The Research Council of Norway

Follow-up plan for the evaluation of research in mathematics

Report prepared by a national committee

Division for Science

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To the Research Council of Norway

The members of the national committee commissioned by the RCN to follow-up the evaluation of research in mathematics at Norwegian Universities hereby submit the following advisory implementation plan. It is our hope that the report will be a useful tool for the RCN in its effort to strengthen the quality of research in the mathematical sciences in Norway.

The views presented in this report are the consensus among the members of the committee.

Elena Celledoni	Bjørn Ian Dundas
Ingrid Kristine Glad	Fred Godtliebsen
Kristian Seip	Ragnar Winther (Chair)

Preface

Norwegian mathematics was evaluated in 2011 by an international committee commissioned by the Research Council of Norway (RCN). Seven universities participated in the evaluation. In their report the committee proposed a number of measures for improving the quality of mathematical research in Norway. After the evaluated institutions had expressed their reaction to the report, the RCN commissioned the present national committee to give advice on how to turn the recommendations of the international committee into realistic actions. Together with a short review of the role of mathematics in modern science, the present report contains a discussion of the recommendations of the evaluation committee, and concludes with a list of suggested actions.

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Content

1 Sammendrag

Betydningen av matematiske fag for vitenskapssamfunnet har forandret seg dramatisk over de siste tiår. Matematikk er naturvitenskapens språk, men også det fundamentale språket for dataanalyse og vitenskapelige simuleringer. Ettersom flere og flere områder av naturvitenskap, ingeniørfag, medisin, forsvar, næringsliv og offentlig sektor baserer seg på komplekse datasimuleringer og analyse av store datamengder, vil betydningen av matematiske fag nødvendigvis bli større. Derfor har utviklingen av norsk matematisk forskning konsekvenser langt utover matematikkmiljøet selv. Anbefalingene som er gitt i denne rapporten må sees i denne sammenheng. Den økte betydningen av matematikk for vitenskapssamfunnet som en helhet representerer enorme muligheter for faget. Samtidig blir det nødvendig for matematiske institusjoner å prioritere mellom nye forskningsfelt og mer veletablerte fagområder. Forskningsrådet bør ha en klar visjon om hvordan de ønsker å påvirke denne utviklingen.

En hovedkonklusjon i evalueringsrapporten fra 2011 er at norsk matematikk holder høy internasjonal standard. Imidlertid framhever også rapporten noen viktige bekymringer. De viktigste utfordringene kan oppsummeres slik:

- En hovedbekymring er rekrutteringen av neste generasjons matematikere og statistikere til norske universiteter.
- Det mangler midler til forskerinitiert matematisk forskning.
- Det er ikke tilstrekkelig mobilitet mellom norske og utenlandske universiteter, og mellom universiteter og industri.
- Kjønnsbalansen er fortsatt et uløst og opplagt problem.

Våre forslag til hvordan evalueringskomiteens anbefalinger kan implementeres er beskrevet i Seksjon 5.1 nedenfor. De fleste av disse tiltakene krever ekstra bevilgninger, og derfor er tiltakene presentert i tre scenarioer. Scenario 1 krever ingen ekstra bevilgninger fra NFR, og tiltakene må gjennomføres av institusjonene selv, og av enkeltforskere. Disse tiltakene er presentert i Seksjon 5.2.1, og adresserer utfordringer relatert til rekruttering, mobilitet og kjønnsbalanse. Imidlertid, uten ekstra bevilgninger er betydningen av disse begrenset.

Scenario 2 er basert på Scenario 1, og i tillegg korttidsfinansiering (3-5 år) fra NFR i form av institusjonsforankrede strategisk prosjekter (ISP) med et totalt budsjett på 30 MNOK. De viktigste tiltakene som vi foreslår er å:

- sikre brobyggingsmidler i tilfeller der eksepsjonelle forskningsmiljøer står i fare for å forsvinne, og skaffe ekstra midler til karriereutviklingsstillinger innen matematiske fag,
- forbedre mobiliteten innen matematikkmiljøet ved å etablere nasjonale nettverk og utvikle bedre undervisningssamarbeid mellom institusjonene,
- supplere BALANSE-programmet ved å bevilge ekstra midler til kvinnelige matematikere,
- sikre friske midler til Professor II-stillinger som skal benyttes til å forbedre kjønnsbalansen og det nasjonale samarbeidet innen matematiske fag.

En mer detaljert beskrivelse av de foreslåtte ISP-tiltakene er gitt i Seksjon 5.2.2.

Scenario 3 omfatter Scenario 2, og i tillegg etablering av et nytt anvendelsesorientert forskningsprogram innen matematiske fag, som også kan omfatte de mer teoretiske deler av IKT (Informasjons- og kommunikasjonsteknologi). Forskningsprogrammet er beskrevet i Seksjon 5.2.3. Dette tiltaket vil, i alle fall delvis, besvare evalueringskomiteens anbefaling om mer midler til forskerinitierte prosjekter innen matematikk. Samtidig vil etableringen av et slikt program skape en nasjonal arena for strategiske beslutninger i en tid da matematisk forskning har betydelig innflytelse på utviklingen innen store deler av forsknings- og ingeniørsamfunnet. Vi foreslår at programmet disponerer 50 MNOK årlig i de neste ti år. Muligheter for å kombinere midler fra programmet med private tilskudd bør undersøkes.

2 Summary

The role of mathematical disciplines in science has changed dramatically during the last decades. Beyond its traditionally recognized role as the language of science, mathematics is also the fundamental language for computer simulations and data analysis. As increasingly more areas of science, engineering, medicine, defence, business, and the public sector rely on complex computer simulations and the analysis of large data sets, the mathematical sciences inevitably play a more important role. Therefore, the development of Norwegian mathematical research has impact far beyond the national mathematics community itself. The recommendations given in this report are influenced by this view. The increased relevance of mathematics in the larger scientific community represents enormous opportunities, but also large responsibilities for the discipline. At the same time, departments are forced to take on strategic decisions concerning how to prioritize between new research directions and more established sub-disciplines. The RCN should also have a clear vision on how they will influence this development in Norway.

A main conclusion of the evaluation report from 2011 is that in general Norwegian mathematics reaches high international standards. However, the report also raises some important concerns. The main concerns can be summarized as follows:

- A main concern is the recruitment of the next generation of mathematicians and statisticians to Norwegian universities.
- There is a lack of funding opportunities for investigator-driven basic mathematical research.
- There is not sufficient mobility, both between Norwegian universities and those abroad, and between universities and industry.
- Gender imbalance remains an evident unsolved problem.

