Education for the future

Morten Hjorth-Jensen[1,2]

Anders Malthe-Sørenssen[1]

[1]Department of Physics, University of Oslo
[2]Department of Physics and Astronomy, Michigan State University, USA

September 2 2015,

Present and future education

- **Research-based education**, from undergraduate studies to a PhD: The Computational Physics group at the University of Oslo as example
- Future challenges and directions

Takeaway message. Excellent research mutually depends on excellent education.

The role of computations, from education to society

Computations are central to our basic understanding of nature and to technological advances. UiO's strength in computational science (education and research) has the potential to make UiO a top European university.

Examples.

- **Nanotech and Materials**: quantum physical systems in nanotechnology; characteristics of new materials; semi-conductor devices and quantum computers
- **The smallest particles in nature**: subatomic physics at its smallest length scale
- **And the largest**: simulating galaxies and the evolution of the universe
- **Life science**: cancer treatment and how the brain works

- **Geosciences**: predicting climate changes and this week's weather, simulating natural disasters
- **Finance**: assessing risk in the insurance and financial industry
- and many many more

Modeling and computations as a way to enhance algorithminc thinking

Algorithm : A set of instructions to solve a problem.

Algorithmic thinking applies to all disciplines. It

- Enhances instruction-based teaching
- Introduces research-based teaching from day one
- Triggers further insights in scientific problems
- Emphasizes validation and verification of scientific results, and integrates science ethics in a natural way
- Ensures good working practices from day one!

What does computing mean?

Computing means solving scientific problems using computers. It covers numerical as well as symbolic computing. Computing is also about developing an understanding of the scientific process by enhancing the algorithmic thinking when solving problems.

Computing competence is about:

- derivation, verification, and implementation of algorithms
- understanding what can go wrong with algorithms
- overview of important, known algorithms
- understanding how algorithms are used to solve complicated problems
- reproducible science and ethics
- algorithmic thinking for gaining deeper insights about scientific problems

All these elements (and many more) aid students in maturing and gaining a better understanding of the scientific process *per se*.

Computing and research-based education

A computational approach allows us to introduce research concepts and engage students in research from *day one*.

What should the education contain?

- Theory + experiment + simulation is the norm in research and industry
- Modeling of real, complex systems with no simple answers
- Insight and understanding of fundamental principles and laws
- Visualization, presentation, discussion, interpretation, and critical analysis of results
- Development of a sound ethical attitude to own and other's work
- Enhanced reasoning about the scientific method
- Individually tailored education in order to let students realize their full potentials and discover their creative powers

This is what we do in the Computational Physics group at UiO!

Computational Physics group at UiO; our visions

Physics students can **pose and solve problems** that combine **physical insights** with **mathematical tools** and now also **computational skills**. This provides a unique combination of applied and theoretical knowledge and skills. These features are invaluable for the development of multi-disciplinary educational and research programs.

A social and scientific learning environment

Goal: Students should realize their full potentials and discover their creative powers

- Students come with different dreams, ambitions, aspirations and topics they wish to study, our approach is to tailor the education to all these aspects
- Our motto: foster students who are better than their supervisors
- Emphasis is on learning and getting new insights
- Students and teachers help each other
- Students with different backgrounds and needs can thrive socially and scientifically

- Not a competitive environment, but a drive and enthusiam for sharing and developing knowledge. This is an important element for the success of for example multi-disciplinary projects

We develop a social and scientific learning environment

- We target bachelor, MSc and PhD students
- Project-oriented work where students develop and mature their own ideas, with an individually tailored approach to each student
- Office space with desktops to every student and large common room for recreational activities (meals, gaming, movies)
- Many students collaborate on similar thesis topics and publish in top scientific journals

