HOW CAN PROFESSIONAL TEACHERS IMPROVE SCIENCE AND MATHEMATICS TEACHING?

Claudia Stübi[1], Brigitte Döring[2], Claudia Fischer[2], Alexander Koch[1], Karen Rieck[2], Silke Rönnebeck[2], Matthias Stadler[3] and Stefan Zehetmeier[4]

[1] Center of Science and Technology Teaching, University of Applied Sciences Northwestern Switzerland, Switzerland

[2] Leibniz-Institute for Science at Mathematics Education (IPN), University of Kiel, Germany

[3] University of Bergen, Bergen, Norway

[4] Institute of Instructional and School Development, Alpen-Adria University Klagenfurt, Austria

Abstract: In Germany, Austria and Switzerland, networks of model schools, teacher training colleges, institutes of educational development and ministries work together in nationwide large-scale programs for the advancement of science education. The initiatives include the networking of teachers and schools, the development of educational materials and units as well as the dialogue between school practice, teaching methodology, research and education policy. The three national programs presented in the symposium are coordinated and directed by the Leibniz Institute for Science and Mathematics Education at the University of Kiel in Germany, the Institute of Instructional and School Development at the Alpen-Adria University Klagenfurt in Austria and the Center of Science and Technology Teaching at the University of Applied Sciences Northwestern Switzerland. In recent years, however, the need to improve science education has also been recognized at a European level. The EU-project S-TEAM was funded within the EU 7th Framework program and worked together with 26 partner universities all over Europe. The German SINUS program reaches more than 850 elementary schools and 4,500 teachers. In Austria, IMST involves 7,000 persons a year, representing schools, ministries and universities. Swiss Science Education SWiSE brings together teachers, trainers and other experts from 14 different cantons. The four projects are evaluated on different levels, for example with teacher and student questionnaires, interviews and/or video studies. The four short presentations give insight into the model programs with their major results and report central experiences and effects of the programs. Conclusively, especially the cross-border comparison is interesting for science education research and teacher professional development.

Keywords: Inquiry-based teaching, Teacher Professional Development, Compulsory School

TOWARDS COMMON RESEARCH-BASED STANDARDS FOR TPD IN EUROPE– INSIGHTS FROM THE S-TEAM PROJECT *(Rönnebeck & Stadler)*

During the last decade, there has been an on-going debate about the need to improve science education in Europe. In 2009, S-TEAM (Science Teacher Education Advanced Methods) started as the first in a series of big projects funded by the EU to address this problem. S-TEAM aimed at improving pupils learning and attitudes by the widespread dissemination of inquiry-based science teaching approaches. A specific strand of work in S-TEAM dealt with the question of effective approaches to teacher professional development (TPD) as one crucial aspect of implementing change in national educational systems. In particular, it should be explored whether a nationally successful model of TPD – the German SINUS model – could be transferred to other educational contexts in Europe. Since it became obvious that a direct

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transfer of ideas would not occur, a general model of TPD was developed based on SINUS, research and information gathered during national workshops in the partner countries. The model summarizes basic requirements of TPD while being at the same time flexible enough to be adapted to different educational, political and cultural systems and is thus supposed to be widely applicable under a European perspective.

Background

Within the last decade, there has been an increasing discussion in Europe about the need to recruit more young people to careers in science and engineering in order to ensure economic development and welfare (European Commission, 2004). The Rocard report (2007) identified inquiry-based science teaching approaches (IBST) alongside with effective forms of TPD as one means to address this need by improving science teaching. As a sequel to these discussions, the S-TEAM project was funded within the EU 7th Framework Programme. It consisted of 26 partners from 14 European countries. The overall objective of S-TEAM was to improve the learning and attitudes of pupils to increase scientific literacy and recruitment to science careers. To reach this goal, teachers should be enabled to adapt inquiry-based methods for more effective science teaching. In this process, they should be supported by providing training in and access to innovative methods and research-based knowledge.

