ACT! ACTive learning in core courses in mathematics and statistics for engineering education

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Summary

We will modernise *content* and *form* of selected core courses in mathematics and statistics serving the 17 Master of Technology programmes at NTNU. Modernising content will make the courses better attuned to the needs of the students that they serve. Modernising form includes use of modern technology, adapting to the diversity in the student group and the desire to provide easily accessible learning resources. A fundamental principle for the project is student active learning. Core courses in mathematics and statistics are provided for up to 1700 students per course and taught by a team of teachers, from learning assistants to professors, in various settings. This is a complex structure with special challenges for instigating student active learning methods. We intend to meet these challenges through smart use of digital technology, and developing learning environments that stimulate student activity. Expected outcome will be core courses better adapted to the engineering study programmes with increased student activity, improving relevance and learning outcome.

Project description

The Department of Mathematical Sciences delivers courses in mathematics and statistics to all students in the Master of Technology programmes at NTNU. The core courses comprise Calculus 1, 2, 3 and 4, Statistics and Discrete Mathematics. We have recently completed a large educational development and research project, KTDiM[1], which has thoroughly reshaped the *form* of two of the largest core courses in mathematics, Calculus 1 (1700 students) and Calculus 2 (1200 students), as well as the course in Statistics (1700 students). See Part D for more details. ACT! will build on the successful experiences from KTDiM by developing these experiences further and implementing them in other courses. ACT! will also take KTDiM one step further by focusing not only on form but also on content and an even higher degree of student active learning. A unique feature of ACT!

[1] Kvalitet, tilgjengelighet og differensiering i grunnundervisningen i matematikk, https://www.ntnu.no/ktdim/

is its size both in terms of number of students, teaching staff and the number of study programmes that will be involved.

ACT! is organised in three Work Packages (WPs), which together form a coherent project. The WPs with their expected outcome are briefly described below and more in detail later.

WP1 Content of core courses in mathematics and statistics: We will develop the core courses in mathematics and statistics so that their content reflects the recent development within the subjects of mathematics and statistics, and within the engineering fields where the subjects are applied. This will make the courses better adapted to the students' needs, both in their study programmes and in their later professional life. WP1 will result in

- Reformed versions of the courses Calculus 3 (1700 students) and 4D (250 students), Statistics (1700 students) and Discrete Mathematics (450 students).

WP2 Interactive digital learning resources: We will develop a variety of multimodal, interactive digital learning resources, as well as a common interface through which all resources can be reached, providing a uniform digital environment in all core courses for teaching, learning and assessment, where components can be easily changed and updated, following the ongoing revision of content (WP1). WP2 will result in

- A comprehensive library of interactive, multimodal digital learning resources covering all core courses in mathematics and statistics, openly accessible on a common platform, and adaptable to reformed content.

WP3 Learning environments: We will develop learning environments characterised by high degree of student activity and close student/teacher interaction that can accommodate large student groups, suitable for use of learning resources developed in WP2. WP3 will result in

- A large scale flipped classroom inspired lecture structure
- A virtual support environment
- A full scale support centre serving all core courses in mathematics and statistics.

In total, the expected result will be a collection of core courses in mathematics and statistics that

- emphasise fundamental and relevant skills and knowledge but also recognise students' needs by being well attuned to the technology programmes for which the courses are required, as well as the way mathematics and statistics is used in industry;

- take place in environments where all teaching and learning situations are characterised by innovation and openness to new demands and opportunities; accessibility of resources; stimulation of student activity; diversity in methods and in resources; and quality at all levels.

This will give an internal coherence among the courses as well as an external coherence between the courses and the user groups. The project is based at IMF[2] with links in particular to IDI[3] and IA[4] at NTNU. The project has active collaboration with national and international partners, working within related areas. Such partners include e.g. MatRIC[5], MEC[6], KHDM[7], and the ABACUS consortium[8]. Of particular importance is the connection to the SFU[9] MatRIC, where the Project Leader is a member of the Management Board and several joint events have been arranged already. MatRIC has a national role in stimulating and supporting innovation and research in university mathematics education and is therefore important for inspiration, collaboration and dissemination related to the project.

