Systemic Innovations in Educational Systems via in-Service Teacher Education

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Abstract

This paper describes strategies for innovating educational systems by teachers' professional development. On the basis of theories of learning and of managing complex systems, structural characteristics of projects are identified that have the potential to promote systemic developments in educational systems. The corresponding strategies for innovations have already been put into practice by large-scale European projects. Strong evidence shows that the chosen approach to teachers' professional development has significant and substantial long-term effects on teachers' beliefs and competences.

Keywords: Educational system, systemic innovation, teachers' professional development, learning environment, complex system.

1. Introduction: Projects from Practice forInnovations ofSchoolEducation

In the so called "RecordReport" the European Commission (2007) analysed initiatives in the field of mathematics and science education to draw from them elements of know-how and good practice that could bring about innovations in the educational system. This report highlighted a project called "Sinus-Transfer" which is the core part of a nationwide, large-scale development process in Germany that started in 1998 and is still going on. Several thousand primary and secondary schools have been involved up to now (see www.sinus-transfer.eu)."Sinus-Transfer is characterized by a long-term, school-based and collaborative approach that is focused on students' learning. It relates to didactical problems in science classrooms and stimulates teachers to evaluate and reflect their teaching in a process of continuous quality development. During the process a strong cooperation is established between teachers within and between schools as well as between researchers and practitioners." (European Commission, 2007). As a consequence of this analysis, the European Union funded several projects to extend this approach to the European level, e.g. the Fibonacci Project (www.fibonacci-project.eu) or the project KeyCoMath (www.keycomath.eu). This paper depicts the theoretical framework, structural characteristics and strategies of these projects that focused on the development of teachers' pedagogical and didactical competences as well as on their beliefs of educational processes.

2. A Model for Teaching and Learning

A very fundamental question in the school system is how to initiate and support students' learning effectively – particularly in the classroom setting. Furthermore, projects for teachers' professional development have to regard teachers as learners (Little, 1994).Therefore, we draw up a model for teaching and learning processes (Fig. 1) that provides the theoretical background for the following sections. It is basedon theories of moderate constructivism and of pedagogical psychology, which describe learning as an *active, individual process of constructing cognitive structures* that is embedded in *social and situational contexts* (e.g. Krapp & Weidenmann, 2006; Reinmann-Rothmeier & Mandl, 1998; Haberlandt, 1997).

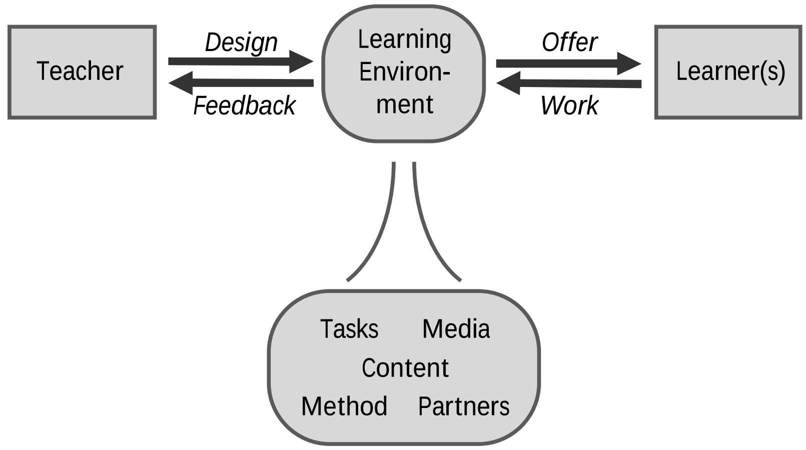

Fig. 1: Model of Learning Environments

The teacher cannot put knowledge directly into the learner's head. The *learning environment* is the essential link between the teacher and the learner. It is part of the teacher's professional expertise to design the learning environment. Thus, heor she offers a basis for the learner's working. This allows the teacher to receive feedback about both the learner and the learning environment.This notion of a learning environment includes five components: the *tasks* for the learner working with the *content*, the *method* of teaching and learning, the arrangement of *media,* and the social context with the teacher and other learners being *partners* for learning. This model is based on and extends the didactical concepts of "substantial learning environments" by Wittmann (1995, 2001) or "strong learning environments" by Dubs (1995).The model in Fig. 1 of course simplifies reality – as any model does. However, the function and the strength of models are to reveal the basic structures of complex situations. On the one hand, this model of learning environments shows that a teacher cannot enforce or steer students' learning directly. Limitations of a teacher's influence on students' learning are revealed. On the other hand, if we think positively, the model points out, that it is a teacher's task to design learning environments in order to initiate and foster the students' learning and to use the feedback for further diagnosis and supporting activities.

