χ: Collective. Individual.

A Project management

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B Abstract

There exists an extensive literature documenting the effect of teaching techniques that lead to improved learning compared to the traditional lecture[1]. The main challenge for a university is how to select, combine and implement different learning activities, into an *optimal* learning environment where each student reaches *far* beyond what is achieved through conventional passive lecturing. **The main aim of this project is to study and disseminate how to design an *optimal* learning environment .** This goal is achieved through the *individual* and *collective* development of both students and faculty.

The project is divided into three work packages.

- WP1 - Develop a framework for how to efficiently implement an *optimal* learning environment that targets the heterogeneous student population.
- WP2 - Extend the perspective on learning to an *individual* performance perspective, using teaching strategies inspired by *training in elite sports* to optimize learning activities.
- WP3 - Use *contest webs* to harness the *collective* intelligence of the student population to generate novel strategies for improved learning.

C An innovative and feasible project plan

This proposal will enter into the project portfolio of the *Center for developing a quality culture in higher education* ($\triangle$**Q**)[2]. The main goal of this center is to study how to efficiently develop a culture for quality in higher education. Such a devlepement has been called for by the ministery of education[3]. This center submitted an application for SFU status in 2016 and has an ambition to strengthen it's positions for the next round of calls for SFU status. The present proposal is an integral part of this ambition.

C.1 Innovation

WP1 - A framework for optimal learning

There exists an extensive literature describing learning activities that improve learning. A recent large scale meta analysis of several hundred studies demonstrate that the effect is clear[1]. Collections of scientifically proven techniques can for example be found in the *Teaching practices inventory*[4] and others[5]. At the same time, cognitive psychology has developed a better understanding of how we learn, and there are many compilations of these results (see for example [6] or [7]). Still, even though though the literature demonstrate the advantage of alternative approaches, the traditional lecture is still the prevailing instructional format.

One reason for the sparse adoption of improved learning activities is the lack of knowledge about these results among faculty. The training of most faculty is limited to a short training program in pedagogy that is quite general and with little impact. To be efficient such a program must be followed by a more discipline oriented and detailed program. This program must effectively develop the *individual* educational expertise of the faculty member.

Yet, there are three additional hurdles to overcome that require significant time and effort: 1) To choose among all the different activities, 2) to create and organize the learning activities for a given course, and 3) to do this in alignment with resources and directions set by the department and the study program boards. Even though this process will inevitably require some time and effort on part of the faculty, the process can be facilitated by an appropriate framework that is linked to study program governance and departmental organization and support.

The framework is a collectively authored online platform based on the following pillars:

- A high quality description[8, 9] of learning outcomes, compatible with the CDIO model and learning outcome matrices[10]. This constitutes a platform for explicit course connections and to facilitate communication and governance of the course development between faculty, department, and study program boards.
- A method for course transformation using a menu of learning activities and guiding principles from cognitive psychology for how to meet the learning objectives most efficiently. This also includes how to organize a course to optimize the use of expert resources and making learning material that is easily transferable.
- A description of available departmental resources, linked to the menu of learning activities, and how to invoke them to lower the barrier for initiating improvements. This will also include short educational training programs for faculty and TAs.
- A description of possible assessment formats and how they can efficiently be implemented for a given type of learning objective[11].

This framework will be linked to an efficient method for continued training and exposure of instructors to results form current educational research. This is essential so that instructors understand the underlying learning mechanics and that the learning activities are correctly implemented. This development program will target both faculty and teaching assistants (TAs)[12].

There are many aspects to address for such a framework and surveys can be found in the literature (e.g. [4, 6]). We will not discuss all these aspects here but highlight a few important points that are perhaps not so well described in the literature and need to be developed, especially those relating the framework to the departmental organization.

There are no indications that resources for teaching will increase in the future so new learning activities must be based on existing levels. Hence, when organizing learning activities, it is important to use the available resources, and especially the available expertise, in an optimal way. A key point being that the person with the most expertise (typical faculty) should be most deeply involved in learning activities for deep learning, while practice of basic concepts and course administration should be delegated to those with less expertise (TAs). Basic facts can be acquired through cheep/free resources (books, video, online quizzes etc.).