Our suggestions on how the recommendations of the evaluation committee can be implemented are described in Section 5.1 below. Most of these actions require extra funding. Therefore the actions are presented for three scenarios. Scenario 1 includes zero-cost actions which have to be implemented by institutions and individual researchers without any extra funding from the RCN. These actions are presented in Section 5.2.1, and address issues related to recruitment, mobility, and gender imbalance. However, given that there is no extra funding considered, the impact of these actions will naturally be limited in scope.

Based on Scenario 1, Scenario 2 assumes in addition a short term funding boost (3-5 years) from the RCN in the form of institutional strategic projects (ISP) with a total budget of 30 MNOK. The main actions we suggest are to

- provide bridge funding when exceptional research environments face depletion, and make extra funding available for career development positions in mathematical sciences,
- increase mobility by the creation of national research networks and cross-institutional educational systems,
- supplement the BALANSE programme by making extra funding available for female mathematicians,
- fund adjunct professorships to attack gender imbalance and improve national cooperation.

A more detailed description of the suggested ISP-actions is given in Section 5.2.2.

Scenario 3 includes Scenario 2, and adds the creation of an application-driven research programme in mathematical sciences, which also may include the more theoretical parts of ICT (Information and Communication Technology). The research programme is presented in Section 5.2.3. This action will, at least partly, meet the recommendation of the evaluation committee to fund more investigator-driven research in mathematics. Moreover, establishing a research programme will create a national arena for strategic decisions at a time when mathematical sciences heavily influence large parts of the scientific and engineering community. We suggest that 50 MNOK are made available for this programme each of the coming ten years. The possibility of combining private and programme funding should be explored.

3 Introduction

The research in mathematics at Norwegian universities was evaluated in 2011 by an international committee commissioned by the Research Council of Norway (RCN). The committee was chaired by Professor Ulrike Tillmann from University of Oxford, UK, and consisted otherwise of members from institutions in Australia, France, Germany, Sweden, UK, and USA. The committee has identified strengths and weaknesses, and has given a number of recommendations on how to improve the quality of mathematical research in Norway[1].

The evaluation covered research performed at the seven universities, namely NTNU, UiA, UiB, UiO, UiS, UiT, and UMB. Research in mathematical sciences is also carried out at a number of other institutions, like the Norwegian School of Economics (Bergen) and at most of the university colleges, but none of these institutions took part in the evaluation. Mathematical sciences are also key disciplines at organizations like the Norwegian Computing Center and the Department of Applied Mathematics at SINTEF ICT, but these groups chose not to participate in the evaluation.

As in the evaluation report we will use the term *mathematics* to denote the mathematical sciences in a broad sense, including pure mathematics, statistics, computational mathematics, and parts of mechanics.

Findings and Recommendations of the evaluation committee

The report from 2011 contains an evaluation at the national level, at departmental level, and at the level of individual research groups. The evaluation committee was challenged to propose a list of possible measures for improving the quality of mathematical research in Norway, and also a list of possible funding strategies that the RCN should consider for the future support of the field. Comparisons with a similar evaluation from 2002 were also part of the mandate. The present report addresses the committee's recommendations at the national level.

- The committee points out that mathematical sciences research and education are vital to the high-tech and engineering industry of Norway.

However, the committee finds that there is evidence that Norway is not investing enough in science and technology, of which mathematical sciences is an essential part.

- The committee concludes that, in general, Norwegian mathematics reaches high international standards. In the opinion of the committee, a majority of the research groups enjoy high international reputation.

To a large extent this testifies that Norwegian mathematical research is thriving. However, the evaluation committee also points out that Norwegian mathematics faces some major challenges for the future.

- A main concern is the recruitment of the next generation of mathematicians to Norwegian universities.

[1] Research in mathematics at Norwegian Universities. An evaluation. The research council of Norway, 2012. ISBN 978-82-12-03058-9

The evaluation committee points out that in a situation where the reservoir of excellent young research mathematicians is limited, whole research groups are likely to be depleted because of the retirement of core members.

- The committee finds that there is a lack of funding opportunities for investigator-driven basic mathematical research.

The committee is of the opinion that the reason for this lies in the nature of the Norwegian funding system, because it does not offer sufficient support for basic research in theoretical disciplines. During the last decade there has been considerable effort in many European countries to focus on collaboration between mathematical research groups and industry. Building closer contact between the academic and the industrial worlds is seen as a key tool for further technological development. However, the committee feels that there is less focus on such cooperation in Norway than in many other European countries.

- The committee finds that there is not sufficient mobility, both between Norwegian universities and those abroad, and between universities and industry.

The committee argues that mobility enhances research productivity.

- The committee emphasizes that gender imbalance remains an unsolved and evident problem.

The committee proposes a number of actions to attack the recruitment problem of Norwegian mathematics. To bridge the gap between post-doc and tenure positions, the committee proposes to create career development positions. Furthermore, to increase the recruitment to higher mathematical education, it is proposed to develop summer schools for talented high school students and bachelor candidates. The committee also urges the RCN to launch a new programme to fund investigator-driven basic research in mathematics. To increase the mobility between the academic world and industry the committee argues for special support for PhD candidates working in the non-academic world. Finally, the committee recommends that mathematics departments and national agencies, such as the RCN, take gender imbalance seriously, and attack it from all angles. The committee appreciates some existing practices, for example allowing employees of the underrepresented gender are given extra sabbatical time to prepare for promotion. The committee recommends that appointment committees for new positions at any level actively seek out specifically applicants from the underrepresented gender.

Purpose of the present report and the follow-up plan

Based on the findings and recommendations of the international evaluation committee, the RCN has invited all the evaluated institutions to express in written form their reactions to the evaluation, describing their own follow-up plans, suggesting actions to be taken at a national level and addressing how the institutions, alone or in collaboration with funding agencies, can contribute to the national follow-up effort. The present report contains a coordinated national follow-up plan that takes into account the input from the evaluated institutions and their suggestions. This work has been commissioned by the RCN to a national committee of Norwegian mathematicians representing the evaluated institutions. The main purpose of the present report is to turn the suggestions of the evaluation committee into realistic actions and measures. Furthermore, to use the available funding as effectively as possible, our recommended actions should also utilize other programmes and mechanism offered by the RCN. For example, the newly announced FRIPRO initiative, targeted to young and talented researchers, can prove to be an effective mechanism for filling the gap between post-doc and tenure, and the new programme called “Balanse” offers mechanisms to attack the gender imbalance. Through alternative programmes the RCN also can fund further cooperation between university research and industry. Finally, in the recent report “Lange linjer – kunnskap gir muligheter” the Ministry of Education and Research proposed the establishment of a new type of tenure track positions, referred to as “innstegsstillinger,” aimed at the early recruitment of promising researchers in temporary posts which can be made permanent upon qualification of the candidate[2]. This is a strategic measure which is part of the ministry plan for the next ten years.

