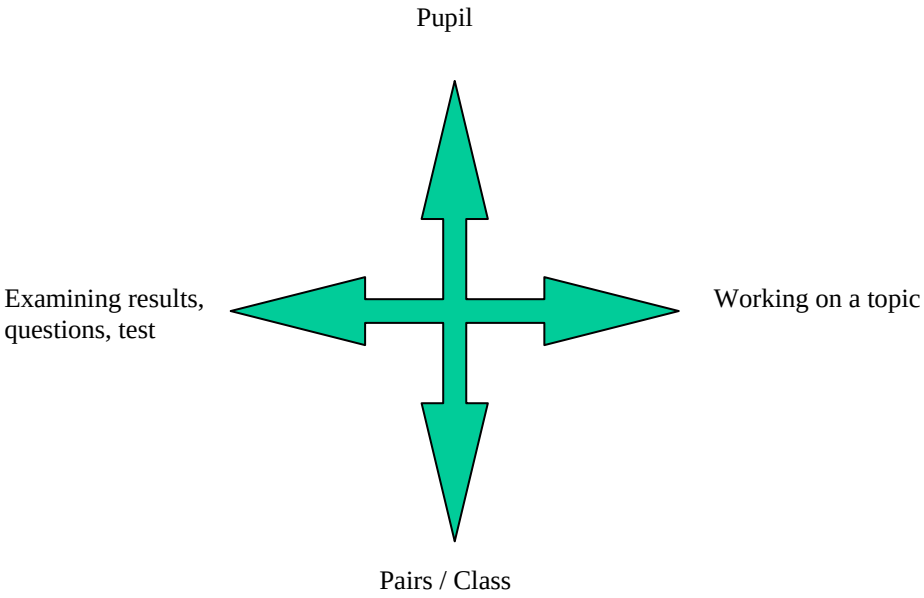

Figure 1: The classroom as a "learning system" for the pupils.

Action and reflection: Maria planned her lessons carefully: she did not only initiate pupils' goal-directed activities but also integrated different situations where the attainment of goals was checked. Teacher's low intervening support and her fostering of mutual explanations among pupils contributed to their critically examining learning.

Autonomy and networking: Maria strongly promoted pupils' autonomous learning. In particular, working in pairs gave them enough scope of freedom to find their own working pace and to share their knowledge about the specific topic. Maria gave hardly any direct teacher input and played pupils' questions back to them. She challenged the pupils to control their attainment of goals by themselves.

Altogether: Reducing the teachers' role to a facilitator not only increases students' responsibility for their learning process but also gives the teacher time for observation, reflection and goal-directed help for individual students, groups or the whole class. With her approach, Maria fostered both pupils' individual learning as well as their joint and critically examining learning. In that sense, she was successful to establish an adequate balance of the four dimensions.

Teachers' learning

The basis for Maria's learning was her innovation project. It was grounded in an action research approach using different methods. She was externally supported by the IMST²-mathematics teacher educator. Maria had at least three "learning systems" where she participated: her class, her IMST²-S3-group, and her school's math and science teachers. This can be visualized as follows (fig. 2):

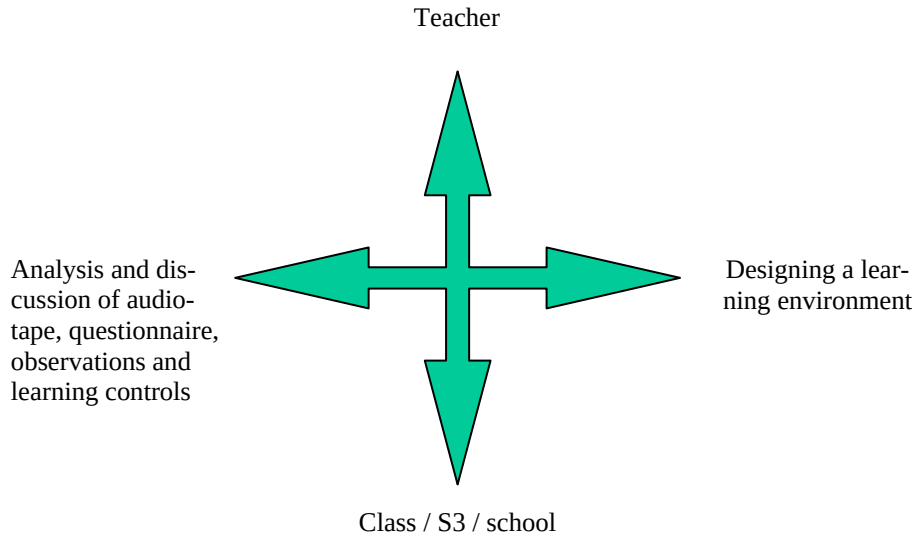

Figure 2: Maria's participation in three "learning systems.