In KTDiM, students played a central role in designing, monitoring, evaluating, and improving the project (Ehrnström et al., 2014) through surveys, interview and evaluation groups. Inspired by this, a Student Panel (12 students) have been actively involved in the development of ACT!. The Student Panel, with varying composition, will be maintained as a permanent body within the organisational structure of ACT! for the whole of the project period and will play an essential role in the implementation and development of the project.

We have extensive experience with digital resources and innovative ways of working with students to enhance learning outcomes and we have systematically collected data on the impact of various action points. Results have been presented at conferences and in papers by members of the Project Group as a result of the work with KTDiM (e.g. Langaas et al., 2017; Rønning, 2014, 2015, 2017; Rønning et al., 2017; Thaule et al., 2017. See also https://www.ntnu.no/ktdim/resultater). ACT! will build on findings from KTDiM and other relevant research, e.g. from our partners. We will ensure communication of results, methods and knowledge acquired in the project, nationally and internationally. Digital resources produced will be made freely available.

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[2] Institutt for matematiske fag
[3] Institutt for datateknikk og informasjonsvitenskap
[4] Institutt for allmennfag
[5] Centre for Research, Innovation and Coordination of Mathematics Teaching (www.matric.no), Universitetet i Agder
[6] Mathematics Education Centre, Loughborough University, UK (www.lboro.ac.uk/departments/mec/)
[7] Kompetenzzentrum Hochschuldidaktik Mathematik, Germany (www.khdm.de)
[8] https://abacus.aalto.fi (Aalto University, Finland)
[9] Senter for fremragende utdanning

WP1. Content of core courses in mathematics and statistics

The core courses are designed to provide the basic mathematical and statistical competence that the engineering students will need, both within their study programmes and as graduated engineers. Fields of engineering are developing rapidly and so are their needs for mathematical proficiency. There are reasons to believe that our core courses are not up to date with this development. We realise that to establish a knowledge base for reforming content of the courses, collaboration between IMF and the engineering programmes is essential. An important part of WP1 is therefore to establish a panel consisting of scientific staff and students from engineering study programmes, representatives from NTNU's Executive Committee for Engineering Education (FUS), in addition to scientific staff from IMF. This panel, referred to as the User Panel, will play the role of a hub and discussion forum for input into the design and description of reformed learning outcomes in the core courses. The first step of WP1 is, in collaboration with the User Panel, to survey and identify the needs for reforming the content of core courses. The next steps will be to implement the changes in the courses. We realise that it is not realistic to cover all the core courses within the frame of ACT! so this is a process that needs to continue. We will start the content reform with one version of Calculus 4, called 4D, and one of the courses in Discrete Mathematics, as well as the basic course in Statistics. Calculus 4D and Discrete Mathematics are targeted to smaller student groups, in particular within the IE Faculty. They are therefore well suited as an "experimental ground" for doing substantial changes to the content. Calculus 3 will be reformed following the principles previously implemented in Calculus 1 and 2 through KTDiM.

The use of computational methods is central when mathematics and statistics are used in engineering applications, as well as in other areas of research and development. The rapid growth in strength and availability of computing power greatly changes the scope of problems that can be handled using mathematical methods. This is the main reason for increased, and different types of, mathematical proficiency in engineering fields. It is therefore to be expected that extensive integration of computational methods and tools in the core courses will be an overarching theme in the reform process. However, exactly how this should be done requires a careful discussion between experts in mathematics, statistics and user groups. The User Panel will constitute the forum for such discussions. A crucial question is to find the correct balance between the need for deep conceptual and procedural understanding (Hiebert & Lefevre, 1986) and "outsourcing" of computations to the computer, as well as to find a good balance between numerical and analytical methods in mathematics. It also needs to be a discussion about particular mathematical topics to include and to

leave out in a modernised curriculum. Contact with the newly established SFU at the University of Oslo, CCSE,[10] will be relevant in connection with computational mathematics. Use of general purpose programming languages is central in computational mathematics. Therefore a close connection to the basic course in programming is necessary. This will stimulate a natural link in particular to IDI and the existing Centre of Excellence, ExcITed.