Proposed actions of the follow-up committee

Below, we will discuss a number of additional actions that the RCN should consider in order to react to the challenges of Norwegian mathematics identified by the evaluation committee. To make a smooth transition to the next generation of mathematicians at the universities, we recommend that the RCN temporarily funds a few tenure positions that can overlap with existing professorships in strategically important fields. The establishment of national networks in certain subfields of mathematics may lead to increased cooperation among different universities, and will have positive potential impact on research groups that are relatively isolated or of subcritical size. In view of the increased political focus on the importance of basic research and the impact of mathematics in most sectors of Norwegian economy, the Norwegian mathematics community should be supported to keep its vitality and improve its level of quality. Although a small nation like Norway cannot produce new breakthroughs in all fields of technology, there are no impediments for Norwegian mathematics to succeed in competing at the highest international standards. Norway is also the host of one of the most prestigious international prizes in mathematics, the Abel Prize. Through this prize the Norwegian scientific community has a unique entrance to a number of international scientific arenas, but to maintain this position the quality of Norwegian mathematics has to be sustained at the highest possible level.

The evaluation committee has recommended that a new investigator-driven research programme in mathematics be established. Appropriate funding of mathematical research is indispensable to permit scientific advancement and enable new discoveries in a range of other research fields, some of which are already well established in Norway and others that are still to be spawned. Innovation and new fundamental ideas is a viable path to strengthen Norwegian economy[3] by making it less dependent on the traditional Norwegian natural resources. Norwegian technological and scientific research has seen a tremendous boost throughout the last three decades with the incentives and demands of the Norwegian oil industry. Today Norwegian technology is to a large extent related to petroleum and gas industry. A renewal of Norwegian technology cannot come exclusively from within these traditional fields, but also by pursuing new endeavours rising from new fundamental research. Mathematics has an important role to play in this development. We therefore recommend that the RCN follows the advice from the international evaluation committee by starting a new

[2] Lange linjer - kunnskap gir muligheter, Meld. St. 18 (2012–2013), 7.2.2.

[3] See also *Økonomiske perspektiver,* Tale av sentralbanksjef Øystein Olsen til Norges Banks representantskap og inviterte gjester, torsdag 14. februar 2013.

research programme in mathematical sciences, devoted to basic research and targeted to potential applications in science, industry and society.

In Norway, research funding comes mostly from the government budget and is divided among several ministries. Compared to other countries, the Norwegian industry and private sector are contributing to research to a lesser extent[4]. A large percentage of the successful university candidates from science and engineering are to be employed in the private sector, and there is a very high demand of such expertise. Many of the most popular disciplines of interest to the private sector have their roots in the mathematical sciences, and some private companies have acknowledged this reality. For instance, the private oil company Petroleum Geo Services is a sponsor of the Niels Henrik Abel mathematics competition as well as of other initiatives for increasing the popularity of mathematics. Recently, also STATOIL has offered considerable funding to support mathematics education. These initiatives are highly appreciated by the mathematical community. However, higher education in universities can only reach the necessary high standards when performed by leading edge researchers. We therefore support the view of encouraging the Norwegian private sector to fund not only activities promoting mathematics education for children and teenagers but also higher education and research in the mathematical sciences.

Before giving specific recommendations on actions that should be taken to increase the quality and quantity of mathematical research and higher education in Norway, in the next section we discuss the role of mathematics in science and in the society at large. Mathematical sciences are the backbone of scientific and technological research, and more than ever mathematical sciences play a fundamental role in the most diverse fields of society and every-day life, from the newest diagnostic medical tools to the Internet search algorithms, from security of banking systems to the entertainment industry. The last decades have seen an expansion of the traditional range of action of mathematical sciences to unprecedented fields of application[5]. This is mostly due to the increased demand and ability of analysing large amounts of complex data produced in science and various other fields, to extract meaningful information (as in discovering the gene mutations responsible for cancer among millions of possible ones). Similarly, numerical simulation has become an ever more attractive and effective means of modelling complex phenomena for decision making, as for example in weather prediction and finance.

4 The role of mathematics in modern science

To place our recommended actions for increasing the quality of mathematical research and higher education in Norway in context, we will begin by discussing the role of mathematics in the scientific community, with further consequences for technology and society in general.

Mathematics as the language of science

Mathematics is acknowledged as the language of science. The mathematical sciences identify structures and study their relationships. They formulate powerful abstract concepts and models that

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[4] Evaluation of the Research Council of Norway, KD, september 2012.

[5] The mathematical sciences in 2025, National Academy of Sciences, 2013, ISBN 978-0-309-28457-8.

unify, clarify and predict phenomena in science and technology. The development of theories and problem solving within such abstract models and the associated interaction with specific applications in more concrete settings, are the essence of modern mathematics. The ability to detect similar structures and to derive results that are applicable across different sciences represents an enormous strength. Modern mathematics was partly created to describe the laws of nature, such as the leading theories of physics developed by Newton and Maxwell. Conversely, a prominent example of mathematics influencing real world applications is Riemannian geometry, which was instrumental in Einstein's formulation of the general theory of relativity.

The temperature of the Earth

Climate scientists strive to understand the history of the Earth's global and regional surface temperatures; there have been reliable observations from a variety of weather stations worldwide since about 1860. Currently there are more than 7,000 stations where temperature is recorded. Despite the high number of measurement stations, computing apparently simple quantities like the uncertainty of the annual mean temperature is a challenge. Similar spatiotemporal datasets are becoming abundant in the applied sciences. In Norway they appear for instance in the context of oil detection as seismic data.