In principle, the three learning systems (her class, her IMST²-S3-group, and her school's math and science teachers) could be visualized by three different figures. However, Maria aimed in all three systems at achieving the same goal, namely to design, to reflect and further develop her teaching experiment. Therefore, taking advantage of the abstract feature of the learning system-model, it is possible to visualize the three systems in one figure. Nevertheless, these three environments in which Maria participated had different contexts and thus also gave her different opportunities to reflect and to learn.

Action and reflection: Maria gathered and analysed – with the support of the teacher educator – several data which helped her to investigate the impact of her teaching experiment and to reflect her learning. In particular, she stresses the importance of the audio-tape (Benke 2005): *"… there one can hear conversations that run in a natural way. And this was very interesting for me. … discussions emerge that I never would see from a written feedback."* Gottfried indicated the same concerning the use of the video-tape. Furthermore, both teachers highlighted the importance of writing down one's experiences in the innovation report. For example, Gottfried stated (Benke 2005): *"Through writing down one thinks much more intensive, one has to accentuate much more clearly, and this is a crucial aspect of the whole project. In order that it continues going in depth, and not only is swimming on the surface. … As a teacher, it was new for me to do such [writing]. However, I do not want to miss it, since I surely would not have accomplished such a lasting final report."*

Autonomy and networking: Maria and Gottfried profited from their pupils' feedback very much. In addition, they participated in two professional communities. Within the IMST-S3-group as well at their school they presented and got essential feedback to their initiative. For example, Gottfried stated with regard to the S3-meetings: *"These meetings have always been illuminating; on the one hand they widened the horizon, and on the other hand, these presentations … were essential for strengthening the self-confidence."* Several times, Maria (like Gottfried) indicated the important role of external help (by Helga): *"Teachers often need a motivation or an impulse. And I think it is important that someone external offers stimuli and support, in order to cross one's threshold*." (Benke 2005)

Altogether: Apparently, Maria's and Gottfried's participation in IMST² offered them opportunities to try out an investigative attitude in their class and to find interested colleagues within the project and at their school that shared their struggle for improving the quality of her teaching.

School's learning

The progress as affected by IMST² was partially built on at least three favourable general conditions at that specific school. Firstly, the principal (being a science teacher, as well) supported the projects by Gottfried and Maria. Secondly, and probably interconnected with that, collaboration among teachers (in particular, in the mathematics group) had some tradition at that school. Thirdly, parallel to Gottfried's and Maria's participation in IMST², the school worked on a school development program and had implemented adequate steering structures. This can be seen as relevant conducive factors for the school's further development in general, and with regard to mathematics and science teaching in particular. Based on these general conditions, it was easier for Gottfried and Maria to find other colleagues at their school to join and spread their actions and reflections as initiated within the context of IMST². This can be visualized as follows (fig. 3):

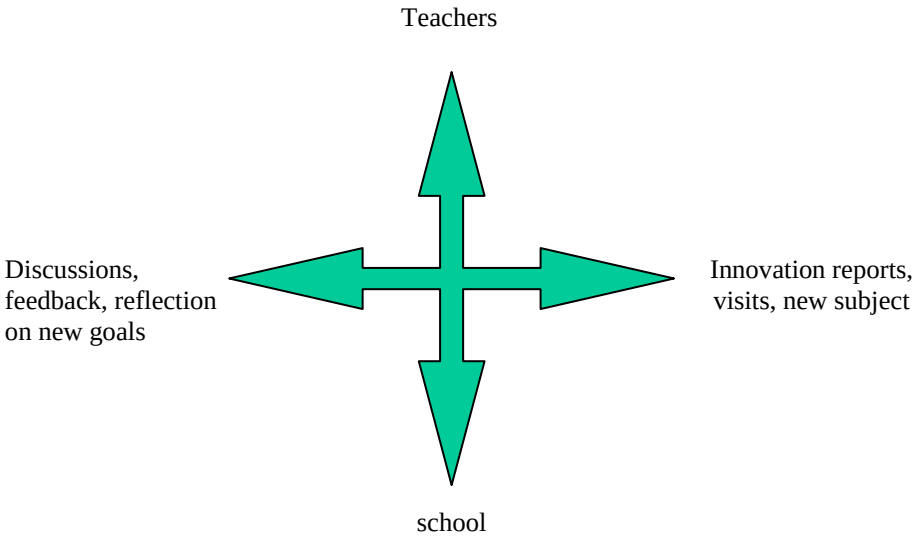

Figure 3: The school as a "learning system".