Recognising that content is closely related to form the work in WP1 is in a natural way connected to the work in WP2 and WP3.

WP2. Interactive digital learning resources

Development of digital learning resources for core courses is an on-going process. Much digital material has been produced, notably videos and web pages, both within KTDiM and earlier. This material has been used extensively (Ehrnström et al., 2014), together with paper-based material (books). Students have reported that the web resources are valuable but that they can be difficult to navigate within. In the present state, these resources are also best suited for large screens and therefore not so easy to use on portable devices, which are becoming increasingly powerful and available. We now plan to develop digital learning material with a higher degree of uniformity, interactivity and multimodality. Text, video and dynamic graphics will be integrated and accessible through one common interface, and made available on a variety of portable platforms. This work will draw on previous work by re-using e.g. videos and web based text but adding more features (e.g. dynamic graphics) and organising the material so that it is easier to navigate within. From a learning theoretic point of view, the importance of multimodality is based on recognising the great significance that the ability to move flexibly between different representations has for the learning of mathematics (Duval, 2006). Compared to the current solution the main additional feature is that users can interact with the material, so that the resources themselves invite student activity. There is no obvious choice of software for this and substantial work is required to test and develop different solutions in order to find the optimal solution for our purposes.

All resources developed will be openly accessible. This principle will ensure that products from ACT! can be easily shared. Many of the resources will also be of value for the BA programmes of technology, as well as for other study programmes where mathematics or statistics plays an important role, within NTNU and elsewhere. The Student Panel has emphasised the importance of

[10] Centre for Computing in Science Education, https://www.mn.uio.no/ccse/english/about/aims-and-vision.html

open access to learning resources because students use them later in their study programme specific courses, after the mathematics and statistics courses are completed. We will investigate the possibilities for using Blackboard as a home for such learning resources.

Through KTDiM we have gained considerable experience using one specific system (Maple T.A.) for digital assessment. Digital assessment tools may help to increase the learning potential of assessment by providing instant feedback to the student. Students report in surveys that instant feedback on the correctness of an answer is highly appreciated but they miss information on why an incorrect answer actually is incorrect (Rønning, 2017). We intend to investigate possibilities, within Maple T.A. or with other systems, for providing conditional feedback on students' answers. Collaboration with the Finnish ABAKUS project, and also MatRIC may be particularly valuable.

WP3. Learning environments

The availability of a large variety of learning resources (WP2) will increase the possibilities for using different types of learning environments. Well adapted digital material will provide a better foundation for implementing a flipped classroom approach (Mazur, 2012). Most reports of successful implementations of flipped classroom come from work with relatively small student groups but there are also reports from work with large student groups such as in our case (Deslauriers et al., 2011; Freeman et al., 2014; Maciejewski, 2016). WP3 consists of three parts. Part 1 involves developing the Interactive Lectures[11] further, based on flipped classroom ideas, and also extending the use of this lecture type to other courses than today. This work will involve use of student response systems, such as Kahoot! and PeLe which have shown to be highly suitable for student engagement and motivation (Wang, 2015), and for increasing student learning outcomes (Bjørkli, 2014). Evaluation of the Interactive Lectures in Calculus 1 and 2 shows that they are highly valued by the students.

NTNU is currently at the beginning of a major campus development. Recently the lecture hall R2 at Gløshaugen has been redesigned and mathematics and statistics are among the main users of R2. This room is much more adapted to student interactivity and collaboration than traditional lecture halls and provides a unique testing ground for large (150+) student groups. We want to make use of the affordances that this type of lecture halls can give to develop the Interactive Lectures further. This can be seen as a concrete manifestation of the shift from focus on *teaching* to focus on

[11] https://www.ntnu.no/ktdim/om - Ny forelesningsstruktur. See also Part D of this document.

learning (Engelbrecht & Harding, 2005). This shift requires a change of culture both among teachers and students, and therefore time and effort to develop efficient ways of working within a student centred environment, along with evaluation and research, is of the essence.