Today mathematics is ubiquitous and indispensable as a tool to describe basic theories in areas like biology, chemistry, geology, economics, and physiology. A more recent example showing the broad impact of mathematics is John Forbes Nash's work on non-cooperative games, for which he received the 1994 Nobel Memorial Prize in Economics. His results have unexpectedly influenced economics and biology for several decades. Mathematicians started a systematic study of game theory in the 1950s, and Nash's concept of equilibrium was a breakthrough opening for an impressive breadth of different phenomena. The societal and political challenges of our times are often being modelled with game theoretic tools. One example is the politics of global warming.

Scientists and engineers engage in the study of increasingly more complex phenomena. This is partly due to the technological development; digital observation tools collect enormous sets of data, for instance in the study of the human genome and the study of the geometry of the universe, and novel methods allow observations at the nano scale. The need for extracting relevant information from such data leads to challenging research problems in statistics. But this technological development also brings new fundamental questions in disciplines like life sciences (biology, medicine). Living organisms have different features and are in many ways more complex than the objects studied in physics, and therefore brand new mathematical tools are required to formulate adequate theories. As an illustration of this development, *The Human Brain Project*[6]*,* which is one of two one billion Euro projects recently funded by EU through the programme for Future and Emerging Technologies, has *Mathematical and theoretical foundation of brain research* as the main theory oriented subproject. Analogous to Einstein's striking use of Riemannian geometry, a strong trend of new branches of mathematics entering applications is becoming evident. Another endorsement of this trend is the scientific programme for 2013 – 2014 at the leading US research centre for applications of mathematics, the Institute of Mathematics and Its Applications, University of Minnesota, which is funded by the National Science Foundation. This one year programme is devoted entirely to scientific and engineering applications of algebraic topology, with specific applications ranging from gene regulation to internet traffic.

[6] http://www.humanbrainproject.eu/

Statistics

Statistics is the mathematical science for the collection, exploration, analysis and interpretation of data, enabling discovery and advancement in science, technology, industry and public services. For example, progress in medicine relies strongly on statistical methodology.

New technology allows collecting, storing and distributing vast amounts of data efficiently, at very low cost. Sensors and instrumentation, data logging capacity, communication and shared processing power have increased the breadth and depth of the data. Such data may carry precious information that can advance science or boost innovation. Statistical methods turn high dimensional data originating from complex multivariate processes into useful information. Statistics can treat many sources of data of different type, scale and quality simultaneously, developing complex dependency structures that require computationally intensive tools. A key idea is to build complex systems as assembled from smaller, comprehensible modules, each involving only a few components that capture important statistical characteristics, using hypotheses of conditional independence and sparsity. Statistics provides a formal discipline for borrowing information across data sets and distributing it from observed data to predictions and estimates of structures. Massive amounts of simultaneous comparisons are required in many applications, for example, large-scale simultaneous hypothesis testing in genomics, searching among several ten-thousands of genes for the ones most able to predict therapeutic efficiency of a drug. Prediction, equipped with realistic estimates of uncertainty, is one of the main achievements of statistics, applied widely in most areas of science and for decision making.

> ***Life sciences***
>
> *Statistical methods are indispensable for research in the life sciences. The application of statistical methods in medical research is among the most important developments of the past thousand years along with e.g. the discovery of cells, genetics, anesthesia and antibiotics (Looking Back on the Millennium in Medicine, New England Jour. of Med. 2000; 342:42-4). Today statistics and mathematics allow us to investigate the complex mechanisms of molecular cell biology, turning the promise of modern genomics into clinical strategies. For example through advanced statistical modelling, a list of 70 genes among 25 000 possible ones has been discovered to distinguish between subclasses of breast cancer, thus allowing personalized treatment and improved patient survival.*

Public archives and registries such as biobanks, web-resources and financial databases, represent invaluable sources of information which can be exploited with statistical tools. In science and society, there is an increasing demand for evidence-based decision-making, performance measurement and uncertainty assessment. Compared to deterministic approaches, statistical measures of uncertainty of phenomena and predictions provide key instruments for risk analyses.

Computer simulations as virtual experiments.

In areas where physical experiments are expensive, or even impossible to perform, virtual experiments based on computer simulations are often viewed as an attractive alternative. A few examples may serve to illustrate the revolutionary importance of this approach, in science and engineering.

Petroleum engineers can investigate the oil content and flow properties of small samples of rock in a laboratory. However, to investigate the flow in a larger rock formation, like an oil reservoir, one has to rely on computer simulations. When astrophysicists try to understand the activity at the sun, they have limited possibilities to perform physical experiments. Consequently, their major approach is to perform computer simulations, and then compare the results with measurements performed by digital observatories. For composite materials, effects at the nano scale can be important in determining macroscopic properties. Therefore, the design of physical experiments, where the goal is to improve certain properties of materials, is rather complex, and such experiments can be both time consuming and expensive. However, by supplementing the experiments with insight gained through computer simulations of the composites, there is a potential for substantially accelerating the process. In fact, today it seems rare to find any field of science or engineering that is not heavily influenced by mathematical modelling and computer simulations. Furthermore, the use of simulations, as a supplement, or alternative, to physical experiments, has not only changed the nature of basic science, but also that of industrial research.

Stability of the solar system

The stability of the solar system is a subject which has fascinated astronomers and mathematicians since the times of Newton, Laplace and Poincaré. The most precise long-term simulation of the solar system is the one performed in 2009 by the astronomers Jaques Laskar and Mickael Gastineau. Unlike previous models, they took into account Albert Einstein's theory of general relativity and this gave dramatically different orbital paths over long times. They found that however remote a collision Earth-Mercury is possible. The two scientists looked at 2501 possible scenarios, 25 of which ended with a severely disrupted solar system. The results rely on the use of powerful supercomputers and the smartest algorithms available and are published in Nature. These results awoke renewed interest in the mathematical study of the stability of the solar system.

The construction of simulators of the real world is usually based on a mathematical model, capturing the essence of the scientific phenomenon, and a numerical approximation necessary for representing the model on a computer. The study of such approximation schemes, which often consists of replacing a continuous model by a suitable discrete model, is usually referred to as numerical analysis, a mathematical research area with substantial growth over the last fifty years. This discipline plays a substantial role in the quality control of simulations, by producing estimates of the error committed in the models and in the approximations used. Analysis of simulation methods proves their reliability as predictive tools, and, most importantly, describes their limitations. However, the construction of a mathematical model for the “continuous real world phenomenon” is in many ways the most fundamental step in this process. The desire to utilize computer simulations has turned mathematical models, and the more abstract mathematical subjects used to describe and analyse these models, into key subjects for progress in almost all fields of science and engineering.