Framing the problem at a European level provided the opportunity to share national expertise in curricula, pedagogy and practice across national boundaries and between different traditions in science education. However, S-TEAM acknowledged that its objectives could not be imposed on national systems but had to be implemented through existing structures and actors, taking into account all relevant stakeholders and combining policy and practice.

One strand of work in S-TEAM was thus to identify optimum ways in which TPD for IBST could be implemented in the specific national contexts. This was done by conducting national workshops in each partner country to initiate discussions about new forms of TPD that could substitute the often ineffective stand-alone courses (Stadler & Jorde, 2012). In these seminars, national stakeholders were introduced to SINUS (see page 4), a large-scale TPD programme from Germany that initiated and accompanied changes in teaching practice in a sustainable way (Ostermeier, Prenzel, & Duit, 2010). The underlying idea was to investigate if a nationally successful model could be adapted and transferred to other educational contexts.

Although a strong interest in SINUS could be observed in many of the partner countries, a direct transfer of ideas did not occur. In this paper, a general model of effective TPD is thus described that was developed in order to support national initiatives to implement change. The model summarizes basic requirements of TPD but is at the same time flexible enough to be adapted to different educational systems.

Methods

The development of the general model is based on a broad research basis, experiences with SINUS (Prenzel et al., 2009) and information collected at the national workshops. After the workshops, countries who indicated interest to start national initiatives were monitored to learn about their challenges, needs and possible ways to support their work. Towards the end of the project, all countries were approached again to gather information about actions following the national workshops. In countries where initiatives were under way, additional seminars, discussions and interviews were used to collect data about these activities to identify challenges, obstacles and supporting factors to implement change.

General model of TPD

In the science education literature, a general agreement regarding crucial aspects of effective TPD exists. It has to be “long-term, school-based, collaborative, focused on students’ learning, and linked to curricula” (Hiebert, Gallimore, & Stigler, 2002). Similar aspects are named by Desimone and colleagues (Desimone, Porter, Garet, Yoon, & Birman, 2002; Garet, Porter, Desimone, Birman, & Yoon, 2001). According to them, the effectiveness of TPD is influenced by the opportunities it offers for active learning, its coherence with teaching and educational goals, and its duration. Moreover, it should have a content focus and teachers should work collaboratively. SINUS (Prenzel et al., 2009) furthermore stresses the importance of support structures at the school and system level. In addition, any kind of TPD should be based on research and theory.

Based on these crucial aspects, the following model for effective TPD that consists of four units influencing each other is proposed (Figure 1). The central unit is the faculty of science teachers in a school ensuring that teachers have ownership of the process. A significant impact of TPD, however, will only occur if teachers work collaboratively, discuss their goals, develop approaches, trial them in classrooms and reflect upon them with their colleagues. The other units are given by the TPD activity itself including structural and organisational as well as content features, the school principal as the main source of support at the school level, the system level represented by educational policy and administration, and the coordinator linking research and practice and supporting teachers on their way to change.