Part 2 involves developing interactivity via digital tools to a new level by using technological systems for interaction that go beyond traditional student response systems, e.g. Sembly[12]. This will enable new ways of communication between students and teacher and also between students. Such systems will also blur the boundaries between classroom sessions and out of classroom communication. We will actively engage in trying out such systems with the aim of creating a virtual forum where students can have peer-to-peer contact in their courses, and also contact with teachers. Part of the developmental work is to find suitable platforms and software that will fulfil our needs. We will aim to accomplish as much as possible within Blackboard.

Part 3 involves further development of the Support Centre (Matte-/Statistikklab), which has been an important part of KTDiM. Within ACT! we will develop the Support Centre to cover all the core courses, whereas in the current model it has mainly been subject specific. In the new model the Support Centre will be a place where students can find qualified tutors covering all core courses in mathematics and statistics. This will turn it into a hub where students from different study programmes and different years can meet and work together. Recognising that learning assistants are very important for students' learning processes we will follow up the development of the Support Centre with improved training of learning assistants, focusing in particular on how to act as a tutor at the Support Centre. This Support Centre will be unique in the Norwegian context, both regarding its scope in terms of courses and the number of students that it will cater for.

There are several existing projects at NTNU working on learning environments, e.g. Tett På[13] at IA where considerable competence in this field has been developed. Both Tett På and IMF are recruiting PhD candidates that will develop their research projects within ACT!. Together with research conducted by permanent staff this will ensure research-based knowledge in the project.

Background for the project

Input factors. The project KTDiM (2014-16) has mainly focused on the *form* of three of the core courses. During the three years the project lasted, these courses have seen deep changes in the way subject matter has been presented to the students, the ways the students have been expected to work,

[12] https://www.sembly.no
[13] https://www.ntnu.no/toppundervisning/tettpaa

and the ways they have been assessed. Changes in form include development of digital learning material and assessment tools, as well as broadening the basis for assessment, increased interactivity in teaching sessions, and development of a student Support Centre. The *content* of the courses has remained largely unchanged. KTDiM has been characterised as a project that "has implemented differentiation in education and combined large class education with individual adaption."[14] Through extensive student surveys as well as focus group interviews throughout the project period of KTDiM we can document great satisfaction with the basic principles of the changes that have been implemented through this project. This view is also supported by the Student Panel. One important change is the restructuring of the lectures. The traditional lecture pattern in Calculus 1 and 2 has been changed from 2x45 min. twice a week to a 2x45 min. Survey Lecture (SK) and a 2x45 min. Interactive Lecture (IL). The basis for every week is a list of *key concepts*, presented on the web. In the SL the key concepts are discussed to give students an overview of the important topics. The IL is based on tasks that are meant to deepen the understanding of the key concepts and is characterised by extensive teacher-student and student-student interaction. Most recently the ILs have taken place in the rebuilt lecture hall R2. Together, the two lecture types form a unit, centred around the key concepts. This change is perhaps the most profound change ever done in these courses. Feedback from students, including the Student Panel, shows that the change has been a success and that it should be further developed and implemented in other courses as well.

Both locally at NTNU, and nationally as well as internationally, one can detect an increased awareness of educational quality. Evidence of this can be found in NTNU Toppundervisning[15] and its sub-projects. One of these sub-projects is *Recognition of Pedagogical Competence*[16], led by the project leader of ACT!. On a European scale evidence can be found in *the European Learning and Teaching Initiative*[17] where NTNU is involved with the project leader as a member of one of the working groups. Our international partners provide evidence that increased attention is given to the basic education of mathematics and statistics also elsewhere. Research on the teaching and learning of undergraduate mathematics is increasing, which is demonstrated by the establishment of

[14] Translated from NOKUT's evaluation of KTDiM's application for Utdanningskvalitetsprisen 2015
[15] Teaching Excellence Programme, http://www.ntnu.edu/teaching-excellence,
[16] http://www.ntnu.edu/teaching-excellence/recognition-of-pedagogical-competence
[17] http://www.eua.be/policy-representation/higher-education-policies/eua-learning-teaching-initiative

international research networks (e.g. INDRUM[18]) and research journals (e.g. RUME[19] and an upcoming Thematic Issue of NOMAD[20]). Locally, the newly established centre SEED[21] and the journal *Nordic Journal of STEM Education* are initiatives that point in the same direction. This shows that the ideas of ACT! are closely linked to current trends in recognising educational quality, and the growth of research on tertiary education.