Mathematics and ICT

One of the many stunning channels through which mathematical sciences affects our everyday lives is evident through the financial transactions most of us now take for granted. The vital role of mathematics for ensuring the security of digital communication is evidenced by the fact that the US National Security Agency is one of the largest employers of mathematicians in the US[7]. Cryptography and coding theory originated as parts of discrete mathematics. As the sophistication of the applications increases and the need for new tools becomes apparent, these fields draw upon an

[7] http://www.nsa.gov/research/tech_transfer/advanced_math/

array of mathematical disciplines ranging from combinatorics to algebraic geometry. Another example at the interface between mathematics and ICT is the science of digital representation of real world images and signals and in particular the recently developed theory of compressed sensing, relying on sophisticated techniques from an amazingly wide range of mathematical fields.

A strict characterization of the interface between mathematics and computer science is hard to make. For example, both computer scientists and large parts of the mathematics community study relations that lead to algorithms to be used in computer programs, and in both communities these algorithms are most commonly discussed in an abstract framework without having a specific application in mind. Mathematics and computer science have a hazy borderline, where also fields that typically are not considered to be part of applied mathematics play an important role. Occasionally the interplay between ICT and mathematics reaches deep into the domain of both subjects, an excellent example of which is the current programme on homotopy type theory at the Institute for Advanced Study in Princeton[8]. These interactions provoke new developments in mathematics as well as in computer science both on a fundamental level and towards concrete applications.

Mathematics in interdisciplinary research

The grand challenges of our time can only be addressed through interdisciplinary research. The interplay of different mathematical sub-disciplines and of mathematics with other sciences has brought us new knowledge and discoveries. A distinct feature of successful interdisciplinary research is that all fields involved are enriched by the joint project. When mathematical sciences take part in interdisciplinary research, the goal will also be to develop new generic models or abstract theory of interest that transcend the specific application at hand. This important general principle of reciprocity between fields may be used to distinguish genuine mathematical research in an interdisciplinary context from more routine applications of mathematical methods.

Mathematics is a fundamental tool to characterize and comprehend nature, and to enable new scientific and technological knowledge. We are now witnessing an increased relevance of mathematical sciences in a variety of fields of science and society, and with the study of increasingly complex phenomena and systems comes a demand for new mathematical tools. As a consequence, new mathematical disciplines will arise. It will be challenging for the mathematics community to relate properly to this development. Departments will have to develop strategies and priorities where the focus on new research directions is balanced with a number of other criteria, like responsibilities for mathematical education and the importance of maintaining strong research groups. Furthermore, funding agencies, like the RCN, should have a clear vision on how they will influence this process.

[8] http://www.math.ias.edu/sp/univalent

5 Suggested actions

As we have outlined in Chapter 3 above, the evaluation report[9] recommends several actions. The main recommendations are listed on page 5 of the report, and several more recommendations can be found in the text. The main recommendations of the report are related to

- the recruitment of the next generation of mathematicians to Norwegian universities,
- a lack of funding opportunities for investigator-driven basic mathematical research,
- the lack of mobility among the universities and between universities and industry,
- gender imbalance.

In Section 5.1 below we give details on how we envision that the evaluation committee's recommendations can be implemented. In Section 5.2 we list three scenarios, one zero-cost, one with a short term funding (3-5 years) in the form of institutional strategic projects (ISP), and one incorporating a strategic research program in mathematical sciences.

5.1 Suggestions for implementation of the recommendations

In this section we suggest how, and to what extent, the recommendations of the evaluation committee can be implemented. All of the first six sections, 5.1.1-6, relate to the four main recommendations of the evaluation committee listed above, while Section 5.1.7 is devoted to other recommendations of the committee where we hope to have constructive suggestions for implementation. Section 5.1.1 is related to the strongest recommendation given by the evaluation committee, namely *to enlarge substantially the portfolio for investigator–driven basic research.* Sections 5.1.2 and 5.1.3 are related to the recruitment of the next generation of mathematicians, Sections 5.1.4 and 5.1.5 discuss possible actions to increase mobility, while actions to attract more women to mathematical research are covered by Section 5.1.6. We emphasise that the order of our suggestions in this section is not a reflection of our priorities. Our priorities are made clear in section 5.2 where we place these actions in three different scenarios.

5.1.1 Increased funding for investigator-driven research

This is the strongest, but also the most expensive, recommendation given by the evaluation committee. According to the evaluation committee[10], *an increase in funds for mathematical research and education is urgently needed to ensure that in the future the R&D capabilities underpinning Norway's industry are adequately served.* In order to survive, most branches of modern industry depend on research and development of new technology, and today mathematical skills are often a necessary tool in these processes. The large number of industries that mathematics is a part of, often as a key contributor, is indeed striking. Key examples are large parts of the ICT-based industry, the petroleum industry, the finance industry, and the biotech industry. In fact, the mathematical sciences

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[9] Research in mathematics at Norwegian Universities. An evaluation. The research council of Norway, 2012. ISBN 978-82-12-03058-9.

[10] Research in mathematics at Norwegian Universities. An evaluation. The research council of Norway, 2012. ISBN 978-82-12-03058-9, page 5

are now present in almost every industry, and the range of mathematical sciences employed would have been unimaginable a generation ago[11].

In Chapter 4 above we have discussed the strategic importance of mathematics for the larger scientific community. Progress in a number of disciplines is heavily dependent on mathematics, but very few , if any, proposals of significant mathematical content have been funded through the more thematic programmes run by the RCN, like NANOMAT/NANO2021, NORKLIMA, RENENERGI/ENERGIX, PETROMAKS, HAVBRUK to name a few. These programmes are simply not designed to support core mathematical research. Therefore, there is a need for other mechanisms to fund more theoretical and methodological research which will be of key importance for these and similar activities in the years to come. A few mathematical projects have been funded through the eVITA programme, which is designed to address computing- and data-intensive challenges in science, technology and medicine. However, the part of mathematical research which fits the scope of the programme is rather limited.

