

The Swedish graduate school in mathematics education

Conception, birth and development
of a new doctoral programme

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In this paper we trace the establishment of the graduate school in mathematics education in Sweden. To provide a useful context for this initiative we review briefly the evolution of the PhD, the development of doctoral degrees and doctoral programmes in mathematics departments in Sweden, as well as the growing popularity of graduate schools. Progress and programme issues encountered to date are discussed in some detail.

In common with many other countries, Sweden has seen dramatic changes in its tertiary landscape over the past three decades. Several new universities and many university colleges have been created. Student numbers at both the undergraduate and graduate levels have increased spectacularly. The number of candidates embarking on doctoral studies at Swedish universities has soared, so that in 2003 the number of doctoral students exceeded the number of all students enrolled at Swedish universities in 1960 (VR, 2001). As a consequence the number of graduates has also increased greatly. In 2002 the number of doctoral degrees awarded in all areas was 2443 compared to 50 in 1920 (Kim, 2000; National Agency for Higher Education, 2003). The growth started in the 1960s and 70s, with 190 degrees awarded in 1960, 380 in 1970 and 810 in 1980 (Kim, 2000).

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The development of the doctorate in Sweden

In Sweden the highest academic degree, the doctorate, has been awarded since the founding of its first universities, Uppsala in 1477 and Lund in 1666. Before 1850 doctoral theses were typically written by the professor in the subject and presented by him (sic) but defended by the doctoral student at a public defence (Swahn, 1984). A more organised research education with supervision and seminars was introduced during the 1890s (Odén, 1991). However, as recently as the beginning of the last century it was common for doctoral students in mathematics to work without a supervisor. This also seems to have been the case for the first female doctoral graduate in mathematics in Sweden, Louise Petré who graduated in 1911 (Grevholm, 1994; Gårding, 1994). In 1870 a new degree, "filosofie licentiat", was introduced based on the first academic degree. The licentiate degree consisted of course work and a thesis and was formally designed to take two years, but in reality took longer to complete. The doctorate ("doktorsgraden") often took many years and became a lifetime achievement. There was little funding for research students and in most cases they had to work for a living while studying for the degree.

During the 1960s the parliament commissioned an investigation into research education and preparation (Forskarutredningen, 1966). Soon afterwards, in 1969, a new ordinance for the highest degree was presented (Prop 1969:31). A new doctoral degree ("doktorsexamen") was established to replace the old "filosofie licentiat" and doctorate ("doktorsgraden"). The overall aims were to shorten the length of study, raise the quality of doctoral programmes, increase the output of doctoral graduates and thus make the programmes more efficient and effective. The new doctoral degree was expected to take four years of fulltime study instead of the normal six to ten years for the former doctorate. Later on (1982-1985) a new licentiat degree was reintroduced, defined to be half way towards the doctoral degree.

There has been research in the area of mathematics education since the beginning of the 20th century. An example of an early thesis is the one by K.G. Jonsson (1919) which was concerned with aspects of problem solving and relied heavily on interview data. F. Wigforss, K-P. Nordlund and I. Werdelin were other early workers in mathematics education (Bergsten, 2002). Over the years there has been a steady growth in the area of didactics, mainly within departments of pedagogy (i.e., general education), strengthened further by the work of Ference Marton in the 1980s (see e.g., Marton 1986). In recent years the government has actively stimulated research through its research policy and its call for subject area departments to enter the field. The initiative to introduce

research education programmes in mathematics education in Sweden, underpinned by supportive funding, marked another important step in diversifying the country's higher educational offerings.

In the next section, a brief summary is provided of the birth and development of the PhD in other countries. This is followed by a short segment on graduate schools in Sweden, an outline of doctoral programmes in mathematics departments, and a more detailed discussion of the development and progress of the new doctorate.

The doctor of philosophy (PhD) – internationally

According to Schweitzer (1965), the first university doctorates appear to have been the Doctor of Civil Law and the Doctor of Canon Law awarded in the 12th century by the University of Bologna for completion of its courses in law. The current format of the PhD as a post graduate degree evolved from an adaptation by American scholars of a 19th century German innovation to use the PhD as a certification of "the culmination of a period of at least *six years of specialised study under the guidance of a professor*" (Sloan, 1993, p. 40, emphasis in the original). In the American model, the PhD was seen as an "add on" to a first degree, i.e., mirrored the last 2-3 years of the German PhD degree. Such programmes, available in the then newly founded graduate schools, relied heavily on seminars and supervision of a research thesis. This tradition of combining course work and undertaken a research project has continued to the present.