Even though running a course in a normal year need to rely on existing resources, the development of a new course structure, with learning activities and materials, can be funded with one-time resources from departmental or other sources (such as this proposal). However, to make such investments profitable, it is important that the changes are not reverted by the next teacher. This entails that courses must somehow be *deprivatized*. It will be important to not take responsibility or credit away from faculty but to rather develop a change in perspective where teaching is seen as a *collective*, rather than individual effort. This will necessarily involve a cultural shift in how teachers perceive courses as well as in the organization of the department. Such a shift in culture is the main goal of ΔQ. The framework should therefore motivate a collective/departmental ownership of the course learning activities.

In this project we will test the framework and the results from WP2 and WP3 on the two courses FY1003 Electricity and magnetism (EM1) and TFY4240 Electromagnetic theory (EM2). Both courses run in the spring. These two have been chosen since they differ in size (around 150 and 50) and represent lower and upper division courses. The proposed framework will probably need to distinguish between large and small class as well as introductory and advanced courses in choice of learning activities.

Building upon previous knowledge is an essential component in developing students towards expert thinking[13]. This will be facilitated through explicit connections between courses. Since EM2 builds directly on EM1 these courses serve as ideal candidates for studying how to maintain course connectivity in the departmental organization. We will study how to describe, maintain, and efficiently make use of such course connections. ΔQ already has an ongoing project to investigate how course connections can be efficiently maintained within a program, and how teacher experience can be efficiently transferred.

Another important topic to be included in such a framework is that students are different and there is no 'one size fits all'. A key point is to allow for flexibility[14]. ΔQ already has a project that focus on universal design for learning and we will incorporate results from this project into the framework.

Deliverables

- A framework for how to use the collective knowledge about learning to generate optimal and flexible learning activities.
- A discipline specific educational development program (based on the principles of the framework) that targets both faculty and TAs.
- A departmental structure that provides resources changes based on the framework and supports deprivatization of courses and course materials. This includes mechanisms that supports and sustains connections between courses.
- Transformation of two courses at *Department of physics* using the framework.

WP2 - Developing the individual: Elite sports

Perhaps the most scientific approach to optimize the learning process and thereby performance, is seen in elite sports. An incredible amount of planning, testing, evaluation, and feedback, to further develop the physical and mental training process, is provided to facilitate that the athlete can reach their potential and perform at the highest levels. In order to strengthen this process, education and teambuilding processes of both athletes and coaches are important tools. Similar approaches are seen in industry, especially in leader training, where people are trained and supported to perform at an outstanding level. This focus on optimal training/learning is quite different from the approach in teaching which is often based on tradition rather than evidence. However, also in sports there is tension between the authority of the coach and scientific results, in which a good process of knowledge translation is required to reach an optimal process. How this tension is resolved could be transferable to academia.

Another difference between elite sports and university education is that in sports one takes a holistic perspective on the athlete. It is not only the training session that is important, but how well the athlete rest afterwards (to achieve super-compensation from the learning process), how motivated he/she is to further develop and prepare the next training session, the total physiological and psychological load, and how to develop the mental stamina to endure intense practice through the entire season.

The aim of this workpackage is thus to use the knowledge base from how athlete development is done in elite sports in order to develop a more holistic perspective on students and learning activities in academia.

Examples of transferable approaches between elite sports and academia that will be investigated are: training log $\leftrightarrow$ metacognition, Mental training $\leftrightarrow$ reduce procrastination, physiological testing and adaption of training program $\leftrightarrow$ formative assessment with targeted feedback. There are probably many more aspects that are transferable and can be used in academic training. This workpackage will identify and implement these approaches. The changes will be included in the framework and tested in EM1 an EM2.

Deliverables

- New concepts for learning activities and learning environment based on inspiration from elite sports. These concepts will enter as part of the course development framework.