The tremendous growth in the ways in which mathematical sciences are being used represents a challenge for the mathematics community. Strategic decisions must be undertaken on how to balance the focus on new research directions, often motivated by potential applications in disciplines with large impact on society, with more traditional criteria of academia based on research excellence and teaching duties. Of course, the mathematics departments themselves are to a large extent responsible for making such strategic decisions. In fact, if departments are operating well, the increased focus on applications will also stimulate the research which takes place in more traditional mathematical disciplines. However, it is the opinion of the present committee that the RCN should also play an active strategic role in the development of Norwegian mathematics in the years to come. Mathematical sciences will have a key impact on the scientific and engineering community in the country, and will therefore influence a number of activities which are considered crucial for the future of Norway. As a consequence, a national strategy will have many significant advantages.

We therefore propose creating a research programme in mathematical sciences that is *application-driven* in the sense that the main purpose is to develop tools and theories that are designed to support activities in science and engineering outside mathematics itself. This research can still be investigator-driven, but the programme should also be open for interdisciplinary research where the mathematical content is sufficiently rich to engender interest beyond the specific application. The suggested programme is outlined in more detail in Section 5.2.3 below. Our proposal for a new application-driven research programme follows only partly the recommendation of the evaluation committee. While we certainly share the opinion of the evaluation committee that it is very important to support, with sufficient strength, high quality investigator-driven research in mathematical sciences without a priori view toward potential applications, we believe FRIPRO should still be the most important source of support for such research. A presumption for our proposal is therefore that the budget frame for FRIPRO be sustained at least at today's level. In this context, we are particularly pleased to see the increase of FRIPRO during the last two years, thanks to "Fellesløftet".

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[11] The mathematical sciences in 2025, National Academy of Sciences, 2013, ISBN 978-0-309-28457-8, page 3-23.

5.1.2 Securing good transition opportunities

The evaluation committee is worried about the prospect that complete research groups are likely to be depleted due to the retirement of several core members in a short time span. The effect of this is serious not only for small institutions, but also at larger institutions the negative effect can be substantial. To maintain the quality of research we suggest that the RCN makes funding available for "bridging positions," i.e., institutions can apply for extra funding such that positions in disciplines which are of strategic importance can be filled with a junior faculty a few years before a senior professor retires. Several institutions are already trying to be pro-active, but the problem will be more easily handled if extra funding is available. Having a national arena where there is open competition for financial support appears to be a good strategy to meet this problem.

5.1.3 The creation of career development posts to bridge the gap between post-doc and tenure

The evaluation committee recommends the creation of career development posts that can bridge the gap between post-doc positions and tenure. In fact, there is a new initiative in FRIPRO targeted to provide better career opportunities for talented young researchers. Furthermore, the introduction of tenure track positions (innstegsstillinger) at Norwegian universities has recently been proposed by the government[12]. These initiatives will hopefully improve the situation and to some extent meet the concerns voiced by the evaluation committee. At the present time however, the impact of these initiatives is not clear, and therefore we also suggest that making extra funds available for candidates in mathematics be considered.

5.1.4 Improving the cooperation between mathematicians at different universities

The evaluation committee argues for more mobility between Norwegian universities and those abroad. They also argue for more cooperation among Norwegian universities, in particular between the smaller institutions and the larger ones. The interaction with foreign universities will improve if more funds are available for international research cooperation and sabbaticals abroad. Furthermore, there already exist some very useful funding schemes for international cooperation, like the Marie Curie Actions targeted to cross-national research education in Europe.

To increase the cooperation at the national level we recommend more funding for national networks. In fact, we also believe that increased cooperation may lead to more mobility between the national institutions. Another possibility that should be exploited is to establish national PhD research schools within mathematical sciences. In some disciplines the local groups may be very small, but at the national level the community may be more robust. An implementation will require that sufficient funding is made available by the RCN to cover the necessary expenses, like travel costs for students. Through the RCN some funding for such actions already exists, but to establish national research schools in mathematics additional funding may be needed.

[12] Lange linjer - kunnskap gir muligheter, Meld. St. 18 (2012–2013)

Research collaborations through adjunct professor positions (10-20%) have proven to be very useful, in particular for small groups at remote locations. This is a very cost effective way of establishing fruitful collaboration among universities. We recommend that funding is made available to cover some new positions for the first three years, where the activity at the smaller institutions is given the highest priority. We also recommend that Norwegian universities assign financial support to their faculty members who would like to spend a sabbatical at another Norwegian university. However, in situations with funding competition inside the institutions, sabbaticals at strong foreign universities should still be preferred. Finally, a possibility for additional funding for national educational cooperation that could be considered by the mathematics community is the SAK[13] opportunity financed through the Ministry of Education and Research.

5.1.5 Encourage mobility between universities and industry

The evaluation committee is encouraging closer contact between the Norwegian mathematics community and industry. The Norwegian research sector has very low mobility in the sense that many scientists work at the university from which they received their degree, and very few scientists change workplace after tenure. We believe that good synergy effects can be obtained through mobility between university and industry. An existing possibility is the 'Nærings PhD' grant financed by an equal amount of RCN and the company where the research is taken place. Another possibility would be to establish 'Nærings professorships' at Norwegian universities, partly financed by participating companies. Such professorships already exist in other disciplines, and it is natural to expect such initiatives also in mathematics in the future. We also recommend that the universities assign financial support to mathematicians who want to spend sabbaticals in industry.

A fruitful collaboration between universities and industry is often initiated when students have summer jobs in companies. The mathematical departments could strive towards maintaining a pool of summer internship positions available for their students.

5.1.6 Decisive action to attract and support women

The evaluation committee observes that women remain seriously under-represented in Norwegian mathematics. They state that *in the long run the greatest effect is likely to come from a clear career structure and a greater sense of job stability.* The present committee supports this view, and we therefore urge the departments to explore the possibilities offered by career development grants described in Section 5.1.3 above. Another recommendation of the committee is that funding agencies, such as the RCN, should explore the possibility of creating schemes where departments receive additional funding when women are appointed. In fact, this possibility already exists in Norway, with funds available from the Ministry of Education and Research. We recommend that the departments of mathematics utilize this opportunity.

The recently initiated RCN programme, BALANSE, is designed to attack gender imbalance throughout the Norwegian scientific community, so this programme ought to be effectively exploited by the departments of mathematics. To supplement the BALANSE programme, we suggest that extra

[13] http://www.regjeringen.no/nb/dep/kd/dok/regpubl/stmeld/2008-2009/stmeld-nr-30-2008-2009-/9/3.html?id=556620

funding is made available to improve gender balance in mathematical sciences. The funding can for example be used to support promising female PhD or post-doc candidates, or to partially support the hiring of female adjunct professors.