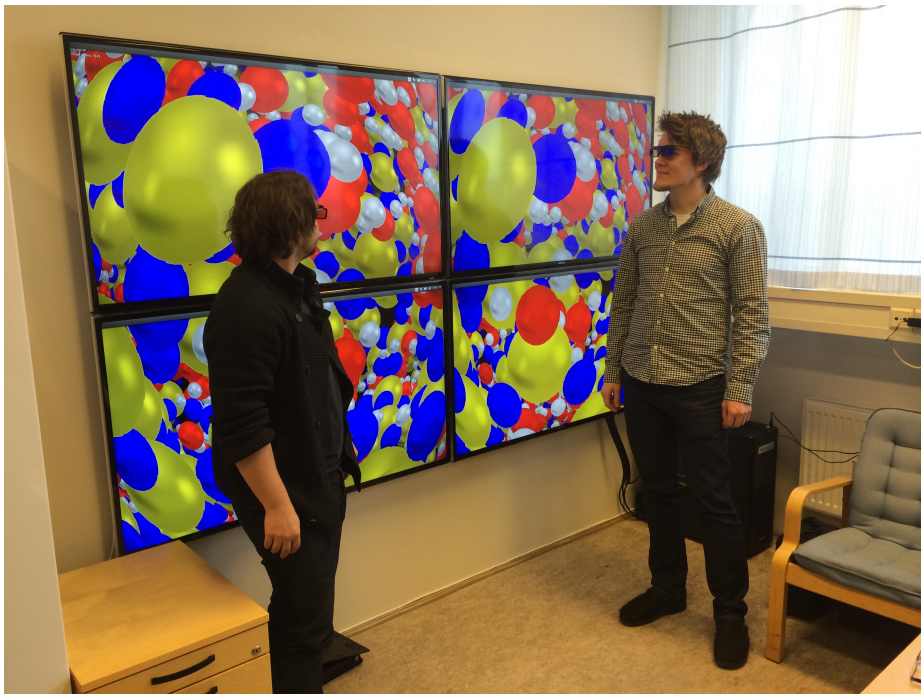
Features of the Computational Physics group

- Our students have made significant contributions to the Computing in Science Education (UiO education prize in 2011) by developing exercises and participating in educational projects at the MN faculty
- Our students have also developed educational tools and applications for understanding complicated physical problems
- A group of PhD students is now developing new textbooks for Computational Life Science
- 2005-2015: $>$ 60 students have finalized their master's theses and 60% have continued with PhD studies
- Many students don't want to leave the group after finishing their studies

Investing in equipment for research and education

Large screens for visualizing and presenting scientific results. And gaming and other social activities.

- Here we see two students displaying results from large-scale simulations of molecules in materials
- With 3D visualization tools one can see structures which where not possible until recently



Building a local supercomputing cluster from titan.uio.no

Our supercomuting cluster. When UiO's previous supercomputing cluster (titan.uio.no) was replaced by **abel.uio.no**, we got 200 nodes for free from USIT and built our own supercomputer. The value in 2006 of all the equipment was close to eight MNOK.

- It helps students run and develop programs for large-scale problems locally
- A successful program can then run on larger national and international supercomputers
- Students run and maintain the local supercomputer
- Used in regular courses as well

8/26/2015 Milliongave til fysikkstudenter - Forsiden

Forsiden > Nyheter > 2012 > 12 > Milliongave til fysikkstudenter

Nettavis for Universitetet i Oslo

UNIFORUM®

Milliongave til fysikkstudenter

Masterstudentene i beregningsorientert fysikk på Universitetet i Oslo er blitt verdens rikeste på regnekraft.

Av Grethe Tidemann
Publisert 17. des. 2012 13:19

ÅRETS JULEGAVE: Supercomputeren *Titan* fyller seks store skap på Fysisk institutt. Studentene *Henrik Sveinsson* og *Fredrik Pettersen*, professor *Morten Hjorth-Jensen*, og studentene *Anders Hafreager* og *Sigve Bøe Skattum* har store forventninger til gaven.