Action and reflection: Maria and Gottfried set a lot of activities that opened the door for other teachers to join them. They did not act as missionaries that can or will tell other colleagues what they should do or how they should change. In contrast, they brought in their questions and challenges, spoke about their learning process, asked for feedback to their teaching, and invited others to give feedback to their teaching material. So they offered a good starting point for reflection of all people concerned. The role of the mathematics educator who supported Maria and Gottfried was very important, since her feedback formed a good basis for the school's reflection and further development. For example, the principal stressed in a recent interview that she found *"Dr. Jungwirth's feedback, written as well as orally"* as extremely supportive; in particular, she highlighted that the written reports that were given to the school *"were dealt with in the working group"* (Benke 2005). This underlines the importance of written documents by teachers since it can be used as a concrete basis for other

people's reflections. In addition, it might be supportive as a feedback for the case-bringer in order to further develop his or her own situation. But also the feedback-givers can learn and use their insights for their individual situation.

Autonomy and networking: The ideas and activities of Gottfried and Maria had its influence at different relevant environments at the school, above all, within the group of mathematics teachers, the science teachers, the conference, and the school board. Apparently, the principal recognized the potential power of their innovations for this school and supported its spread and networking at different levels. For example, Gottfried stressed that *"the principal's readiness or positive indicating our participation at IMST²"* always was very positive, and that they *"reported continually in conferences"*. For him, this leads to the fact that *"the importance of such participations is raised"*, that *"one is not smiled at by the teaching staff"*, and that *"the other teachers might see a benefit for them"* (Benke 2005).

Altogether: Two very concrete and well-planned activities at the school overlapped, namely Gottfried's and Maria's participation in IMST² (leading e.g. to mutual classroom visits) and the school's activities towards a school development program (leading e.g. to the generation of a new subject in science). These two strands finally flow together, using the dynamics within the mathematics and science group and using elements of it as a model for the whole school. Gottfried and Maria, supported by a powerful principal, together with other colleagues formed a critical mass of teachers jointly aiming at improving teaching (in mathematics and science, but also in all other subjects) and – for example, through establishing peer-groups and a new subject – at further developing the basis for a lasting support system for this innovation process. The school learned with the help of these initiatives that evaluation is not a threat for a school or its individual members, but, in contrast, it can be regarded as an opportunity to grow. Gottfried and Maria thus strongly contributed to the further development of their school's innovation and evaluation culture.

6 Summary and Outlook

What can be regarded as the main explanation factor for this learning of pupils, teachers and the school as a whole? Referring to the four dimensions and the framework of "learning systems" one can conclude: it has to do with the *balance* of *doing innovations and of evaluating them*, and of *looking consequently at the benefit of all elements of the system* (the school's individual members, the corresponding teams, and the organisation as a whole). The development built on the one hand on substantial *internal resources* (human resources, structures, etc.), on the other hand it highly profited from professional *external help* embedded in a larger project which was accepted by teachers, schools, school administration, etc. on a nation-wide level.

The development process, however, is not restricted to that school. The school as a system is interconnected with or embedded in larger systems that can profit from this development. The story of these two teachers and their school – being told in a more practice-related way or with a stronger emphasis on theoretical insights (this paper aims at linking both) – can be a starting point for further discussions and developments, at the school and in other systems. For example, parts of these developments have been reported by the teachers, by the supporting teacher educator and by the author at several meetings and conferences, nationally and internationally. It is then taken as a starting point for reflection and networking in these communities, but also has the potential to be used in the sense of a new scope of freedom for all participants' autonomous or socially shared plans and actions.

There are a lot of research initiatives all over the world that report similar stories and results. In the following, some papers from the Journal of Mathematics Teacher Education (JMTE) published in the last years are taken as an example. These papers show that teachers play an important role between the pupils as learners, and the schools as organizations that build the backbone of all learning and teaching processes. However, if looking more deeply, the same papers also show how teachers can learn from their pupils and that teachers' learning can influence a school's development process.

Lachance and Confrey (2003) stress that in professional development initiatives content and community need to be interconnected (see also Krainer 2003a). Other papers show that a third dimension, putting the focus on the organizational aspect of learning, has to be taken into consideration, as well. Thus, *three Co's* and their interconnection are apparently playing a major role:

- *Contents* that are *relevant for all* who are involved (e.g., interesting mathematical activities for the pupils, challenging experiments, observations and reflections for teachers, constructive initiatives and discussions at schools);
- *Communities* (including small teams, communities of practice and loosely-coupled networks) where *people collaborate with each other* in order to learn autonomously but also to support others' and the whole system's learning;
- *Contexts* (within the professional development program, at teachers' schools, in their school district, etc.) have *conducive general conditions* (resources, structures, commitment, etc.).