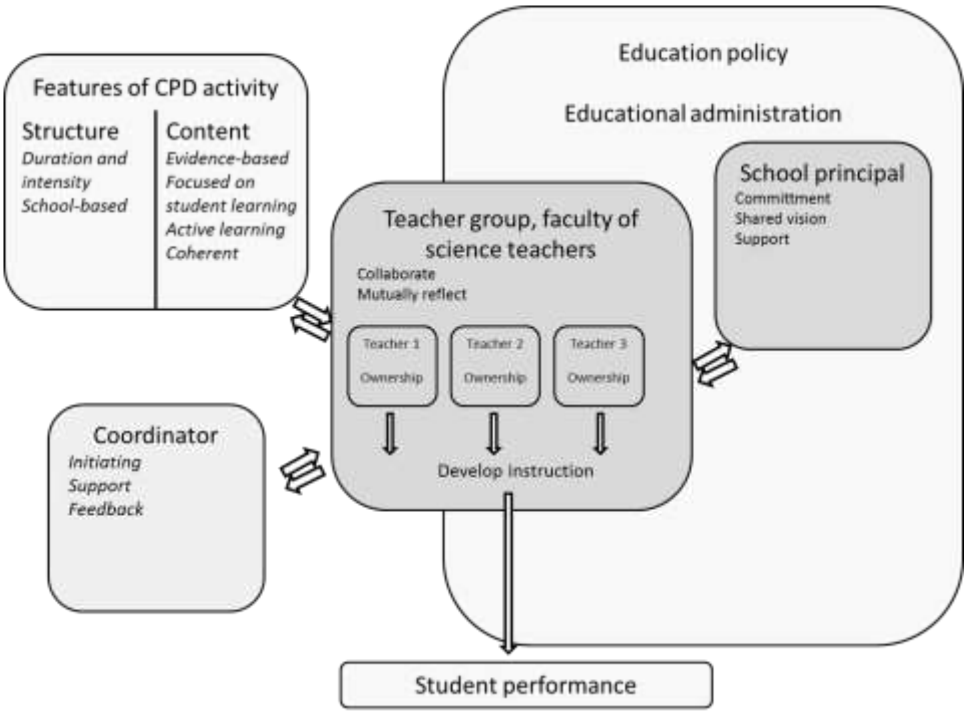

Figure 1. Model of effective TPD (for a similar model see also Adey, 2004).

Conclusions

The presented model aims at the improvement of classroom instruction. It makes clear that a set of quality aspects has to be accounted for when substantial impacts are expected. On the other hand, it is flexible enough to be adapted to different educational systems and conditions. Training packages and resources for teachers developed in other contexts can be fitted into the model. At the same time the model provides a theoretical basis for a successful implementation of these materials. In that way, the general model for effective TPD can contribute to more coherence between the outcomes and products of different projects and initiatives.

INVESTING IN TEACHING WITH SINUS *(Rieck, Fischer & Döring)*

Teaching aims to improve students' competencies and help them reach their full potential in a specific domain. Teachers have to ensure an effective process of competence development. As international comparative studies such as TIMSS, PISA and PIRLS have indicated, the reality in German classrooms is far from this goal. For this reason, the SINUS program (Improving the Efficiency of Mathematics and Science Teaching) addressing groups of teachers in individual schools was launched in Germany in 1998. The program is meant to help develop actual teaching. SINUS is a long-term professional development initiative from the perspective of situated learning and is implemented on a large scale. The focus is on mathematics and science teaching. Initially intended for high schools, the program was later adapted for elementary schools.

The SINUS Concept

Findings from continued professional development programs point out the importance of different expertise: Scientists and experts in didactics rely on results from their research. Teachers rely on their expertise in teaching and learning. The SINUS program brings these two perspectives together and encourages teachers to improve their skills: learning new methods, getting new information on science and mathematics and making their instruction more meaningful. For these reasons SINUS invites teachers to find suitable solutions to problems and to reflect on the results (similar to the SWISE-approach).The program provides 10 content areas which describe typical problems in professional development and which are based on findings from empirical studies (Demuth et al. 2011). Teachers are expected to make one or more of these areas the starting point of their analysis and practical work. According to the SINUS concept teachers cooperate on the school level and with other (neighboring) schools (this concept can also be found in the Austrian IMST-project). This concept was also adapted and transferred to other educational contexts (e.g. S-TEAM project).

Method

In accordance to findings from international research professional development in training programs is assessed on four successive levels (Kirkpatrick & Kirkpatrick, 2012). It should be evaluated in the course of the program:

(1) taking part in a program, understanding its objectives and feeling comfortable with the procedures can be measured as the *reaction* of participants in terms of customer satisfaction,
(2) *learning* in a program means the extent to which participants change attitudes and improve knowledge and skills as a result of taking part in the training,
(3) *behavior* can be understood as the change in visible procedures that a training participant includes in his or her routines and
(4) *results* are the final outcomes resulting from the participants attending the program.

