SCIENCE AND MATHEMATICS TEACHERS OF THE FUTURE

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Abstract

This paper presents the project Science and Mathematics Teachers of the Future. The aim of the project is to develop and implement a graduate level equivalent degree program in mathematics and science instruction for in-service teachers of lower secondary education. This aim is achieved in the programme through involving the teachers in design, implementation and evaluation of innovative instructional sequences, which deals with a wide range of aspects of mathematics and science, e.g. modern science and the importance of science in society. In the program contemporary science and mathematics education research serves as a basis for the design and development of warranted practices with which the teachers may experiment in their classroom. We will focus on the outcomes of offering a program which is intimately tied to (i) contemporary science and mathematics education research, (ii) modern science and mathematics and (iii) the teacher's practices in the classroom.

Keywords: Educational reconstruction; Professional development; Teacher-researcher collaboration.

Resumo

Este artigo apresenta o projecto Professores de Ciência e de Matemática do Futuro. O objectivo deste projecto consiste em desenvolver e implementar um programa de graduação em educação de matemática e ciências destinado a professores dos primeiros anos do ensino secundário (3º ciclo do ensino básico em

Portugal). Este objectivo é alcançado no programa através do envolvimento dos professores na concepção, implementação e avaliação de sequências de ensino inovadoras, relacionadas com um leque alargado de aspectos de matemática e ciências como, por exemplo, a ciência moderna e a importância da ciência na sociedade. Neste programa, a investigação contemporânea em educação de ciência e matemática serve de base à concepção e desenvolvimento de práticas que os professores poderão experimentar nas suas aulas. Neste texto, centramo-nos nos resultados da oferta de um programa intimamente ligado: (i) a investigação contemporânea em educação de matemática e ciência; (ii) a ciência e matemática modernas e (iii) à prática lectiva dos professores.

Palavras-chave: Reconstrução educacional; Desenvolvimento profissional; Colaboração professor-investigador.

Introduction

In the last decade there has been an increased focus on science education in general and science education in the lower secondary school in particularly. Not only do the students lack interest in learning science – science teachers find it challenging to connect the science in school to the everyday life of the students. From the Danish government there has consequently been a call for an improved professional development of science and mathematics teachers (Andersen, Busch, Horst & Troelsen 2003; Niss & Jensen, 2002). In 2006 *The Ministry of Education's committee for preparing a strategy for science education in elementary school* proposed to educate municipal science education consultants (UVM, 2006). To meet this challenge Michelsen and Sahl-Madsen (2006) suggest the development of a research based master degree program[1] in mathematics and science education for in-service teachers.

To these ends the Center for Science and Mathematics Education at the University of Southern Denmark has since November 2006 conducted the pilot project "*Science Teachers of the Future*"[2], for an education program in mathematics and science education for in-service lower secondary science teachers. The aim of this pilot

[1] In the Danish context of professional development, the term 'master degree' refers to a one year full-time equivalent professional development study on the graduate level. A master degree is studied at the university whereas the university colleges are responsible for the education of teachers for the elementary and lower secondary school.

[2] The project is financially supported by the *European social fund*.

project is to develop and implement a master degree program. On the base of the results of this pilot project, the Danish accreditation counsel has now approved the program as the first Danish master degree program in mathematics and science education for in-service teachers.

The strategic aim of the program is to provide a sufficient number of teachers with skills and competences in helping students to learn mathematics and science in a rational way that reflects the need of improving the proficiency and competence level in the Danish lower secondary school. The *Science Teachers of the Future* project involved teachers as key partners in the development of the master program by involving teachers in trying out and take ownership of the sequences developed in the program. When teachers are working together in ways that provide professional support for one and another the outcome is improvements in practice (Loughran 2006). Reflecting about practice through collaboration with trusted colleagues makes the tacit explicit and develops knowledge, skills and expertise in practice. As a consequence the master program is organized as workshops and open seminars with the purpose of making it possible for the teachers to share their ideas and experiences with their colleagues and having contacts with academic experts in the fields of science and mathematics and educational research. During the development of the master program it was permanently emphasized that the aim of the collaboration of educational researchers and teachers is to produce meaningful change in the teacher's classroom practice. The pilot project was initiated with participation of 24 science and mathematics teachers.

This paper presents the content, structure and theoretical underpinning of the *Science Teachers of the Future* project. Further some findings of emergent themes in the participating teacher's reflections on what they have gained from the in-service teacher training received in the project. These themes suggest objects for future research.