3. Shifts towards more Balance in Teaching and Learning

In the previous decades international assessment studies like TIMSS and PISA have given remarkable impulses for initiatives aiming at developments of the educational system. The European projects mentioned in section 1 resulted from that (European Commission, 2007). They aimed at shifts in teaching and learning from traditionally rather teacher-centred instructions towards students' more individual activity and cooperative learning. In the following, we use the notion of "exploratory learning" as keyword for describing the underlying general didactic concept. However, we have to keep in mind that this is only one manner of learning and that real-life education should be based on a broad variety of didactical and pedagogical concepts.

3.1 Exploratory Learning

How can exploratory learning be described? It is characteristic that the learner

- explores a topic
- which is to some extent new and complex for him
- Through individual cognitive activity.

The learner should feel a certain *complexity* and *novelty* of the topic so that tasks cannot be solved just by applying existing knowledge and well-known strategies. Typically, *exploring* a topic means, e.g.

- looking at phenomena and examples, varying given situations,
- connecting new phenomena to existing knowledge,
- formulating observations and conjectures,
- structuring situations and detecting patterns,
- Describing results and giving reasons for them.

This notion emphasizes *individual cognitive activity*. Of course, this can be combined with and supported by hands-on activities. Moreover, in the classroom setting it is very natural to include collaboration and exchange with others. As learning is a social process, individual and cooperative learning should even be intertwined closely in class. We will come back to that in section 3.3 when we consider methodology.

3.2 Tasks for Exploratory Learning

The tasks for students are a core element of learning environments (see section 2). They carry situations for thinking, working and discussing. This raises the question: Are there tasks that are especially good for exploratory learning in school? Surely, tasks by themselves cannot be "good" or "bad" since it is crucial which objectives are aimed at and how tasks are used in actual teaching and learning situations. However, there are attributes of tasks that offer a certain potential for initiating and supporting exploratory learning in classroom settings.

- Tasks for exploratory learning should at least to some extent be*open*, i.e. they should outline a content-based situation that offers different approaches to and various possibilities for working.
- Tasks should be *rich*, i.e. they should refer to subject-related content of a certain depth and complexity for the learners. Thus, it should be worthwhile for the learners to engage themselves with the tasks some amount of time. These should offer possibilities to work in a comprehensive way, to increase or to deepen personal insights and understanding.
- Tasks should be *challenging* and motivating for the students. This is a basic requirement for the students' engagement in tasks.
- Tasks should be *easily accessible* to all students, i.e. each student should have the possibility to begin working with the tasks and experience a sense of achievement and success.
- Tasks should *support working at different levels*, i.e. weaker students should have opportunities to expand their abilities and achieve specific results. On the other hand, gifted students should be able to work on their more advanced levels.

It is part of the teachers' professional competence to develop and to provide adequate tasks for theirstudents and to integrate these tasks in inspiring learning environments.

3.3 Teaching Methods for Exploratory Learning

Tasks for exploratory learning can unfold their potential in the classroom setting only if they are embedded in appropriate learning environments. Particularly, they have to be combined with teaching methods that support students' exploratory learning.From the wide variety of methodical concepts, the following table shows just one example that seems to be quite natural for exploratory learning in the general framework of school lessons. It combines individual learning with cooperative learning in both small groups and the class as a whole. Its basic structure is not new and has already been described by expressions like "Think – Pair – Share" (Green& Green, 2005) or "I – You – We" (Gallin & Ruf, 2014).