The studies in the SINUS program evaluate all four levels.

(1) The reaction levels measured in 2010 and 2013 in a survey include all principals and teachers of the SINUS-schools. The four annual reports also give information about the participants' reaction.

(2) The learning level is monitored using different measures: information from the surveys and the reports give insights into what teachers learned in the trainings and what they plan to realize in their teaching.
(3) On the behavior level the analyses of teachers' documentations provide insights into whether, how, and to what degree the program contributes to the professional development process in various content areas. A smaller study, focusing on mathematics, investigates teachers' classroom practices and asks how teachers select and analyze tasks they use in their teaching. From an external perspective the video-study also provides insights into changes in classroom management.
(4) The results are considered on different levels: On the teacher level, the analyses of classroom videos provide information about the differences between everyday classroom instructions given by teachers working in the program and those not working in the program. Case studies provide more detailed information concerning the implementation of the professional development program in the entire school. Some of the schools in the development program are included in large-scale national and international studies assessing student competencies in science and mathematics to investigate students' learning outcomes. This provides the opportunity to compare the achievement of students in schools working in the professional development program to similar schools not in the program.

Studies

Figure 2 shows the studies executed from 2009 to 2013.

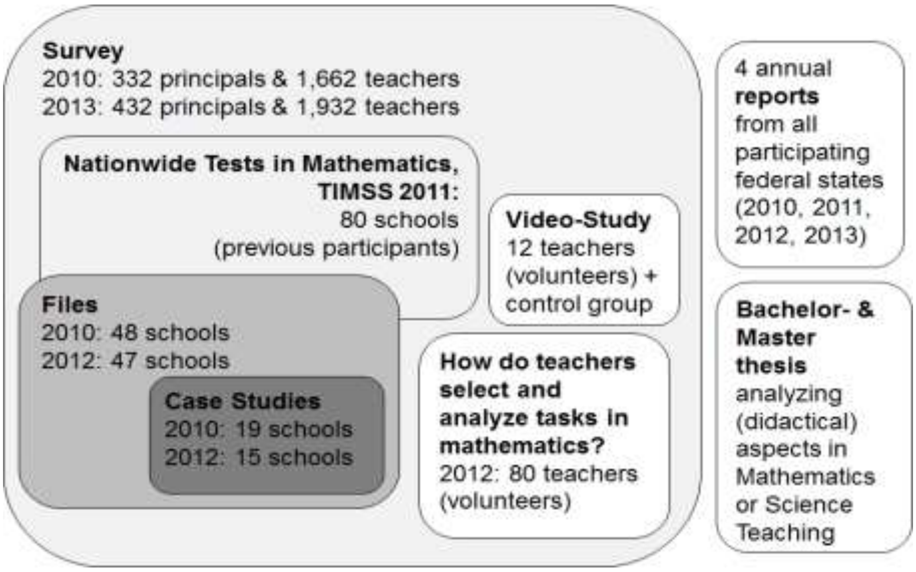

Figure 2. Scientific studies monitoring *SINUS for elementary schools*.

First results and perspectives

First results can be reported based on data from the 2010 studies: teacher and principal surveys, reports and documentations.

An online questionnaire was developed for the teacher survey. The questions were mainly based on a similar instrument used in previous SINUS programs. The data from the teacher survey 2010 are based on the answers of 1662 teachers (levels reaction and learning). We find that teachers feel supported in their professional development process by the program. They have little additional work due to the program and perceive a sense of satisfaction as well as a positive development especially with regard to new contents, classroom teaching and diagnostic competencies. The longer teachers take part in the program the stronger they also feel the program's impact.

In 2010, 48 schools handed in files identifying problem areas, objectives, actions, and reflections. The analyses of 163 records gave insights into the teachers' professional development process (level learning). The first results show that professional collaboration becomes increasingly more common. Teachers mostly follow a cyclical professional development process which includes well defined aims, actions, and reflections.