At some universities, female candidates, close to advancement to full professor, are offered extra funding and less teaching duties. This is an important tool which should be used to a larger extent.

5.1.7 Other recommendations

We offer suggestions on three topics which the evaluation committee has discussed, but which we have not considered to be part of their main recommendations.

i) In an advanced technological society, it is crucial to recruit some of the brightest students to the mathematical sciences. We are convinced that summer schools can contribute to this, and one may even consider if some of these should be dedicated to female participants only. Summer schools of this type should be financed directly from the Ministry of Education and Research.

ii) In order to channel funding to excellent projects in mathematics, the universities are also encouraged to support researchers when they are trying to obtain financial support. The application procedures and project management of large grants may often be so complex that researchers are scared away. We share this view of the evaluation committee, and recommend that administrative support is developed at the department level.

iii) The evaluation report notes that number theory, mathematical physics, and probability are areas particularly under-represented in Norway, and advises the RCN to strengthen the research in probability. However, a strengthening of the research in these and other directions will have to be decided at the department level.

5.2 Actions according to three cost scenarios

Presentation of actions suggested by the present committee is given for three different scenarios. Scenario 1 is a zero-cost budget and described through 5.2.1 below. Scenario 2 comprises actions in 5.2.1 and 5.2.2. The final option is Scenario 3 which includes Scenario 2 and a new strategic programme described in 5.2.3.

Though the creation of a strategic research programme is listed last, we emphasise that this is *not* to be misconstrued as not giving priority to the evaluation committee's clearest recommendation, *the committee urges the RCN to open a new programme to fund investigator-driven basic research,* but rather reflects the cost inherently tied to this most urgent action. In fact, we believe that it is crucial that mathematical research is given a more central position in the strategic programmes handled by the RCN.

5.2.1 Zero-cost actions

Description
The actions were described in Section 5.1 and should be performed during the next ten years. All actions should be initiated by 2014 and implemented by the universities in agreement with their strategic plans.

Since these actions are not depending on extra funding, we have not prioritized these actions and the numbering is more or less arbitrary. The activities include

1) career development through tenure track positions and by exploring the new FRIPRO initiative (cf. Section 5.1.3).

2) exploiting the possibilities offered by the BALANSE programme. The universities should also offer extra opportunities for female candidates close to advancement to full professorships (cf. Section 5.1.6).

3) extra awareness on the early career development of female candidates. This includes allocating funding for female candidates to participate at conferences and summer schools with particular relevance (cf. Section 5.1.6).

4) encouraging mobility, for example through sabbaticals at strong foreign universities. However, in some cases sabbaticals at other Norwegian universities may also be a useful alternative (cf. Section 5.1.4).

5) exploiting the RCN's opportunity for establishing research schools (cf. Section 5.1.4).

6) encourage candidates to apply for 'Nærings PhD.' Furthermore, one should open for sabbaticals in industry, and consider taking initiatives to create 'Nærings professorships' (cf. Section 5.1.5).

7) continue to develop systems at the universities for administrative support for grant applications (cf. Section 5.1.7).

8) create increased possibilities for students to visit foreign universities and to have summer internships in industry (cf. Sections 5.1.4 and 5.1.5).

9) encourage more cooperation between Norwegian universities by creating new adjunct professorships (cf. Section 5.1.4).

Justification
This list comprises the initiatives not needing extra funding described more fully and justified in Section 5.1.

Financial implications
This is a zero-cost alternative in the sense that the resources needed for implementing the actions must be found at the institutions and through participating in existing grant schemes.

Responsible
The responsibility for implementing the actions lies largely with the institutions and individual researchers, and the progress rate will be largely determined by the budget at each institution.

5.2.2 Institutional strategic projects

In this section we describe a scenario including the actions of Section 5.2.1 with the addition of actions which will require extra funding in the form of institutional strategic projects made possible by the RCN. Through ISP the RCN makes funds available for short term actions (3-5 years) to overcome some of the main concerns raised by the evaluation committee. Priority should be given to actions which give lasting structural improvements or important consolidations.

Description
In agreement with the discussion give in Section 5.1 above, we suggest that the ISP-actions should

1) provide bridge funding when strategically important research groups face depletion and where immediate action can ensure excellent candidates, cf. Section 5.1.2. Depending on the impact of other initiatives described in Section 5.1.3, creation of extra career development positions should also be considered.

2) support the creation of national networks by establishing national research groups, research schools, and cross-institutional educational systems as described in Section 5.1.4.

3) supplement the BALANSE programme with gender initiatives described in Section 5.1.6.

4) fund adjunct professorships if the criteria of Sections 5.1.4 or 5.1.6 are met.

Justification
The actions taken at the evaluated institutions combined with the ISP-actions will provide a follow-up of many important suggestions given by the evaluation committee.

Financial implications
Action 1: 18 MNOK
Action 2: 5 MNOK
Action 3: 4 MNOK
Action 4: 3 MNOK

This suggestion means that RCN must dedicate 30 million NOK to ISP.

Responsible
RCN will be responsible for the administration of the proposed ISP.

5.2.3 A research programme in mathematical sciences

The third scenario includes all actions described in Sections 5.2.1 and 5.2.2, and in addition the creation of an application-driven research programme in mathematics as outlined in Section 5.1.1.

Description

The goal of an application-driven programme in mathematical sciences is to support the development of mathematical results and tools that contribute to the advancement of science, industry, and society. The purpose is to supply the Norwegian research and engineering community with knowledge that will benefit projects in a number of areas important for society. The programme should support the mathematical part of joint projects between mathematics and other disciplines, such as life sciences or petroleum, but also studies of more abstract theories and generic models of interest beyond a single specific application. On the other hand, proposals where no application aspects of the research are discussed should still be evaluated through the FRIPRO-programme. Projects from any subfield of mathematics can potentially be supported, but a discussion of the applied potential of the research will be a prerequisite for any proposal to be funded by the programme. Furthermore, more routine use of mathematical models, in any discipline, should not be considered mathematical research, and should therefore not be supported by the programme.

Due to the close connection, and the hazy borderline, between mathematics and computer science, one may also argue that the programme should be extended to include parts of the theoretical disciplines of ICT. With respect to funding, theoretical computer scientists often encounter similar problems as mathematicians. In a longer time span their research is highly relevant for a number of applications, but when it comes to funding from thematic programmes, proposals with a more immediate potential for applications are usually preferred. Therefore, creating a programme that includes basic research in mathematical sciences and theoretical computer science seems like a sound idea, one that the RCN ought to consider. A more detailed description of the programme is beyond the scope of this document.