(a) Individual Work Since learning is an individual process, students initially work on their own. They are faced with the necessity to explore the content, activate their prior knowledge, develop ideas and make discoveries.
(b) Cooperation with Partners Learning is a social process. It is very natural for students to discuss their ideas with partners in small groups and work on problems cooperatively. This communication helps to order thoughts and to get more ideas. Meanwhile, the teacher can stay in the background or turn his attention to individuals.
(c) Presentation of Ideas After having worked individually and in groups the students present their ideas and discuss them in class. The different contributions reveal multiple aspects of the topic so it can be viewed from different perspectives. Moreover, students develop presentation, communication and argumentation skills.
(d) Summary of Results Finally, the students' results are summarized and possibly expanded by the teacher. It is the teacher's task to introduce subject-related conventions and to consider curricular regulations. However, since the students have already explored the new content on their own paths, they are more likely able to integrate the teacher's explanations into their individual cognitive structures.

Tab. 1: Methodical Concept for Exploratory Learning

Of course, this concept is only an idealized model of real teaching and learning processes. In reality in school, the four phases might overlap or there could be cycles. However, a concept like this can help to design and structure learning environments for students' exploratory learning.The basic feature of this concept is the natural combination of different phases of learning in class, with each of them having specific functions for educational processes: The students have the freedom to work on their own and to develop individual understanding. They discuss and present their ideas and results, which helps them to develop skills for communicating and arguing as well as to deepen their subject-related competences. The teacher can finally add structure to the students' ideas, make things clearer, summarize results and explain further content.

Here again we have to consider that this methodical concept is only one of many methods. It would be one-sided and imbalanced if lessonswere organized only in this way. Lively school lessons should draw on a broad spectrum of teaching methods.

4. Innovating Complex Systems

All over the world there are many efforts to innovate educational systems – on regional, national and international levels – aiming at changes of teaching and learning. In order to understand the structure of these initiatives, a short glance at theories of cybernetics is quite useful.

4.1 Complex Systems

In theories of cybernetics a system is called "complex", if it can potentially be in so many states that nobody can cognitively grasp all possible states of the system and all possible transitions between the states (Malik, 2008;Vester, 2015). Examples are the biosphere, a national park, the economic system, the educational system in any country and even a concrete school.Complex systems are usually networks of multiply connected components. One cannot change a component without influencing the character of the whole system. Furthermore, real complex systems are in permanent exchange with their environment.

4.2 Steering of Complex Systems

The fundamental problems of mankind dealing with complex systems are how to manage the complexity, how to steer complex systems successfully and how to find ways to sound states. With reference to theories of cybernetics two dimensions of steering complex systems can be distinguished (Malik, 2008). The first one concerns the manner, the second one the target level of steering activities (Fig. 2).

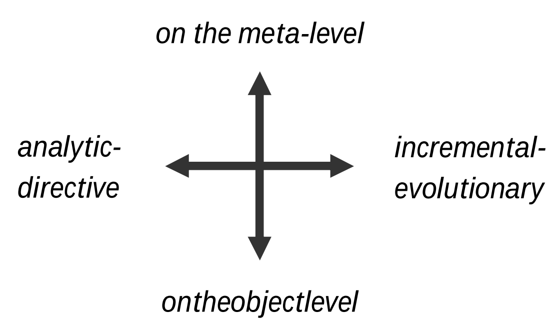

Fig. 2: Steering Complex Systems

The method of *analytic-directive* steering needs a controlling and governing authority that defines objectives for the system and determines ways for reaching the aims. Authoritarian systems with strong hierarchies are founded on this principle. However, fundamental problems are caused just by the complexity of the system. In complex systems no one has the chance to grasp all possible states and transitions of the system cognitively. Thus, the analytic-constructive approach postulates the availability of information about the system that cannot be reached in reality.In contrast, *incremental-evolutionary* steering is based on the assumption that changes in complex systems result from natural growing and developing processes. The steering activities try to influence these systemic processes. They accept the fact that complex systems cannot be steered entirely in all details and they aim at incremental changes in promising directions.The focus on little steps is essential, since revolutionary changes can have unpredictable consequences which may endanger the soundness or even the existence of the whole system.

The second dimension distinguishes between the object and the meta-level. The *object level* consists of all concrete objects of the system. In the school system these objects are e.g. books, computers, buildings etc. Changes on the object level take place if new books are bought or if a new computer lab is equipped. Of course, these changes are superficial without reaching the substantial structures of the system.The *meta-level* comprehends e.g. organizational structures, social relationships, notions of the functions of the system etc. In the school system e.g. notions of the nature of the different subjects and beliefs concerning teaching and learning (e.g. Maaß & Schlöglmann, 2009; Pehkonen & Törner, 1996; Leder, Pehkonen & Törner, 2002) are included.