First videotaped lessons give insights into SINUS-teachers' classroom management.

In 2011, 80 SINUS-classes (fourth grade) took part in a nationwide test in mathematics and in TIMSS 2011. These schools started their SINUS-activities in 2004. Students had to be instructed by a SINUS-teacher at least for one year. First results from 1580 students show significant gains of SINUS-students compared to students from other schools.

THE IMST PROJECT IN AUSTRIA: A NATION-WIDE INITIATIVE FOSTERING EDUCATIONAL INNOVATIONS *(Zehetmeier)*

International comparative studies like TIMSS and PISA had a considerable influence on the national educational policy in many countries. In Austria, as a reaction to the disappointing TIMSS 1995 results at the upper secondary level, a national initiative with the aim to foster mathematics and science education was launched in 1998: the IMST project. It has been prolonged several times since then, and it is still running.

The aim of IMST was to establish a culture of innovation and to strengthen the teaching of mathematics, information technology, natural sciences, technology, and related subjects (MINT) in Austrian schools (see e.g., Krainer, Hanfstingl, & Zehetmeier, 2009).

IMST was implemented in three phases:

- *IMST research project* (1998-1999): It analysed Austria's poor TIMSS results at secondary level II, and offered suggestions for consequences on the basis of the national and international analyses.
- *IMST² development project* (2000-2004): It focused on the secondary level II in response to the problems and findings described. In addition, it elaborated a proposal for a strategy plan for the ministry, aiming at improving the learning of MINT at secondary schools.
- *IMST3 support system* (in three stages 2004-2006, 2007-2009, and 2010-2012): It started to broaden the focus to all school levels and to the kindergarten, and also to the subject German language (due to the poor results in in PISA).

The following sections provide some more details regarding these phases:

IMST research project

The task of this project was to analyse the situation and to work out suggestions for the further development of mathematics and science teaching in Austria. The project team decided not only to analyse the results of TIMSS but also to carry out additional analyses, for example, describing exemplary reform initiatives in other countries, and to offer suggestions for consequences on the basis of the national and international analyses.

The project identified a complex picture of diverse problematic influences on the status and quality of mathematics and science teaching: For example, Austrian students showed poor results in particular with regard to items which referred to higher levels of thinking.

Moreover, mathematics and science education as well as related research were seen as poorly anchored at Austrian teacher education institutions. In chemistry education, for example, no university had a university professor for that scientific domain. The collaboration with educational sciences and schools was – with exception of a few cases – underdeveloped.

In sum, the overall findings showed a picture of a fragmentary educational system of lone fighters with a high level of (individual) autonomy and action, however, there was little evidence of *reflection* and *networking* (see e.g., Krainer, Dörfler, Jungwirth, Kühnelt, Rauch, & Stern, 2002, p. 25; Krainer, 2003). However, the focus to change was not only directed to the teachers (as policy often tends to do), but on the whole educational system, including teacher education and the situation of research of mathematics and science education.

IMST² development project

The recommendations of the research project IMST (see above) led to the project IMST² (2000-2004). This project (Krainer et al., 2002) focused on the upper secondary school level and involved the subjects biology, chemistry, mathematics, and physics. It adopted enhanced *reflection* and *networking* as the basic intervention strategies.

The main goals of this project were

- to initiate, promote and make *innovations* visible, to carry out a scientific analysis and to disseminate innovations, with the emphasis on generating “good practice” concepts and on supporting teachers in further developing their teaching;
- to take part in setting up a *support system* for the further development of school practice in MINT subjects, in particular by encouraging practice-oriented, scientifically grounded subject didactics.

The theoretical framework built on the ideas of *action research* (e.g., Stenhouse, 1975; Altrichter, Posch, & Somekh, 1993), *constructivism* (e.g., von Glasersfeld, 1991; Ernest, 1994), and *systemic approaches* to educational change and system theory (e.g., Fullan, 1993; Willke, 1999).