Theoretical Framework

In the community of science and mathematics education researchers it is generally believed, that the teachers do not use educational research to improve their teaching. The critical feature is here that someone outside the classroom decides what is wrong and what changes teachers have to make. A basic motive stems from the experience that traditional research approaches in mathematics education with their

focus on descriptive knowledge, hardly provide prescription with useful solutions for a variety of design and development problems in the teaching and learning of mathematics. As a rule the majority of the teachers are interested in improving and enriching their teaching methods, but as Tyack and Cuban (1995) point on: teachers need help in adapting or developing new instructional practices. McLaughlin et al. (2006) emphasizes the importance of inclusiveness: Experiences from the past century, both in schools and in research, show that innovations in schools can more readily survive if the recipients, mainly the teachers, have been involved early in the decision-making. Taking the perspective of change in teaching practice and the use of research in the process Richardson (1990) argues that research should provide teachers not just with findings in the form of activities that work, but also with ways of thinking and empirical premises related to thinking and learning. In this way research becomes a basis for the development of warranted practices with which the teachers may experiment in their classroom. Teachers exercise considerable control over the decision of whether and how to implement a change in teaching practice, and any intervention should acknowledge this control, and help teachers understand and held accountable for the intervention. This calls for a strategy for teachers' professional development aimed at motivating teachers to use more effective practices. According to Mamlok-Naaman, Navon, Carmeli and Hofstein (2005) action research is an effective means of helping teachers to reflect on their practice, if they are provided with an environment of support, collegiality, and a chance to collaborate with researchers and other teachers. Teachers experience a new dimension of professional development trough action research in three main areas: (1) implementation of change through action research (2) having sense of being a part of professional community, and (3) having contacts with academic experts. Michelsen (2005) points at that in design-based educational research teachers and researchers collaborate to produce meaningful change in the classroom practice. This means that goals and design constraints are drawn from the local context, and leads to the suggestion of a design strategy that deliberately create opportunities for the stakeholders to influence the design process and focus on adaptation to already existing practices. The design process thus calls for the cultivation of the ongoing relationships between teachers and researchers. In this context pre-service as well in-service teacher plays a crucial role. With the rationale of supporting teachers to participate in and contribute to the design process there is a clear-cut for including instructional design in teacher education.

The model of *educational reconstruction*, developed by Kattmann, Duit,

Gropengießer and Komorek (1996) offers a promising frame for involving teachers in action research with a focus on designing, implementing and evaluating innovative instructional sequences and was adopted as the underlying educational approach. This model proposes a cyclic process of analysing scientific contents, studying student's perspectives and developing sequences of instruction. Two reasons for choosing this approach can be spelled out. First, the triadic model of educational reconstruction allows that change-of-practice processes can be vehicles for connecting knowledge of scientific and pedagogical content[3] and classroom practice. Thus the model would, in theory, facilitate the development of warranted teaching practices. Second, the model was originally developed as a research model for science education research, and as such it fits naturally with the aim of equipping the participating teachers so as to implement action-research-type projects. According to the model of educational reconstruction, what the science educator does in this process is to *reconstruct* scientific knowledge "in order to make the science point of view understandable and meaningful to learners" (Kattmann et al., 1996, p. 3). And it fleshes out a beneficial process of reconstruction involving (i) analysing content structures so as to identify salient concepts and their relations; (ii) investigating students' pre-scientific conceptions – both cognitive and affective; and (iii) developing instructional sequences on the basis of the first two steps (Kattmann et al., 1996).

In the context of the program an approach was adopted on which the participating teachers are guided through multiple cycles of developing, implementing and evaluating instructional sequences. The model of educational reconstruction comes to the fore in the process of developing such sequences. And in this respect the model of reconstruction has shaped the content and curriculum of the degree program. In order to properly analyse content structures one must have a firm background of content knowledge across mathematics and the science subjects. Being able to reconstruct a specific content means in the first instance to be able to navigate the field to which that content belongs. Further, a proper investigation of student's pre-scientific conceptions requires both analytical investigatory tools as well as background knowledge in the dialectics of the psychology of learning. To this end the degree program offers to

[3] In this context pedagogical content knowledge is taken to include (i) understanding of possible difficulties involved in students' acquisition of a given subject content, (ii) knowledge of how a given subject matter content can be represented so to best overcome possible learning difficulties (Van Driel, Verloop, & De Vos, 1998), and (iii) an particular type of understanding of a given subject matter which can be readily applied in teaching situations (Ball & Bass, 2000). (For an extensive elaboration on how the concept of 'pedagogical content knowledge' can be identified within the model of educational reconstruction see van Dijk & Kattmann, 2007).