4.3 Innovations in Complex Systems

The pivotal question is: how can substantial innovations in the complex educational system be initiated successfully? The theory of cybernetics provides useful hints. Attempts of analytic-directive steering will fail in the long term, since they ignore the complexity immanent in the system. Changes on the object level do not necessarily cause structural changes of the system. According to the theory of cybernetics it is much more promising to initiate *incremental-evolutionary changes on the meta-level* (Fig. 3). They are in accordance with the complexity of the system and do not endanger its existence. Nevertheless, they can cause substantial changes within the system by having effects on the meta-level, especially when they work cumulatively.

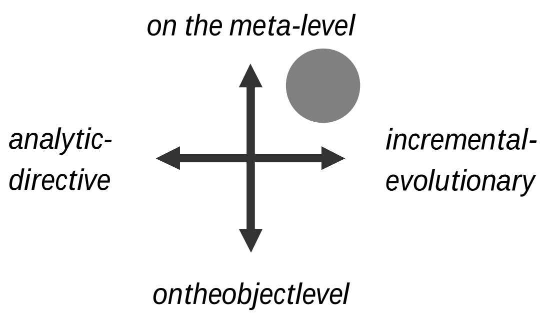

Fig. 3: Innovations in Complex Systems

5. Strategies for Systemic Innovations of Education in School

Combining the theories of cybernetics, learning and learning environments we get a theory-based way of initiating innovations in school. Activities are most promising if they focus on incremental-evolutionary changes on the meta-level of beliefs and attitudes of all agents involved. The concept of learning environments may serve as a framework for learning processes of teachers *and* students. How can this be done concretely?As a conclusion from all reflections above we sketch and propose a pattern for innovation projects in the educational system.

(a) Aiming at Teachers

The key people for innovations in school are the teachers. Their beliefs, motivation and professional expertise are crucial for everyday teaching and learning in school (Kunter et al., 2011). Thus, projects for innovations in education should focus on the teachers' professional development.

(b) Networks of Schools

Since learning is a social process, regional networks of schools should be established. They form frameworks for teachers' exchange of experience and for their cooperative learning.

(c) Coaches for Teachers' Professional Development

The model of learning environments can be applied to teachers' learning: The regional school networks for teachers' professional development are led by a coach or a team of coaches who could be e.g. very experienced teachers, teacher educators or scientists. These coaches design learning environments for teachers' learning. The teachers are made familiar with general didactical and pedagogical concepts. They relate these ideas to their daily work at school; they design learning environments for their students, use them in their classes and adapt their assessment practices. They present, discuss and reflect their experiences cooperatively in their network of schools guided by their coach.

(d) Aiming at the Meta-Level

As shown in section 4.3, initiatives for substantial innovations of the educational system should aim at the meta-level of attitudes and beliefs. This concerns e.g. the role of the teacher, the role of the students, the nature of subjects and general aims of education.

(e) Development of Learning Environments

Maybe, “aiming at the meta-level” sounds quite abstract and difficult. But the concept of learning environments and the didactic strategies in section 3can serve as a suitable framework to bridge the gap between theory and practice, to create strong relationships to the teachers’ regular work at school. Teachers individually and cooperatively develop learning environments for their students, work with them in class, optimize them on the basis of all experiences and exchange and discuss them in their school network. Thus, by designing and working with concrete learning environments teachers get acquainted with general pedagogical ideas. Teachers’ learning is “driven by examples”. In this way developments on the meta-level of attitudes and beliefs are initiated. Learning environments serve as tools for systemic teachers’ professional development.

(f) Areas of Activity

Since systemic innovations are incremental-evolutionary, participating schools and teachers should concentrate on one or a few areas of innovation, e.g. exploratory learning, promoting students’ cooperation, cumulative learning or fostering key competences. It is not promising to aim at total changes of education – because of the complexity of the system. However, such bounded fields of activity enable teachers to begin with substantial changes without the risk of losing their professional competence in class.