Justification

In Chapter 4 and Section 5.1.1 above the influence of mathematics on modern science, engineering, industry, and society is discussed. The main justification of the programme is the tremendous growth in the use of mathematics in disciplines outside itself. By also including theoretical parts of ICT in the programme, the RCN will create a mechanism to support disciplines of basic research which will be key contributors to future science and engineering, but which is completely overlooked by the more thematic programmes.

Financial implications

The programme should mainly support research projects which should last for 3-5 years, and with a yearly budget of 1-3 MNOK. We suggest that the RCN commits approximately 50 MNOK per year for ten years. The possibility of combined private and programme funding of projects should be explored.

Responsible

The RCN will be responsible for the programme.

Appendix A: Mandate for the National Committee to follow-up the evaluation of research in mathematics

On the basis of the report from the Evaluation Committee, the Research Council of Norway invited (letter of 25 June 2012) the evaluated research institutions to describe:

1. Their own plans for follow-up of the evaluation
2. Suggested actions that should be carried out at the national level
3. How the institutions, on its own or in association with others, can contribute to the follow-up-work at the national level.

The Research Council received input from all the research institutions by 15 September 2012. The Research Board, Division for Science, appointed a national committee to follow-up the evaluation consisting of 6 representatives from the research institutions.
The Committee shall draw up a follow-up plan for research in mathematics on the basis of the evaluation report's recommendations and input from research institutions. The plan shall as far as possible provide specific advice and recommendations for measures that can be implemented at the national level. Measures can be discipline specific and/or of structural nature and include both short-term measures and initiatives with a longer time horizon (5-10 years). The proposed actions should be given in prioritized order and the responsibility for the various tasks should be identified. The suggested measures should be within a realistic budget. The plan can also provide advice to the Ministry of Education and Research as well as to other relevant ministries on specific measures and financial needs.
The plan should give advice on:

- Measures for the further development and strengthening of research in the mathematical sciences.
- Measures to promote national collaboration and coordination, as well as international research collaboration and mobility.
- Measures to improve gender balance and promote recruitment to research in mathematics; in particular, the recruitment of women to the permanent scientific positions.
- Specific disciplines within mathematics that should be strengthened.

In addition the plan should provide the Research Council with

- Advice on specific measures to follow up the recommendations in the evaluation
- Strategic initiatives that will help develop and strengthen research in mathematics in Norway and the role of mathematics in the national strategic research areas.

The Committee is requested to finalize the plan by May 2013. The plan should be written in English. The work will be carried out in close dialogue with the RCN.

The follow-up-plan will be sent to the Evaluation Committee for comments and will be discussed with the research institutions at a meeting in August 2013.

Appendix B: Description of the members of the committee

Elena Celledoni is a professor at the Department of Mathematical Sciences, at the Norwegian University of Science and Technology. She received her Ph.D in computational mathematics from the University of Padua, Italy. She held post doc positions at the University of Cambridge, UK and at the Mathematical Sciences Research Institute, Berkeley, California. Her research field is in numerical analysis and in particular structure preserving algorithms for differential equations.

Ingrid K. Glad is professor of statistics at the Department of Mathematics, University of Oslo. She received her PhD from NTNU in Trondheim, and spent a postdoc period at University La Sapienza in Rome before being appointed at the University of Oslo. Glad's research activity includes various themes in statistical methodology, in particular non-parametrics, Bayesian inference and high-dimensional regression. Her research is motivated by scientific questions related to medical image analysis, molecular biology, cancer research and computational biology. She has been associate editor (2006-2012) and national editor of the Scandinavian Journal of Statistics. Glad is key scientist of the sfi centre Statistics for Innovation since 2007 and leads the research group in statistics at the Department of Mathematics.

Bjørn Ian Dundas is a professor at the Department of Mathematics, University of Bergen. He has held positions at Aarhus Universitet, UiO, NTNU and UiB and been visiting scholar at Stanford University. He is a member of the Royal Norwegian Society of Sciences and Letters and has been awarded Ingerid and Ulrikke Greve Dal's price for excellent research. Professor Dundas' primary fields of research are higher K-theory and algebraic topology. In recent years he has become increasingly interested in the link between geometric symmetries and arithmetic structures over the sphere spectrum.

Fred Godtliebsen is a professor at the Department of Mathematics and Statistics, University of Tromsø. He received his Ph.D. in statistics from the Norwegian Institute of Technology (NTH) in Trondheim. His research fields are smoothing methods, scale-space analysis, pattern recognition, and image processing. Professor Godtliebsen is a group leader in Tromsø Telemedicine Laboratory (TTL), a Norwegian centre of research based innovation financed by the RCN. Currently, he is the vice dean for research at Faculty of Science and Technology at University of Tromsø. He also holds an adjunct position at the Norwegian Polar Institute.

Kristian Seip is professor at the Department of Mathematical Sciences, NTNU. He received his Ph.D. from the Norwegian Institute of Technology. His research field is mathematical analysis, and he has worked mainly in operator related function theory and time-frequency analysis. Professor Seip chaired the Department of Mathematical Sciences at NTNU from 1997 to 2001 and served as vice dean for education at the Faculty of Information Technology, Mathematics and Electrical Engineering at NTNU from 2006 to 2012. He chaired the Abel Committee from 2006 to 2010 and served on the Editorial Board of Acta Mathematica from 2003 to 2012. He is a member of the Norwegian Academy of Science and Letters, the Royal Norwegian Society of Sciences and Letters, the Norwegian Academy of Technological Sciences, and he is a fellow of the American Mathematical Society. He was an invited speaker at the International Congress of Mathematicians in 1998.

Ragnar Winther is a professor at the Department of Mathematics, University of Oslo. He received his Ph.D. in applied mathematics from Cornell University, USA. His research fields are computational mathematics and partial differential equations. Professor Winther served as director of the Centre of Mathematics for Applications, a Norwegian centre of excellence financed by the RCN, during its entire life span from 2003 to 2013. He was also chairman of the board of the Niels Henrik Abel Memorial Fund from 2004 to 2010. He is a member of the Norwegian Academy of Science and Letters, and a fellow of the American Mathematical Society. He was an invited speaker at the Fifth European Congress of Mathematics in 2008.

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