participating teachers an analytical toolbox of scientific and mathematical content knowledge and a background in historical and contemporary educational research. In addition, the participating teachers are introduced to multifarious tools to render successful their reconstruction – such as insights into the usage of a variety of teaching formats and the usage of alternative learning environments. It is thought that the *parallel expansion* in, on the one hand, the dimension of knowledge of subject matter content and, on the other hand, in the dimension of educational tools will equip teachers properly for the development, implementation and evaluation of instructional sequences (see fig. 1). This process is thought to result in dissemination of the sequences, increased networking of the participating teachers; and teachers' reporting to academic experts, each other and other teachers thus facilitating a lasting way of sharing their ideas and experiences with their colleagues and having contacts with academic experts.

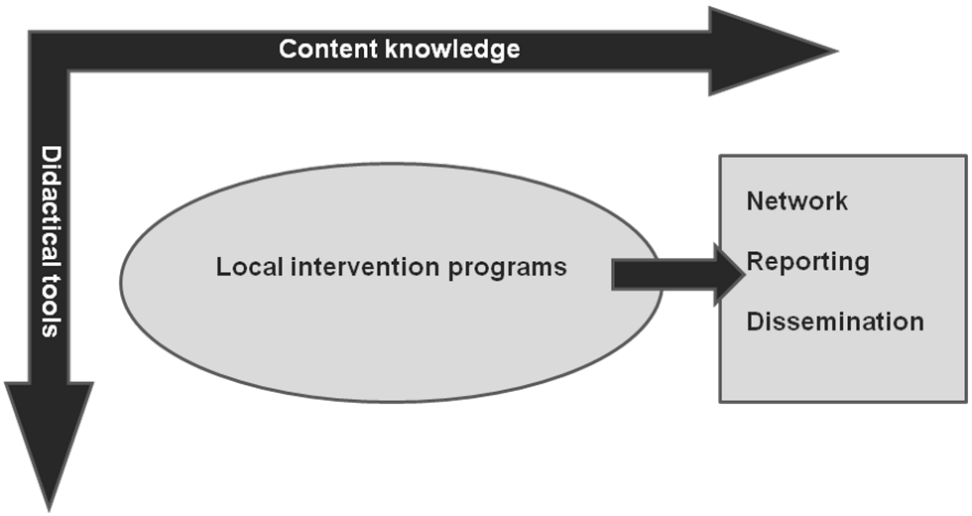

Fig. 1.: A diagram of the educational outlook behind the project *Science Teachers of the Future* in Denmark.

The Structure and Content of the Program offered in the Pilot Project

The program offered in the pilot project is a one-year full time equivalent study program on graduate level and conducted over 4 semesters. Each semester constitutes an individual unit with an overall theme. In each semester the teachers attend to workshops, discussion groups, seminars and lectures. Each semester is concluded with an examination, and the program as a whole is concluded with a Thesis.

The pilot project began with the participation of 24 teachers from 4 municipalities

in the region of Southern Denmark. Prior to launching the project, a developmental support group was formed with members who represented the four municipalities, two of the regional university colleges and a regional science center.

In order to facilitate processes of educational reconstruction the program offers a wide range of input. First, by introducing the teachers to the newest research in different science fields, the teachers not only familiarize themselves with the state of the art research, they also learn how the scientist works to produce new results. This aspect was provided by lectures, workshops and seminars by and with researchers in science and in science and mathematics education from the University of Southern Denmark. Two key themes have been continuously stressed in this respect: (i) the historicity of science and mathematics in general and the histories behind the concurrent research products; and (ii) the everyday work of a science and/or mathematics researcher.

Second, the teachers were introduced to educational theories specifically aimed at science and mathematics education. This might also mark a novel opportunity for teachers since Danish teachers are educated in general educational theory at the university colleges and only to a very small degree get acquainted with course specific educational theory.