In order to take systemic steps to overcome the fragmentary educational system, the approach of a “learning system” (Krainer et al., 2002, p. 26) was taken. Thus, the research project highlighted possible implications at different levels: Improvements could be achieved if both students’ competencies and autonomy would be enhanced. These issues should be accompanied in a first step by professional development programmes for teachers (and later to implement changes in initial teacher education), which should focus particularly on reflection of teachers’ own practice, on networking with colleagues, and on communication with and support by external academics.

The basic intervention strategy of IMST² was to enhance *reflection* and *networking*. However, this was not confined to students, but also teachers and teacher educators needed to be seen as learners (e.g., acting as role models).

IMST3 support system

The overall aim pursued by IMST was to broaden its impact, supposing to win over ever more teachers to a culture of innovation. In IMST3, the focus of IMST² on supporting teachers and schools was broadened up to the whole educational system. Starting as "learning system" meant to adopt enhanced *reflection* and *networking* as the basic intervention strategy to initiate and promote innovations not only at schools, but also at teacher education institutions, and in the educational system itself.

The structure of the current IMST project stage (2010-2012) is divided into a *network programme* and *thematic programmes*:

One major emphasis of the *network programme* is laid on regional networks. By way of regional educational planning, these networks can set their own priorities.

IMST has is supporting *thematic programmes* for classroom and school projects. The programme teams, composed of academics and of school staff, monitor approximately 20 classroom and school projects per theme and school year. Special attention is paid to gender equality, which is integrated by way of the gender network into both the content and the structure of all the areas covered by IMST.

Outlook

The focus of the upcoming IMST project phase (2013-2015) is clearly laid out: setting up and strengthening a culture of subject-based innovations in schools and classrooms, and anchoring this culture within the Austrian educational system. Another goal is to contribute to other educational initiatives (e.g., national educational standards, middle school reform, standardized exit examinations, school quality initiatives, etc). The new thematic programmes on offer (and provided with additional academic support and a broader institutional structure) and the promotion of networks constitute the basis for these developments.

SWISS SCIENCE EDUCATION - INNOVATIVE TEACHER PROFESSIONAL DEVELOPMENT *(Stübi & Koch)*

SWiSE - Swiss Science Education has been a joint initiative of ten Swiss-German educational institutions since 2009: The Schools of Teacher Education PH Bern, PH FHNW, PH St. Gallen, PH Thurgau, PH Central Switzerland and PH Zurich, the Institute Unterstrass of the PH Zurich, the Swiss Science Center Technorama, and the two training bodies PZ.BS Basel-Stadt and Baselland FEBL. SWiSE aims to develop interest in science and technology in 4- to 16-year-old students. The project started with training and teaching development at the level of teachers and schools from kindergarten to secondary level. Teachers are supported to reflect the scientific and technical education and develop a competency-based education, to exchange the experience with other schools and build networks.

SWiSE represents a unique collaboration between the different regions. In Switzerland, educational policy is regulated by canton and thus, the diversity of the educational systems is tremendous and challenging. SWiSE brings together experts from different educational institutions, research centers, ministries and school practice.

Annual conference in science and technology education

Since 2010, the annual conference in scientific and technical education is part of the SWiSE program. It offers a mix of lectures, market stands, workshops and meetings with teacher-colleagues from different regions of Switzerland. The conference encourages an experimental culture in science and technology education and highlights the range of current teaching and learning materials, instruments, extracurricular offers and teacher trainings.

Training modules

SWiSE has been offering 59 training modules in experimentation, extracurricular learning sites, task culture / learning environments, technology, and acting for the future. Based on common conceptual principals, the participating institutions elaborated training 15-hour modules that keep a close relation to school practice and the individual development of each participant. Ideas and material developed in the course are implemented in teachers' own teaching and experience is exchanged and discussed on the next course day. There are several weeks between course blocks, time to try out the elaborated lessons and reflect. Participants share concrete scientific, technical and didactic ideas with other teachers and experts in didactics, and so may refine teaching and the school environment.