Foto: Grethe Tidemann

I september i år erstattet Universitetets senter for informasjonsteknologi (USIT)

http://www.uniforum.uio.no/nyheter/2012/12/supermaskin-til-jul.html 1/3

Undergraduate student publishes in PNAS

Participating in research from day one!

- Bachelor and master students publish in scientific journals
- Undergraduate students are exposed to research at early stages, often working with more advanced students

- Students are exposed to all stages of the scientific process
- Projects are tailored to the interests of the students
- Focus on insights and sharing knowledge

UiO : Fysisk institutt

Begynnerstudent gjør oppsiktsvekkende oppdagelse

Bachelorstudent gjør ryktet om middelmådig norsk forskning til skamme ved å få sin forskning publisert i et internasjonalt topp-tidsskrift.

Henrik Sveinsson. Foto: Oda Hveem

Vanligvis deltar ikke studenter i forskning før etter 4-5 år på universitetet. Nå er fysikkutdanningen ved UiO endret slik at studentene raskt blir i stand til å forske på reelle problemstillinger. Studentene får mulighet til å være med i toppforskning gjennom et prosjekt som kalles "Grand Challenge".

Henrik Sveinsson er en av studentene som har deltatt i Grand Challenge-prosjektet.

Forstå jordskjelv

—Henrik viste tidlig både talent og interesse for forskning. Derfor mente jeg det var viktig å gi ham ekstra utfordringer. Allerede i sitt første år som student gjorde Henrik helt nye oppdagelser om friksjon som kan være nyttig for å forstå jordskjelv, sier Anders Malthe-Sørenssen, initiativtaker til Grand Challenge.

Henriks forskning ble publisert i det prestisjetunge tidsskriftet "Proceedings of the National Academy of Sciences" (PNAS) i juni 2014. Selv for etablerte forskere er dette en prestasjon. For en bachelorstudent er det oppsiktsvekkende.

Multiscale modeling is the big open research question in the 21st century

- Present and future problems, unlike traditional science and engineering, involve complex systems with many distinct physical processes
- The wide open research topic of this century, both in industry and at universities, is how to effectively couple processes across different length and energy scales
- Progress will rely on a *multi-disciplinary* approach

We need to foster candidates with the right multi-disciplinary background and computational thinking!

The future: A new type of students

Computations will play a central role in almost all aspects of scientific investigations and technological innovation

Candidates who are capable of modeling and understanding complicated systems, are in short supply in society.

We need students that

- can handle large and demanding multi-disciplinary projects. This requires structured thinking and good analytical skills and a thorough understanding of the problems to be solved

This knowledge makes the students unique on the labor market, a labor market which in the years to come will experience heavy automatization and massive loss of jobs.

This will lay the foundation for cross-disciplinary educational, research and innovation activities.

Create the Department for Computational Science!

UiO's strength in computational science (education and research) has the potential to make UiO a top European university

How to achieve it.

- Establish a new center/department with focus on computational science and its applications to a wide range of fields (natural science, medicine, social sciences, humanities, applied research etc)
- Hire ten young professors (age < 40) dedicated to innovative *computational* research and education
- Establish another ten professorships with shared positions between the new department and the discipline-specificdepartment (physics, chemistry, ...)
- Establish best practices for computational and educational innovations, with a particular focus on new learning material

The process must start now in order not to lose momentum.

Our takeaway messages

- Computing plays and will play an even more important role in future scientific and technological advances
- A successful research program cannot be disconnected from education and vice versa
- An educational and research program which focuses on these issues needs to be established as soon as possible
- Key goal: students must realize their own potentials and creative power

Computational Physics and the Computing in Science Education project (UiO educational prize in 2011)

The results, insights, ideas and thoughts presented here, would have been impossible without the infinitely many interactions with colleagues in the Computing in Science Education project **and all our fantastisc students who continuously give us new insights! Thanks**

- Hans Petter Langtangen
- Knut Mørken
- Arnt Inge Vistnes
- Oyvind Ryan

- Solveig Kristensen and Annik Myhre
- Hanne Sølna