Third, the teachers were introduced to different aspects of, and ways of thinking about, the relation between science and society. This topic is challenging for students to work with and equally challenging for the teacher to convey (Sjøberg, 2005). In the program, the teachers experience the forefront of scientific research and how it relates to and impacts on society. Fourth, the program offers an overview of, and work with, multiple approaches and teaching strategies – e.g. multifarious learning environments. The teachers were introduced to what Sjøberg (2005) calls the three dimensions of science namely (i) the products of science –in the recent scientific results (ii) the processes of science – in the presentation from the scientists on how they reached their results and (iii) the role of science in society – in seeing that the recent result of science is applied by the society. These three dimensions are being introduced explicitly with the aim that the teachers will let these dimensions play a part in the designed sequences. Fifth, the teachers were given courses in participatory action research and multiple forms of data collection. Thus they acquired the tools for implementing and evaluating new reconstruction sequences in their own classroom. This was the examination assignment for the second semester – i.e. a written report on

how they individually had developed a sequence, and how they implemented and evaluated it on the basis of their own data collection.

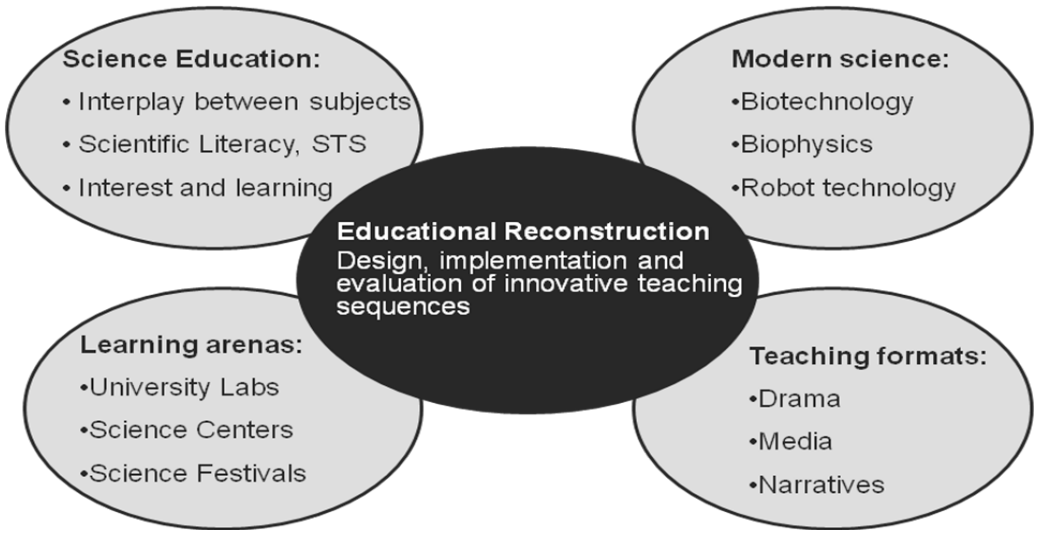

Fig. 2.: A diagram of the different tools offered to teachers for their educational reconstruction.

In order to facilitate that the teachers report and disseminate their work in the program, the teachers will have the opportunity to publish their third semester written report in a special issue of the *Series* from the Center for Science and Mathematics Education, at the University of Southern Denmark. Further it is expected that the teacher's work on their final thesis will be presented to other teachers at a seminar.

Case Study – The Teachers' Reflections on the Pilot Project

Methodology

It was decided that the in-house evaluation of the structure and curriculum of each semester should be merged with a more focused qualitative research study into the salient themes of the degree program from the perspective of the teachers. The present study adheres to the basic tenets of the "naturalistic inquiry paradigm" (Lincoln & Guba, 1985; Lincoln & Guba, 2000) allowing for a study process in which categories were stipulated as embracing clusters of emergent themes. Given the number of participating teachers, and because of the nature of this project as being a pilot project, a "general inductive approach" (Bryman & Burgess, 1994; Dey, 1993) was adopted through which possible key themes could emerge and guide further subsequent studies as well as the continuous development of the degree program.

Our data consisted of:

1. Transcribed videotaped semi-structured interviews conducted prior to the first semester of the degree program. A total of 8 teachers were interviewed on their reasons for commencing the program and on their expectations.
2. Two rounds of 20-item questionnaires with open-ended questions. These questionnaires were distributed to the participating teachers at the end of the first semester and again at the end of the second semester. The questions focused on the teachers' experiences with, and attitudes towards the structure and content of the completed semester as well as their expectations for the following semester.
3. Written assignments handed in by the participating teachers during the course of study.
4. A two pages essay where they reflected over five components in the teacher's self: (1) Self-image, (2) Self-esteem, (3) Job motivation, (4) Task perception and (5) Future perspective.

(It is expected that similar questionnaires to the one mentioned above (item 2) will be distributed at the end of the third and the fourth semester. Further, follow-up interviews that latch on to the ones mentioned above (item 1) are planned to be conducted at the end of the entire project.)