The first American PhD was granted by Yale University in 1861. In Britain, the PhD was introduced still later and only after considerable debate, with Oxford University pioneering the degree in 1917 (Simpson, 1983). By the late 1920s,

the PhD had arrived at all British universities: symbol of the modern era of organised training in research – conceived and nurtured in Germany, imported and commercialised by America and finally introduced into Britain in order to wean the latter's students away from the former's universities (Simpson, 1983, p. 159).

The Swedish doctorate has clearly been influenced by the structure of both the German and the American PhD programmes.

Graduate schools

Graduate schools with programmes leading towards doctoral degrees are now common in Sweden. Although there is not yet a firm national policy

for the establishment and management of such schools (Kim, 2000), their number has grown extensively during the 1990s (National Agency for Higher Education, 2000a). Based on the American model of organizing educational research, they are considered an effective method of facilitating higher degree studies.

In addition to the general requirements for graduate studies as defined in the regulations and Higher Education Act, the National Agency for Higher Education (2000a) considered the following to be crucial for a graduate school: a distinct organisation for running research education; well regulated supervision; co-operation between subjects/universities in courses and seminars; multi- or interdisciplinarity; and both national and international networks.

A wide variety of graduate schools now exist in Sweden. Most schools were created by local initiatives within one or several departments and within one university or through cooperation between several institutions. Many have extensive external funding. In 2001 the government established 16 graduate schools (Prop 2000/01:3), making graduate schools part of the official research policy. The decision was a political one, based – as noted earlier – on the assumption that graduate schools will improve the quality of doctoral programmes. These 16 graduate schools always involve several institutions, among them university colleges which depend on universities for their graduate programmes. Part of the normal public funding of research to the universities is specifically dedicated to graduate schools.

Some graduate schools, among them the new 16 schools funded by the government in 2001, are built around one institution which acts as a centre and is responsible for the administration of funds and the planning of core activities. This is not the case with the graduate school in mathematics education. All nodes in the network play an equal role in the graduate school.

Doctoral programmes in mathematics education – in Sweden

All doctoral (PhD) programmes in Sweden are now formally of four years duration. PhD programmes build on a Bachelor degree (three years) with at least 90 ECTS¹ points in the relevant subject. This is the minimum formal requirement, but in many areas and subjects students have at least four years study and 120 ECTS points in the subject or the equivalent of a Master's degree before starting their PhD studies. In mathematics, students have either the higher level qualification from a Science faculty or a masters degree in engineering, with a specialisation in applied math-

ematics as a background for PhD studies in mathematics. Therefore, in reality all PhD students in mathematics exceed the minimum formal prerequisite background in mathematics before entering the doctoral programme. The PhD programme typically consists of a balance between coursework and thesis work.

Sweden has retained the system of a public defence of the thesis: candidates thus face an opponent who is a specialist in the area of the thesis, and a grading committee with at least one member from outside the faculty. This holds for all PhDs, irrespective of discipline.

The graduate school – from conception to birth

In March 2000 the board of the Bank of Sweden Tercentenary Foundation approached mathematicians and mathematics educators within the Royal Swedish Academy with an offer to support mathematics education through some kind of research initiative. The Foundation is an independent body for funding research, mainly in the Humanities and Social Sciences. It was established by the Swedish parliament. Although it is independent, it retains close links with the parliament and with the research community. At the time of creation of the graduate school, the chairman of the board was a politician deeply involved in the leading party's policy for education and research. The board of the foundation decided to set aside 45 MSEK for a graduate school in mathematics with didactics of mathematics². The board declared two goals for the graduate school:

- To provide teacher training institutions and upper secondary schools with a larger number of mathematics teachers with research training;
- To develop didactics of mathematics as a research area in Sweden³.

The overall aim was to establish a graduate school of high quality and optimum efficiency, and thus support effective research programmes in line with official policies. The starting date was set for September 2001.