(g) Universities as Innovation Centres

In these processes teachers and the coaches should get guidance and advice by universities. They could serve as innovation centres for teacher education. They provide regular and systematic in-service teacher education offers and coach the coaches. This teaching and learning can be designed according to the concept of learning environments described in section 2.Thus; the participants become acquainted with didactical and pedagogical theories and concepts by making personal experiences in learning environments designed for them.

(h) Cross-Community Networks

Systemic innovations in the educational system as depicted above need collaborative efforts across professional communities. Teachers, teacher educators and scientists provide their specific expertise to each other in networks for professional exchange. Common work on the design of learning environments for students and teachers helps the members of the different communities with their specific background to find a “common language” and to get into deep communication.

(i) (Inter-) National Teacher Education

Teachers and teacher educators should be given possibilities to exchange experiences with colleagues and to participate in professional development offers on regional, national and international level. Thus, they understand that problems and necessities of innovations have systemic character and concern the fundaments of education far beyond their own professional sphere. Moreover, they receive ideas for innovation activities from a large community.

(j) Evolutionary Processes Take Time

Finally, these evolutionary processes take time (Cambone, 1994). This seems to be rather trivial. Since developments on the levels of beliefs and attitudes of a “critical mass” of teachers in the educational system are envisaged, a realistic timeframe covers about 10 years. But for that we need prospective and foresighted political decisions to fund long-term innovation programmes or series of projects that build on one another.

This approach to innovations in the educational system may be called “theory based and task driven”. On the basis of the theory of cybernetics and theories of learning the teachers involved make incremental-evolutionary steps on the meta-level of beliefs and attitudes by designing learning environments, working with them in their classes and reflecting and discussing experiences in professional networks. The work with learning environments can be seen as a tool to transport general didactic and pedagogical ideas and as a catalyst for developing the complex system of education as a whole.

6. Projects for Teachers' Professional Development: Fibonacci and KeyCoMath

The concept for innovations in the educational system by means of teachers' professional development described in the previous section was realized in practice e.g. by "The Fibonacci Project" from 2010 to 2013 and by the subsequent project "KeyCoMath" from 2013 to 2015 (see www.fibonacci-project.eu, www.keycomath.eu). The first project focused on exploratory learning in mathematics and science education, it involved 38 partners from 27 European countries. The second one aimed at supporting students' key competences through mathematics education with eight partners from eight countries.Weexemplarily describe the structure of project activities and report some results of an evaluation study since this provides empirical evidence of effects of the strategies for teacher professional development outlined in section 5.

6.1 Structure and Strategy of Project Activities

In the framework of both projects, a network of 94 primary schools with about 500 participating teachers was set up in Swabia, a region in the south of Germany.In this network about four to five schools, which were located close to each other, formed a regional sub-network with about 25 teachers (see section 5 b). Each sub-network was coached by a tandem of very experiences teachers (see section 5 c) from September 2010 to August 2015. In these groups the teachers met about five times a year. They became acquainted with general ideas and theories of teaching and learning (see sections 2 and 3), they discussed and reflected on educational processes.

To bridge the gap between theory and practice, the teachers' project activities were strongly related to their regular work in class. The teachers cooperatively developed learning environments (see section 5 e) for their students, tried out new ideas in their classes and reflected all their experiences cooperatively in their network of schools. In this process they were guided by the coaches mentioned above.On a further level, all participating teachers met two times a year at central meetings, which were organized by a university. Here the participants deepened their theoretical background by lectures and workshops andexchanged ideas. Furthermore, the university led the group of the coaches and offered guidance and advice for their work as teacher educators (see section 5 g and h). This structure for organizing in-service teacher education processes is depicted in Fig. 4.