Data Analysis

A qualitative analysis of the data was performed using the general inductive approach. After systematic reading of the collected data, codes and categories were assigned in order to identify possible key themes emerging from the data (Byrne, 2002; Creswell, 1998; Creswell 2002). The identified codes and categories were then renegotiated and a second coding process was undertaken. The frequencies of the occurrence of the individual themes were subsequently recorded.

Findings

The teachers' general evaluations of both the first and second semester of the program are overly positive about both their gains and the close contact to researchers of science and science education. A clear progression is indicated according to which

teachers after two semesters feel

- more inspired,
- more motivated,
- more secure in planning their teaching, and
- more secure in giving reasons for their pedagogical decisions.

Further the teachers generally report that they have become more sensitive to the intricate and deep relation

- between their subject(s) and other subjects, and
- science in general to society.

A few points that might be improved, however, are mentioned by a number of teachers. In the teachers' evaluation of the first semester, around half of the teachers express that information about the aim, structure and content of the program could have been made more explicit prior to the program. However, they seem to ascribe this lack of information to the fact that the program is indeed a pilot. Taken in conjunction with the fact that the majority of the teachers have been asked by their supervisors to participate, it is indicated that future such pilot projects should beware that even though the teachers are aware that they participate as *partners* in a *pilot* project, it is possible that some will see themselves as participating in not just a pilot project.

When asked to reflect on the outcomes with respect to subject matter content of the sessions involving lectures from science researchers at the university, the teachers' responses for both semesters can be seen as falling (almost evenly distributed) within the four categories of *more content knowledge*, *inspiration for their teaching*, *more knowledge about the processes of science*, and *a deeper understanding of the connections between subjects*. Statements of the following type are recurring (all translations are our own):

> *"I have gained a greater insight into the research work at the university"* (Teacher 14, 2. Semester)
>
> *"*[I] *have gained a wider foundation in the other subjects, e.g. biology, to which the visits to SDU* [(University of Southern Denmark)] *were very inspiring and important as motive force"* (Teacher 15, 1. Semester)
>
> *"I have been inspired on [different] scientific areas through the guest lecturers. It*

has been really exiting" (Teacher 20, 1. Semester)

In general, however, it seems that the teachers place even greater value on what they have gained with respect to theories of learning and educational tools. This interpretation is supported by a look at the teachers' explication of their expectations. Roughly there seems to be a pattern of different expectations towards gains in subject matter content and towards pedagogical content, respectively: While the subject matter content part of the program is expected by the teachers to be *inspirational* for their teaching, the pedagogical content part is expected to provide a solid background in theories of learning which affords *reflections* of their practice leading to change. (Clearly some weight has to be given to the difference in conceptualization, but more inquiry must be done into how much 'inspiration' is linked to 'change of practice'.)

Returning to the teachers' reflection on what they have gained with respect to theories of learning and educational tools, after the first semester their responses fall within the categories of *more solid background knowledge*, *provoking reflections on own practice*, *acquisition of new teaching strategies*, and *brushing up on already acquired knowledge*. Statements of the following type are recurring (all translations are our own):

> *"After nine years of practice it is really good to both read new and reread educational literature and be able to latch it on to a self-perceived reality"* (Teacher 12, 1. Semester)
>
> *"It is almost a new world which has opened itself up* […] *Today I have far more course specific educational competencies when I have to plan my teaching in the science subjects"* (Teacher 22, 1. Semester)
>
> *"I have gained more overview and connection in what I have "looked at" in other contexts. And I have learned something new. I have, among other things, read about scaffolding (theoretical), and it has had direct influence on my practice"* (Teacher 21, 1. Semester)
>
> *"It has been* [a] *cause for considerations of my own practice"* (Teacher 20, 1. Semester)

There is a clear progression from the first semester to the second in this respect. Here two categories describe the majority of the teachers' responses: *solid knowledge of multiple theories of learning and their individual tenets*, *affordance of tools for*

practice. In general, the teachers feel much more able to distinguish among theories of learning on the basis of basic assumptions and contexts. Not surprisingly, the teachers seem to have chosen one or two concrete theories as favorite objects for further study, and to some extend also as favorite worldviews of their own. There is also an increased tendency of teachers to be more concrete in terms of how what they have learned has changed their practice (all translations are our own):