The year 2000/2001 was used for planning the structure and organization of the programme. A special board was established, with responsibility for developing activities, confirming admission of students, evaluating and following-up of results, and decisions on renewed funding for each student every year. The board, whose membership is broadly constituted and includes members from outside the university, is also responsible for planning the budget and balancing the accounts. Two other features are noteworthy. Through the establishment of the graduate school, a larger

number of mathematics departments (eight) are now involved in mathematics education. And, as mentioned earlier, in contrast with other graduate schools in which one institution plays a leading role, all nodes in the network play an equal part.

Although there has been no explicit discussion about what is meant by an effective programme, it is reasonable to define it as one in which students finish the degree within a specified time, and with a good quality thesis. It is further intended that they are subsequently able to continue a career as a researcher in the area, are able to formulate new research questions, apply for funding successfully and carry out research supervision. A recent Nordic conference at Umeå University dealt with the issue of supervision of doctoral students and a paper discussing a model for effective supervision was presented by Grevholm, Persson & Wall (2003).

The graduate school in mathematics

The graduate school is constructed as a network, with departments at several universities as the nodes. All mathematics and general education departments in the country were initially invited to take part in the graduate school. The steering group set up a number of criteria for participation in the graduate school and for ranking among departments. Ten departments were chosen out of 14 which expressed an interest. Three international experts who evaluated the suggested programmes and the resources at each department assisted the steering group in this decision. At the same time the steering group selected 20 doctoral students out of 140 applicants to the graduate school. The students had also applied to one (or in some cases several) departments and were chosen according to specified general qualifications and a ranking based on local decisions.

The graduate school has consistently attempted to strengthen the student group by giving them opportunities to meet and work together. For example, during common courses and seminars there are opportunities for discussions with peers as well as with supervisors, opportunities to critique each other's work, and to develop academic skills and understandings of the research process. A discussion forum on the internet has also been established. It is hoped that these arrangements and levels of support will enable the students to complete their PhD studies successfully and efficiently.

Common courses have been developed and are given by departments in the network. Approximately one course is given per semester, and each course corresponds to 25% of one semester full-time study. The courses are organised as residential courses, with two sets of meetings

over 4–5 days and additional work at the home department in-between and afterwards. All courses address topics in didactics of mathematics from some perspective.

All doctoral students in the graduate school – with few exceptions – have participated in the courses offered. As well, about five to ten students outside the graduate school – not the same students each time – have taken these courses. Some supervisors have also attended all or parts of the courses. In addition, a number of special meetings have been arranged for supervisors and/or doctoral students with themes of general interest, for example, supervision and ethical questions. The graduate school covers travel and accommodation expenses, as well as most of the costs for developing and delivering the courses.

Students in the graduate school in mathematics

The students are enrolled within their faculty as regular PhD students, follow a programme established by the faculty and will get their PhD from the university in which they are enrolled. Hence it is not possible for the graduate school to impose new requirements once the departments have joined the school.

All doctoral students are employed by their universities under the same conditions as other graduate students. This means that they are engaged in PhD studies for 80% of the time and spend the remaining 20% as teaching assistants or doing other work at the department. Since PhD programmes are of four years duration full-time, the time envisaged for completion for an employed PhD student is five years.

From its inception, the graduate school has funded 80% of the salary of each doctoral student (there are some variations in the exact amount since students have locally agreed salaries). It is envisaged that this funding will continue for five years. The graduate school is also contributing to the cost for supervision, at a standard rate, for the same period. Yearly follow-ups are done and funding continues as long as students continue with their programme.

The background of the students in the graduate school is typically a degree as an upper secondary school teacher with at least the equivalent of 90 ECTS study points of mathematics, the level of mathematics that is required for teaching at this level. Some students have a different background, e.g., as engineers or they have a degree with a general natural science content. About half of the students have only the minimum prescribed level of mathematics.

The doctoral programmes

The doctoral programmes in the graduate school are interdisciplinary with the aim of combining thorough mathematics schooling with training to become an independent researcher in mathematics education.

As with other PhD programmes, the doctoral programme consists of coursework and a thesis. The course work should not exceed two years fulltime study. Consequently the thesis work corresponds to at least two years full time work. The course programme covers a broad area, ranging from mathematics to didactics of mathematics and research methodology. Students have different academic backgrounds. This is considered a strength of the group as a whole but also means that some of the mathematics courses in the programmes need to be designed specifically with this in mind. However, students are expected to take some of the courses included in the regular course programme for mathematics PhD students as well as a number of common courses delivered within the graduate school.