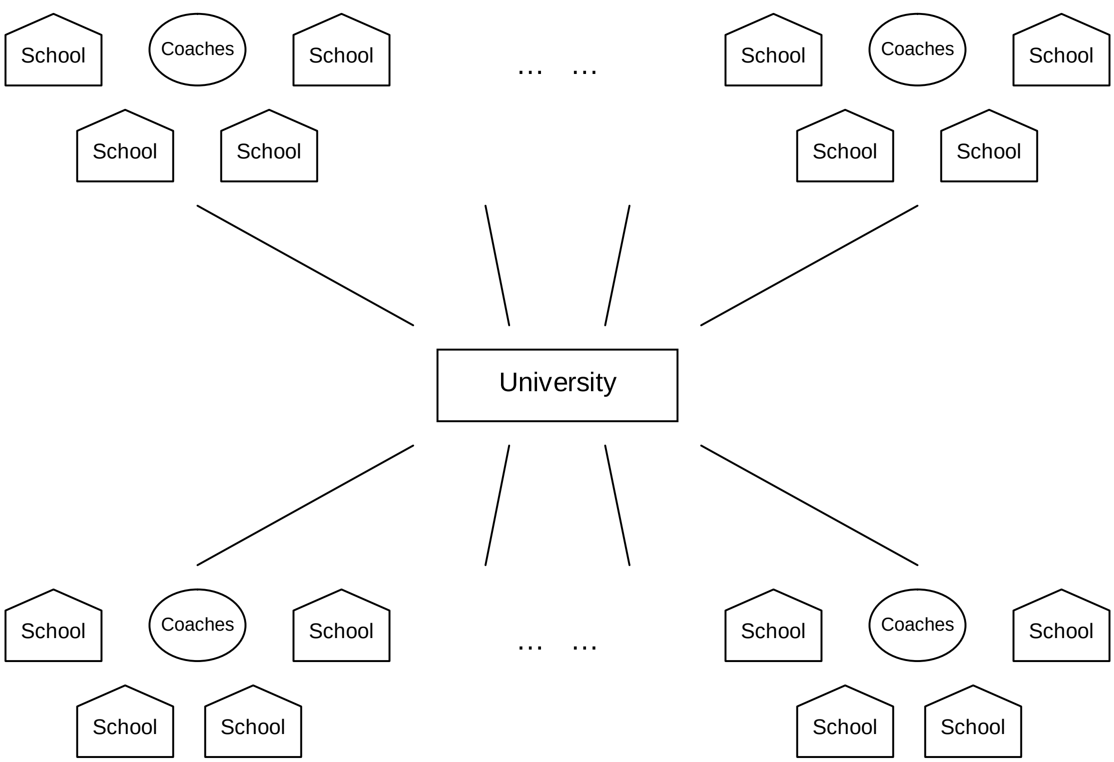

Fig. 4: Structure of Network of Schools and Coaches

6.2 Measuring Effects of Teachers' Professional Development

One main objective of the Fibonacci Project was to strengthen teachers' confidence in workingwith their students in an exploratory way in mathematics lessons as it is described in section 3.To do so,a teacher has to master various challenges in different phases of the lessons. For example, they have to encourage students to plan investigations, to make observations and conjectures, to work cooperatively, to discuss ideas, to analyse mistakes, to note down and to present results etc. Furthermore, the teacher has to use adequate methods to assess students' performance (e.g. oral presentations, free productions, student diaries etc.). In the project meetings of the regional networks described in section 6.1 the teachers developed learning environments according to these didactical aims; they put their ideas into practice in their classes and cooperatively reflected their experiences afterwards.

These in-service teacher education activities should increase the teachers' confidence in organising mathematics education in an exploratory way (see section 5 d, e). They have taken place from autumn 2010 to winter 2012.To measure developments over the course of the project in the network of 94 schools 150 teachers were randomly chosenfor a *pre-test*in the beginning of the project in 2010. At the end of the intervention in 2012, 150 teachers were again randomly chosenfor a*post-test*. They were asked to fill in a questionnaire with the twelve items from Tab. 2 and thus to give feedback on their confidence inpromoting exploratory learning each time.

How confident do you feel as a teacher in …	Not confident at all	Rather unconfident	Slightly confident	Confident	Very confident
… encouraging students to plan their own investigations?					
… encouraging students to make careful observations?					
… encouraging students to make conjectures and predictions, to think about relationships themselves?					
… arranging for students to work in groups or teams?					
… encouraging/helping students to write notes of experiments or observations?					
… inviting students to explain and make deductions from observations or results?					
… helping students to generalise from observations and results?					
… inviting students to present their ideas or results?					
… encouraging students to use mathematical vocabulary and words correctly?					
… encouraging students to analyze their mistakes themselves?					
… offering the possibility to make experiments/research beyond the goals of the syllabus (especially for the gifted students)?					
… using different assessment methods (tests, oral presentations, free productions, student diaries or logs etc.)?					