IMF has access to excellent graduate students who are involved as learning assistants and trained by IMF in cooperation with UNIPED[22] through the LAOS-programme[23]. IMF also contributes to MatRIC's Induction Course for newly appointed mathematics teachers in higher education. IMF can document high research quality through RCN-evaluations (The Research Council of Norway, 2012) and also has an active research group in mathematics education. The project leader has professor competence both in mathematics and in mathematics education.

Process factors. Technology education has been criticised for being over-adapted to a narrow range of learning styles, despite that it is well known that people learn in different ways, see e.g. (Felder & Silverman, 1988) for the case of engineering students. Based on theories emphasising the need for stimulating students' affective, behavioural and cognitive engagement, we have been developing learning environments encouraging participation, communication and interaction (Mokhtar et al., 2010; Fielding-Wells & Makar, 2008), thus shifting the emphasis from teaching to learning (Engelbrecht & Harding, 2005). This has been the guiding principle for projects like KTDiM. A broad variety of digital resources have been produced and in combination with interactive lectures and a support centre, a significant increase in student activity has been observed. Evaluation and student involvement are taken several steps further in KTDiM and in the planning of ACT!:

- extensive annual evaluation in core courses, achieving a high response rate;
- interview groups used for evaluation and research;
- student panel for evaluation of digital resources in KTDiM;
- student panel for the planning of ACT!

Result factors. NTNU dominates technology education in Norway, awarding around 40 % of all university degrees in technology, and on master level more than 75 %. Hence, the output from

[18] International Network for Didactic Research in University Mathematics
[19] International Journal for Research in Undergraduate Mathematics Education
[20] Nordic Studies of Mathematics Education
[21] Center for Science & Engineering Education Development at NTNU
[22] Section for Educational Development at NTNU
[23] http://www.ntnu.edu/ipl/laos

NTNU is of great national importance. We acknowledge the difficulty of assessing the impact of the core courses as part of the total programmes. In particular, it is well known that the first two calculus courses in the master programmes are challenging for many students. Data from student surveys and feedback from reference groups since the start of KTDiM indicate that students experience increased study activity and better learning outcomes. Furthermore, the proportion of grades A and B in these two courses has increased from 17 % (2012 and 2013 average) to 33 % (2014 and 2015 average). However, it is not known what possible connection there may be between students' success in the core courses in mathematics/statistics and their inclination to complete their studies. Our surveys show a high degree of agreement with the statement "a good result in Calculus 1 is important for my motivation to continue the studies" but more information is needed on this matter. It would therefore be of interest to engage in collaboration with FUS and the leadership at NTNU to gain more knowledge about the impact of the basic education on the drop-out rates.

Evaluation, research and dissemination

Mathematics and statistics are important for many study programmes at NTNU and resources and approaches to education developed in ACT! will be of value for other programmes, in engineering, teacher education and other fields. It is also the ambition to have a long-term impact on mathematics in engineering education in Norway as a whole and to be a source of inspiration for similar education programmes in other countries. To fulfil this ambition, we have devised a varied plan for dissemination (see Action Plan). In addition to specific events mentioned in the Action Plan we will arrange seminars addressing specific topics in order to communicate our work and ideas, and also to get input from peers and stakeholders for further work. Continuous impact and feedback will be secured by actively engaging the Student Panel and the User Panel. This will form an important part of the evaluation. In addition we will run surveys of different kinds throughout the project period. Additional support is mainly required for developing new material and practices that will be sustainable after the project has ended. This has been accomplished also with KTDiM.

Research on project activities will be performed by permanent staff and PhD candidates, focusing jointly on technological solutions and educational aspects, also forming a central part of the evaluation. Results will be disseminated through traditional channels. The openly available resources that are developed are also an important part of the dissemination. We plan to collaborate with MatRIC in its established annual conference and other activities. Our international partners are also important for maintaining exchange of experiences and stimulation for further work.