The programme aims at a double competence. Thus the depth expected in mathematics may not be the same as for other PhD students in mathematics, since students in the graduate school will also be taking courses outside the mathematics department. Nevertheless, the thesis component is subject to the same process of evaluation as for other doctoral degrees. Since different departments have different programmes the balance between mathematics on the one hand and didactics of mathematics on the other varies. However in all cases research and thesis work should be within didactics of mathematics.

An overview of the different organizational structures in place in the participating universities is given in Table 1. The focus is on the university departments involved in the graduate school so that the table does *not* give a comprehensive account of research programmes in mathematics education in Sweden. Explanations for the headings and some of the entries are given below the table. Numbers of students and supervisors refer to August 2003. It should be noted that the situation is not static but changes continuously.

In the next section, broad issues raised with respect to doctoral programmes in education are discussed, to provide a context for assessing progress to date of students in the new graduate school in mathematics education.

Table 1. *Selected characteristics of the research education environment at each of the departments in the graduate school.*

University department	Degree of integration	Disciplines/ areas represented by supervisors	Total number of students, in ME and (within the grad school)	Number of supervisors in the grad school at dept and (external)	Beginning of doctoral programme in Math Educ within the department (at the university)	Driving force
Mathematics dept, Univ of Gothenburg	Multi-disciplinary	Mathematics, Didactics /general education	4 (3)	3 (1)	Start of grad school (Programme in place)	Internal/ external
Mathematics dept, Linköping Univ	Inter-disciplinary	Mathematics, Didactics of math	2 (1)	2 (1)	Start of grad school (Programme in place)	Internal/ external
Dept of math, Luleå Univ of Techn	Inter-disciplinary	Mathematics, Mathematics and learning	4 (2)	3 (1)	1996	Internal/ external
Math and Science dept, Univ College of Kristianstad (PhD programme of Luleå)	Inter-disciplinary	Mathematics, Didactics of math	2 (2)	1 (1)	Start of grad school	Internal/ external
Mathematics dept, Stockholm Univ	Multi-disciplinary	Mathematics, Didactics/ general education	1 (1)	1 (2)	Start of grad school	Internal
Dept of numerical analysis and computer science, KTH/SU (PhD programme of SU)	Multi-disciplinary	Mathematics, Didactics, Applied computer science	1 (1)	1 (2)	Start of grad school	Internal
Math and Science dept, Univ College of Mälardalen (PhD-programme of SU)	Multi-disciplinary	Mathematics, Didactics/ general education	2 (1)	1 (1)	Start of grad school	Internal
Mathematics dept, Umeå Univ	Inter-disciplinary	Mathematics, Didactics of math	6 (3)	2	1995	Internal/ external
Mathematics dept, Uppsala	Inter-disciplinary	Mathematics, History of math, General education	2 (2)	3	Start of grad school	Internal
Math and comp science dept, Växjö Univ	Multi-disciplinar	Mathematics, Didactics/ general education	4 (2)	2 (1)	Start of grad school	Internal

Notes.

University department: The department is specified here. Some of the departments without a doctoral programme of their own adhere to a programme at another university.

Degree of integration: According to Gibbons et al. (1994), multidisciplinary co-operation is based on autonomous disciplines addressing a research problem requiring expertise from the different disciplines whereas interdisciplinarity refers to a deeper cooperation between disciplines characterised by the development of common terminology, methodology and/or theoretical structures.

Disciplines/areas: The areas are indicative of the main supervisor's research area.

Number of students: Number of graduate students enrolled at the programme "Mathematics with didactics of mathematics" (or equivalent) within the department. The number of students funded by and participating in the graduate school is shown in brackets.

Number of supervisors: The number of supervisors of students in the graduate school appointed at the department. The number of supervisors of students in the graduate school appointed at other departments is shown in parenthesis.

Starting point: This indicates the starting time of the current doctoral programme at the department. In some universities a doctoral programme admitting dissertations in Mathematics Education was already in place earlier, see Bergsten (2002). The latter is shown in parenthesis.