Tab. 2: Questionnaire on Teachers' Confidencein Promoting Exploratory Learning

The five possibilities to answer each question were assigned to the natural numbers 0 = "not confident at all", 1 = "rather unconfident", 2 = "slightly confident", 3 = "confident" and 4 = "very confident". Because of the linguistic gradation of the possibilities to answer, it can be assumed that the data is at the interval level of measurement. Thus, the arithmetic mean of a teacher's responses to all items can be interpreted as a measure of this teacher's confidence in arranging mathematics lessons according to the didactic concepts described in section 3.This mean is a rational number between 0 and 4. It is used as an index measuring the teacher's confidence in promoting exploratory learning.

To measure long-term effects of the intervention two and a half years later, in summer 2015, 150 teachers were again randomly chosen in the network of 94schools and were asked to fill in the questionnaire (*follow-up test*). In the meantime, i.e. from 2013 to 2015, these teachers took part in the follow-up project "KeyCoMath", which did not focus on exploratory learning but rather on the diagnosis and assessment of students' abilities and the development of key competences. Thus, the teachers' confidence in promoting exploratory learning was not explicitly supported by the project activities.

6.3 Results of Statistical Analyses

Firstly, we analyze whether teachers' confidence in promoting exploratory learning increased during the two-year intervention. For this, we compare results of the pre-test in 2010 and the post-test in 2012. Secondly, we relate these findings to results of the follow-up test in 2015 to gainempirical evidence of the long-term impact of these teacher education activities.Since we would like to get empirical evidence of positive effects of the project, we formulate the null hypothesis H_0: "The teachers' confidence in promoting exploratory learning did not increase between the pre-test and the post-test." As we would like to get highly significant results, the significance level $\alpha = 1\%$is chosen.Each single teacher's answers on the questionnaire are condensed to the index measuring the teacher's personal confidence in promoting exploratory learning (see section 6.2). Thus, the pre-test and the post-test provide this index of 150 participating teachers each.We gain first insight into this statistical data by box plots(Fig. 5) and statistical indices of the distributions(Tab. 3).They clearly show an increase in the teachers' confidence in promoting exploratory learning during the period of the intervention.

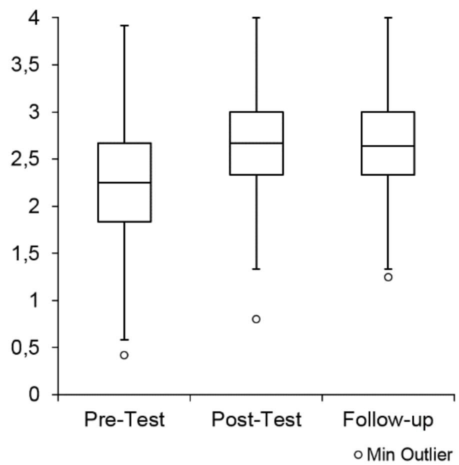

Fig. 5: Box Plot of Teachers' Confidence in PromotingExploratory Learning

	Pre-Test(2010)	Post-Test(2012)	Follow-up Test (2015)
Size of sample	$n_1 = 150$	$n_2 = 150$	$n_3 = 95$
Lower quartile	$Q_{0.25;1} = 1.83$	$Q_{0.25;2} = 2.33$	$Q_{0.25;3} = 2.33$
Median	$Q_{0.5;1} = 2.25$	$Q_{0.5;2} = 2.67$	$Q_{0.5;3} = 2.64$
Upper quartile	$Q_{0.75;1} = 2.67$	$Q_{0.75;2} = 3.00$	$Q_{0.75;3} = 3.00$
Arithmetic mean	$\bar{x}_1 = 2.24$	$\bar{x}_2 = 2.68$	$\bar{x}_3 = 2.66$
Standard deviation	$s_1 = 0.62$	$s_2 = 0.60$	$s_3 = 0.52$

Tab. 3: Statistical Indices for Comparing Pre-, Post- and Follow-Up Test

We further analyze by a one-sided t-test, whether this development from the pre- to the post-test is *statistically significant*. With the size of the samples$n_1 = n_2 = 150$ we have the degree of freedom$df = 298$. Thus, the significance level $\alpha = 1\%$ corresponds to a critical t-valueof$t_{cr} = -2.34$.The data from Tab. 3 gives the empirical t-value:

$$t_{emp} = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1{}^2}{n_1} + \frac{s_2{}^2}{n_2}}} = -6.17$$