> *"[I have gained] a greater insight into the necessity of student involvement. Story line sequences or variations of such have received great respect in my mind"* (Teacher 5, 2. Semester)
>
> *"I have been presented to a "bouquet" of theories from which I can pick. I have gained a foundation for comparison to when I consider or discuss theories of learning. The homework assignment caused me to work in depth with a single theory (flow)"* (Teacher 9, 2. Semester)
>
> *"I have become more aware of using some of the "knowledge" about learning which at the moment is derived from modern neuroscience"* (Teacher 3, 2. Semester)

After the first two semesters the majority not only feel they been moved to reflect on their own practice, but actually express that they have changed their everyday practice. (Only a few teachers who feel that the participation in the program is very time consuming explicitly mention that they have not yet had the time available for changing their everyday practice.) An important insight might be found in this progression. It might well be that genuine and well reasoned change of practice is more profitably facilitated by a *long term* study of the theories of learning and educational tools in which teachers' studies includes work with both the historical/dialectical field of learning theories as well as in-depth work with a self-chosen learning theory.

The teachers to a wide extend stress a discovered importance of discussing/disseminating what they have learned with/to other teachers. In general there seems to be generally agreed focus on the importance of *professional networks* and *cooperation* between teachers, and some teachers already have taken initiative to establish subject networks on their school. Further, around half of the teachers have concrete examples of types of future networks and projects they would like to participate in. Such examples include networks/projects between schools and universities; municipal and regional science teaching networks/projects; and projects

such as PARSEL and IFUN[4] in which the educational researchers at the University of Southern Denmark are participating partners.

The last points can be seen in conjunction to a progression from the end of the first semester, where the teachers, in general, wanted to learn more about how to perform graduate level studies, to the end of the second semester where the teachers, in general, look forward to learn more about doing participatory action-research in their own practice. This not only indicates a progression in self-efficacy with respect to what could be called study-specific issues, it also indicates that the participating are very serious about their desire of understanding and improving the practice of their own practice as well as the regional science teaching in general.

Some further notable progressions deserve a mention. First, a recurring theme seems to be the progression from the teachers having their focus on and interest in one or maybe two subjects, to teachers expressing a discovered insight of the *connectedness* of their subject(s) to (i) other science subjects, (ii) subjects from the humanities and social science subjects, and (iii) society as a whole. And there is a perceived importance of using and highlighting these connections in classroom teaching. Second, in conjunction with the will to discuss educational approaches with their colleagues in professional networks, there is a tendency that the teachers feel more secure about issues concerning such discussions – e.g. a number of teachers explicitly state that they feel more secure in arguing for their decisions about planning their teaching.

To summarize, after two full semesters into the degree program the key themes emerging from the teachers' evaluations of the program involve categories such as *development of and reflection on practice, connectedness of their science subject(s) to others and to society*, *professional networking, inspiration*, and *research into own practice*; and there has been a perceivable cognitive and affective progression on the side of the teachers within the fields denoted by these themes.

Conclusions and Implications

It is essential for teachers to be provided with experiences that allow them to deepen, extend and share their own knowledge and understanding of their teaching

[4] For more information of the PARSEL project see Graeber et al. (2008); for more information on the IFUN project see Michelsen (forthcoming).

practice. Korthagen et al. (2001) distinguish between two types of knowledge in teacher education: episteme and phronesis. Episteme is characterized as abstract, objective, a propositional knowledge. Phronesis is perceptual knowledge, consisting of assertions of a general nature that apply to many different situations in the practice of teaching. Phronesis is being developed through experience and its value is related to the particular person using this knowledge for action. According to Korthagen et al. (ibid) the development of phronesis is most important for teacher education. As a consequence, the professional learning of teachers starts from concrete experience. This aim is achieved in the master program through involving the teachers in design, implementation and evaluation of innovative instructional sequences, which deals with a wide range of aspects of mathematics and science. It is indicated that long-term professional development programs have a positive effect on how teachers think about, and are actually able to perform cogently, practice change. A future topic, which deserves to be explored, is the modulation of teacher identity through such programs. According to Bjuland, Cestari and Borgersen (2008), positive change of identity involves (i) *integration* of old practice within practice changes, (ii) a *transformation* from an asymmetrical relation of teachers to educational researchers to a symmetrical relation in which the teacher conceives of herself as being on par with the researcher, and (iii) increased *reflection* on the aspects linked to learning processes. All of these elements in some way emerge as themes in our data from the Danish teachers. In future studies it would be interesting to enquire identity modulation in the context of the long-term professional development program provided in the masters degree program.

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