Driving force: The last column indicates the department's motives - inferred from the application documents to the graduate school - for starting an interdisciplinary doctoral programme in Mathematics with didactics of mathematics at the department. By internal driving forces we mean motivation from an internal scientific perspective. By external driving forces we mean societal demands, e.g., teacher education and its connection to research, and references to concrete research problem areas rooted in school practice. This distinction between internal and external driving forces is based on the discussion by Gibbons et al. (1994).

Reflections on doctoral programmes in education

Reviews of doctoral programmes, and of the progress of doctoral students, invariably point to the pivotal role played by the candidates' supervisor(s). For example, Faghihi, Rakow and Ethington (1999) surveyed just under 100 doctoral students close to completing their degree to determine factors that had influenced their progress.

Results indicated that both students' research self-efficacy and their relationships with their advisors and committee members significantly contributed to dissertation progress, and these effects were consistent for all students, regardless of gender, age, degree of financial impediments, or number of years in the doctoral programme (p. 1).

Leder (1995) and Leder, Forgasz & Landvogt (1996) discussed the rights and responsibilities of both supervisors and students at some length. The

National Agency for Higher Education has published a *Doctoral Student Handbook* in which the rights and demands of Swedish doctoral students are outlined (National Agency for Higher Education, 2000b). The Handbook is available on the net and is updated continuously.

Ways in which supervisors can facilitate students' progress are discussed in the next section, with comments of particular relevance for the graduate school of mathematics education added. These latter notes are based on two written evaluations gathered from students and supervisors in the graduate school⁴, on data provided in the annual progress reports, as well as on informal feedback from supervisors and students to "outside" academics contributing to the graduate school in mathematics.

Progress issues

Supervisors should provide guidance with the research topic and the candidate's programme. Given the continuing knowledge explosion, this is increasingly challenging. An appropriate balance must be maintained between course work and time spent devising, executing, and writing up the research project.

Comment: The design of local courses in the programme can be problematic. Some departments require students to study courses from the doctoral programme in mathematics without considering whether these add to the mathematics education component of the thesis work. For some students this is a critical issue. An important aim of the annual study plan (see Figure 1 below) is to facilitate the monitoring of student progress.

Students should be offered direction about the size, scope, and standard of a doctoral dissertation. Despite the apparent uniformity of standards across universities, there is considerable variation in acceptable research procedures and methods of reporting.

Comment: For students in the new mathematics education doctoral programme, having to balance the needs and expectations of two disciplines – and the preferences and biases of supervisors from two distinct disciplines – is generally quite challenging.

The multi- or inter-disciplinary nature of mathematics education places special demand on supervision. Doctoral students often have several supervisors with different competencies or one supervisor, who covers several subject areas.

Comment: In the graduate school in Sweden students combine not only mathematics and pedagogy but also a number of other disciplines. There are students looking at history and mathematics teaching and learning,

students investigating sociological issues, students whose research is focused on the psychology of learning, as well as other examples of multidisciplinary. In the graduate school most students have supervisors from mathematics, mathematics education and/or some other area. The supervisors' different research traditions can create tension or confusion, especially in the early stages of candidature before all parties know each other well.

Supervisors are expected to comment, from the outset, on drafts of work as it develops. Constructive feedback, positive as well as critical, is needed.

Comment: The collaborative nature of some of the special courses and seminars organised for students in the graduate schools offers regular opportunities for such feedback.

Advice on ethical considerations and requirements may also be needed.

Comment: Ethical issues relevant in research conducted with children or adults may be new to supervisors who have worked exclusively in mathematics. A short course on this topic has already been part of the doctoral programme.

Students may be relying on supervisors for ensuring that appropriate physical resources are available and that the amount of "outside" work is not excessive.

Comment: The board of the graduate school does, at least formally, monitor these aspects as well.

Much can be learnt from attendance and presentations at department seminars and outside conferences and these activities can be encouraged by supervisors.

Comment: Again, the graduate school offers strong (financial) support for these activities.

Students may need support with scientific writing.

Comment: For Swedish students the question of what language to choose for the thesis and what format, a monograph or a collection of published papers, is fundamental. The lack of tradition, the existence of few role models, and the expectation by supervisors with roots in mathematics for a thesis to be written in English make the decision even more difficult. Some students who have experimented with writing in English have found it excessively time consuming and difficult to express the subtle nuances of which they are capable when they work in Swedish. These students intend to write at least part of their thesis in Swedish.