Since$t_{emp} < t_{cr}$, the null hypothesis can be rejected with an α-error of 1%.This means that the increase of the teachers' confidence in promoting exploratory learning is highly significant.We should make sure that this effect is not only significant but that it is also meaningful. Therefore, we consider the *effect size* and calculate Cohen's d (which is equal to Hedges' g in this case of samples of the same size):

$$d = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s_1{}^2 + s_2{}^2}{2}}} = -0.71$$

Since the absolute value of d is between 0.5 and 0.8 we have a "moderate to strong effect" (according to conventions of Cohen (1988)).Furthermore, we take the β-error into account by calculating the power $1 - \beta$ of the test. According to Bühner, Ziegler (2009) we consider the *post-hoc test power*. It is defined as the probability of t-values smaller than $t_{cr} = -2.34$ when assuming the t-distribution with the expectation $t_{emp} = -6.17$. Fig. 6 shows this situation. The densities of the t-distributions with the expectation 0 and the expectation t_{emp} are depicted. The post-hoc test power can be interpreted as the area between the left graph and the t-axis left of the vertical line at t_{cr}. It has the value $1 - \beta = 1.00$.

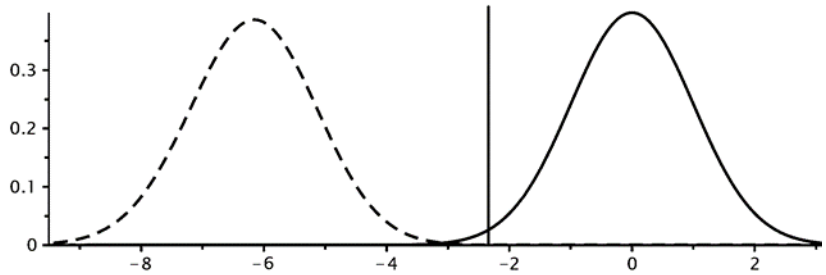

Fig. 6:The t-Distributions with Expectation 0 and t_{emp}

Summing up these statistical analyses, we gain the following results:

- There is *highlysignificant* increase of the teachers' confidence in promoting exploratory learning during the two-year intervention$(\alpha = 0.01)$.
- This increase is meaningful with respect to the effect size since we have a *moderate to strong effect*$(d = -0.71$.
- The statistical test has a *high post-hoc power*$(1 - \beta = 1.00)$.

Of course, some caution is necessary when interpreting these results. There is strong statistical evidence that the teachers' confidence in promoting exploratory learning increased during the period of the teacher education project. This effect could be caused not only by the project activities but also by further reasons (e.g. other teacher education events, general developments of pedagogical strategies in the school system).However, since the participating teachers were quite intensively involved in the project with at least six meetings a year, it can be assumed that this project had a dominant influence on the teachers' professional development.

Finally, we analyze whether the increase in teachers' confidence in promoting exploratory learning diminished or disappeared when the corresponding teacher education offers ended or whether there are long-lasting effects of these professional development activities. Therefore, we compare the results of the post-test in 2012 and the follow-up test in 2015. In the follow-up test, 150 teachers who participated in the project "KeyCoMath" were randomly chosen from the 94 schools in the project network andwere asked to fill in the questionnaire of Tab. 2. They also had to indicate whether they had already taken part in the preceding "Fibonacci" project. Only the teachers who affirmed that are considered in the statistical analysis of long-term effects. These are $n_3 = 95$ people.Comparing the box-plots in Fig. 5 and the statistical indices in Tab. 3we see very little differences between the post-test and the follow-up test. A one-sided hypothesis test shows that there is no significant decrease of teachers' confidence in promoting exploratory learning, even on a significance level of $\alpha = 30\%$ ($t_{emp} = 0.28$; $p = 0.39$). Furthermore, the effect size of $d = 0.04$also indicates that there is no relevant decreasing effect between the post-test and the follow-up test.

Summing up, further results are:

- The level of the teachers' confidence in promoting exploratory learning remains stable when the corresponding teacher education offers have ended.
- Even two and a half years after the intervention there is no significant decrease in the impact of the professional development activities.

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