For example, Empson and Junk (2004) investigate the knowledge growth of 13 teachers at a single elementary school while implementing a student-centred curriculum in the context of a district-wide reform. The study shows that involving teachers in situations where they are challenged to understand students' mathematical thinking is a crucial starting point for promoting their knowledge and beliefs regarding mathematics and its teaching. The teachers realize that they can learn from their learners, as one teacher in the study states: *"We've always thought, well, we're the ones that give information. But they [the children] give me information … They bring things to my mind."* Also Maria and Gottfried realized that their learning is fundamentally based on carefully observing students' learning, and that it is worth further developing their teaching, thus taking seriously not only their pupils' feedback (which causes increased commitment etc.) but also their own professional demands.

The paper of Ambrose (2004) deals with the change in beliefs of 15 student teachers who participated in a mathematics course and an early field-experience at an elementary school. The paper analyses the nature of the experience, considers the factors that contributed to its intensity and examines the effects of the experience on the student teachers' beliefs. The data shows that most of the teachers were surprised that mathematics teaching was more difficult than expected. They began to consider the importance of providing children with time to think when solving mathematical problems, thus aiming at fostering their autonomous learning and reflective thinking like Gottfried and Maria.

Chamberlin (2005) focuses on specific instances during the discussions, when the teachers engaged in "mini-inquiries". The teachers' joint critical reflection, led to

situations where they *de-centered from their own perspective* and considered students' mathematical activities from their students' perspective. It indicates that changing from *teacher-centered* to *student-centered* perspective is no easy process and needs external stimulus. Also Gottfried and Maria, supported by their mentor Helga, used data from their pupils as starting points to revise their teaching by putting more emphasis on pupils' autonomous work.

Nickerson and Moriarty (2005) describe an urban school initiative aimed at teachers' professional development with the goal of increasing teachers' mathematics content knowledge and helping them improve their practice. Among others, the research shows that general *social and organizational conditions* like mathematics teachers' relationships with the school administration and other teachers or the presence of a teacher leader are relevant for (the further development of) good mathematics teaching at schools. From that perspective, Gottfried and Maria acted as content-related teacher leaders, strongly supported by a far-sighted principal.

Research on "successful" schools shows that such schools are more likely to have teachers who have continual substantive interactions (Little, 1982) or that inter-staff relations are seen as an important dimension of school quality (Reynolds et al. 2002). The latter study illustrates, among others, examples of potentially useful practices, of which the first (illustrated by an US researcher who reflects on observations in other countries) relates to teacher collaboration and community building (p. 281): *"Seeing excellent instruction in an Asian context, one can appreciate the lesson, but also understand that the lesson did not arrive magically. It was planned, often in conjunction with an entire grade-level-team (or, for a first-year teacher, with a master teacher) in the teachers' shared office and work area. [Referring to observed schools in Norway, Taiwan and Hong Kong:]… if one wants more thoughtful, more collaborative instruction, we need to structure our schools so that teachers have the time and a place to plan, share and think."*

This demonstrates that "community" is always influenced by administrative and organizational aspects such as support from administrators, time, space and other resources, by general conditions of the educational system (e.g. the power of principals to hire teachers, the existence in schools of content-related departments which have specific responsibilities) or the cultural and societal character of a region or nation (e.g. the autonomy and reputation of teachers, a shared understanding in society about "good practice" at schools).

In mathematics teacher education, as a field of practice and research, the connection between contents, communities and contexts is highly complex. We need not only to look at teachers' learning, but also to look at pupils' and schools' learning. Looking at pupils' (and also teachers') learning affords mathematical knowledge, investigating school's learning needs knowledge about organizations. This has to be complemented by psychological, socio-cultural, philosophical, etc. aspects in order to describe teachers' learning in that context. This shows that *teacher education is a demanding inter-disciplinary field*, and it has the *additional challenge* that in many cases the researchers and the teacher educators are the same.

Although mathematics education, for good reasons, has a major focus on mathematical learning, we also need to put considerable attention to social and organizational learning. In particular, we need more research how instructional and school development are interlinked and are influencing each other.

Endnotes

[1]: Reflections on the importance of stories about teachers' professional development can, for example, be found in Cooney (1999).

[2]: More details can be found e.g. with regard to teaching mathematics (Krainer 1993), teachers' professional practice (Altrichter & Krainer 1996), and "learning systems" in different matters of mathematics and science education (Krainer et al. 2002).

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