For supervisors in the Swedish graduate school issues such as those listed above are pertinent and timely, with some more complicated to resolve than others. As already indicated, courses and seminars specially designed for those associated with the School have addressed many of these questions.

Programme issues

As indicated earlier in the paper, doctoral programmes have been granted in the USA for close to 150 years. Yet, as is illustrated by the flurry of projects in that country aimed at re- or deconstructing the doctoral experience, those involved in doctoral programmes continue to search for ways to improve their scope, structure, and delivery. For example, Young (2001) cites three major (American) programmes aimed at improving or revitalizing doctoral education: those funded by the Pew Charitable Trust, the Woodrow Wilson National Fellowship Foundation, and the Carnegie Foundation for the Advancement of teaching. Nyquist (2002)

<p>Main supervisor: Alfa Persson Other supervisor: Beta Persson</p> <p>Special study of 120 points: A study on the relation between text book tasks in mathematics and tasks given in national assessments in Sweden.</p> <p>The following parts are included</p> <ol style="list-style-type: none">1. The study of theories in mathematics education of importance to this investigation2. To describe the concrete research problems and decide about limitations3. Pilot study and carrying out a limited part of one of the research problems4. Investigation of and comparisons with similar investigations in Sweden and outside Sweden. <p>Study course (a list of courses selected)</p> <p>To finalise the degree participation in the research seminars of the department is compulsory. We have today agreed upon this plan.</p> <p>Signed Anna Doktorsson Alfa Persson</p>
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Figure 1. *Study plan for PhD in mathematics didactics for Anna Doktorsson, department of mathematics, A-town University.*

lists some 20 examples of funded projects contributing in various ways to "doctoral education reform", though not all of these are concerned with the discipline of education.

In Sweden, before a university can offer a doctoral programme, the faculty board has to prescribe a general study plan and title for the subject. Thus there is considerable diversity in the list of subjects on which the doctoral students can draw. The study plan usually includes the requirement that the student and supervisors devise the student's yearly study plan which is used for the annual evaluation of the student's progress. A typical individual study plan is shown in Figure 1.

Student progress

At the time of writing this article, the graduate school has been in existence for two years. Not all students have remained in the course: three out of 21 have left the programme for different reasons and two have suspended their programme for a limited period of time and are expected to take up their studies again. Some new students will be admitted soon. All students who are still part of the school have so far followed the programme successfully. Most of the time has been spent on course work, but all students have started on pilot projects or even progressed further with their research projects. Several of the students plan to present a licentiate thesis and hope to get their licentiate degree during the next academic year (2003/04)⁵. This is not compulsory and some will progress directly towards the doctoral degree.

A final comment

In this paper we have sketched the conception, birth, and early development of the graduate school. We have described the context in which the programme was established, its overall aims, agenda and progress issues. At this relatively early stage, some two years into the programme, there is much cause for optimism. The majority of students appear to be progressing satisfactorily, both in their course work and design and execution of their thesis. A more comprehensive evaluation of the programme, as well as the longer term impact of its graduates on Swedish mathematics education at the school and university levels, is an important task for the future.

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Notes

- 1 60 ECTS study points corresponds to one year full time study.
- 2 The designation of the graduate school is word for word "Mathematics with (direction towards) the subject area didactics – In Swedish: Matematik med ämnesdidaktisk inriktning". It is translated by the shorter "Mathematics with didactics of mathematics". Throughout this document we refer simply to "the graduate school".
- 3 The term "matematikdidaktik" has a broad meaning in Swedish. It can best be translated to mathematics education research or didactics of mathematics.
- 4 Space constraints do not allow elaboration of these evaluations.
- 5 At the time of writing, four students have successfully completed their licentiate degree.

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Sammanfattning

I artikeln beskriver vi införandet av en forskarskola i matematik med inriktning mot matematikdidaktik i Sverige. Som en bakgrund granskar vi kort utvecklingen av begreppet filosofie doktor och av doktorsexamina liksom utbildningsprogram för doktorander inom matematiska institutioner i Sverige. Vi redovisar framväxten och den ökande populariteten hos forskarskolor. Programinnehållet och utvecklingen hittills inom forskarskolan diskuteras mera detaljerat. Frågor om handledningens roll i ett tvärvetenskapligt sammanhang diskuteras.