Teaching and school Development at SWiSE schools

SWiSE supports schools teachers to realize their individual further development in focusing on science and technology. The 61 SWiSE- schools (20 kindergarten / primary, 38 secondary, and 3 comprehensive schools) are distributed over six autonomous regions. In three school years (2012 to 2015), two so-called SWiSE-teachers per school commit themselves to engage in science and technology education and receive a tuition, financed from cantonal funds and contributions from the Foundation Mercator Switzerland, the AVINA Foundation and the Ernst Goehner Foundation as a compensation. Initially, teachers decide about their further development, regarding their own teaching and the school in science and technology education. Along with their school administration, they analyze needs, define individual goals in the areas of inquiry based learning, competence orientation and education for sustainable development. During the project, SWiSE-teachers visit training modules and participate in practice meetings and other SWiSE events. SWiSE schools and teachers are accompanied and supported by science didactic specialists, school development and education policy. They also network with training institutions, other schools and teachers from all areas of German-speaking Switzerland. Together, they face the challenges of everyday teaching and the education policy changes in the Swiss educational system (see www.edk.ch/dyn/11659.php). They start to implement the new Swiss German-speaking curriculum (Curriculum 21) and evaluate the initial experience with competence orientated teaching and assessment. The involved natural science teaching professionals and trainers ensure the link to didactic trends and research, the representatives of the cantonal education departments (ministries) bring in the current educational standards and policies. These, in turn, will receive valuable insight and feedback from school practice through which they can organize their work. In addition to training, coaching and practice meetings, there is also a dialogue on virtual networking platforms on which teaching materials and other documents can be exchanged. SWiSE schools form development centres from which other teachers and schools can benefit. SWiSE teachers share their ideas and experiences, projects and educational materials at the annual public conference, in practice meetings, in trainings, at open days and in publications.

Evaluation of SWiSE

As the project aims to increase student interest in science via the development and professionalization of teachers, the evaluation had been set to the level of teachers. In our approach we incorporate the idea attitudes play a vital role in training evaluation and rely on Kirkpatrick & Kirkpatrick (2006) that suggest successful evaluation should include (1) participants' satisfaction and their intention to continue in the program; (2) participants' change in attitudes, improved knowledge, and/or increased skill as a result of the program. (p.22); (3) and (4) include behavioral change and the benefit in acting as a result of attending a program. Our primary research questions are: To what extent is SWiSE superior to traditional further education? What is the relation of teacher competence development to the increase in students' interest?

We evaluate SWiSE in a double controlled multi-level panel design. In the experimental group, 118 teachers receive SWiSE offers as is explained below. Control group one, colleague teachers in SWiSE schools (n≈40), is used to follow indirect SWiSE effects on colleagues. Control group two, off SWiSE's reach (n≈18), follow their usual practice. The evaluation started in November 2012 and will end in summer 2015.

Altogether 25 relevant constructs are used on school level (e. g. leadership, transfer climate, school aims), teacher level (e. g. constructivist view on learning and teaching, meta-cognition, collegial co-operation, knowledge acquisition, benefit of offers in the program), and student level (e. g. learning motivation or flow experience).

All constructs are valid scales taken from large-scale assessment studies and will be administered in a questionnaire in a pre-post-post-post design (begin of school year 2012/13, end of school year 2012/13, end of 2013/14, end of 2014/15), except the operationalization of teachers' knowledge. There we use an online version of the vignette test construed and validated by Brovelli, Bölsterli, Rehm, & Wilhelm (accepted 2012). The vignette test qualitatively assesses knowledge aspect sensu Shulman (1987) and will be administered pre in winter 2012 and post in summer 2015.

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