WP3 - Developing the collective: contest webs

Wikipedia has evolved as an ubiquitous tool with an amazing degree of quality, demonstrating the power of collective intelligence. However, one drawback is that Wikipedia only presents a single solution to a given problem (e.g. explanation of a topic). Using a concept from optimization theory, the solution can reach a local minimum in the solution space for the posed problem and the search for the global minimum is halted. Another issue is that there is no systematic way to reuse sub-parts or earlier versions of a solution in current wiki technology.

A solution that addresses these issues is so called contest-webs [15]. Contest-webs makes it possible to search for multiple solutions to a problem simultaneously while encouraging reuse of material. Such a web takes a problem, breaks it into separate parts, which again are divided into subparts (and so on). Then, for each level, an online contest is created, where participants (in our case, students) provide solutions. At higher levels participants generate new solutions based on solutions to contests at lower levels. Thereby, solutions to subparts can be assembled in multiple ways for the main problem. In this way reuse is encouraged and the solution space is probed to a greater degree. An example of such a contest web is the ClimateCoLab [16] where over 90000 users participate to provide solutions for how to address climate change.

We will create such a contest web for a course. The contest web will aim for a main question like 'What is the optimal learning activities to learn *Topic*'. For this project the *topic* is electromagnetism. The question for the main topic can be broken into questions for smaller topics, e.g. dielectrics, Maxwell's equations, and wave propagation. At lower levels the contests can ask questions like 'How do we best motivate students for electromagnetism?', 'What is the best learning activity to remember basic concepts'? 'What is the best way to visualize the meaning of $\nabla \times \mathbf{E}$?'.

Such a contest-web will lead to new ideas for learning activities and presentation of material but will also have multiple other positive effects on student learning and development.

Through the participation in such collaborative approaches the students will develop a better appreciation of a collective effort and develop the *collective intelligence* of the group[17]. Thinking about collective intelligence is a different mindset from group activities. The primary focus shifts from the development of the individual to developing the collective knowledge for all, including the teacher. By focusing on the collective students develop a mindset where they do not only focus on their own knowledge, but rather on the potential of a group, where their knowledge is a key brick, but not the whole wall. On the other hand collaborative learning is one of the learning approaches with the strongest scientific support for significant improvement in learning (second only to active learning)[5]. Therefore participation in contest-webs will also have a positive effect on *individual* development.

Another important aspect is the democratic deficit that exist in student feedback to the instructor. Typically, a reference groups is used which often will be unrepresentative of the student population. By using contest-webs, the opinions on learning activities from the entire student population can be heard and harnessed.

By having to think about how to optimize their own learning students will develop strong metacognitive skills which has been highlighted as a factor in developing deep learning (see for example [6]).

Also, the instructor, as an expert, have often conceptually combined many of the steps towards understanding a concept and it can be difficult to assess what is the optimal explanation for students[7]. Students can through these contest-webs provide the instructor with clues for knowledge and understanding that needs to be made more explicit.

Deliverables

- An implementation of the XCoLab server[18] as an online contest for course development.
- Arrange contests aimed at new learning activities for the pilot courses in this study.

Project plan

The proposed framework will be developed through the three WPs. The framework will be tested by developing the learning activities in the two connected courses, EM1 and EM2.

The details of the project plan is provided as an appendix. Briefly, the first semester will be used to develop the framework (WP1) and analyze the learning objectives of EM1 and EM2. The framework will then used to reform EM1 and EM2. The reformed version of the courses will be tested in the second year. Simultaneously, the framework will be developed using inspiration from elite sports (WP2), and the contest-web will be developed and deployed (WP3). The courses will then be refined based on the new framework and experience from the first iteration. The second iteration of the reformed courses will be given and evaluated in the third year.

Project organization and partners

The project will consist of the following project partners. Their combined expertise across a range of educational and disciplinary disciplines provide the necessary background for the successful completion of the project (see section D1, Input factors for details).

Associate professor Magnus Lilledahl (ML) Project manager. *Department of physics*.
Professor Erik Wahlstrøm (EW) *Department of physics*.
Associate professor Rolf Jonas Persson (RJP) *Department of teacher education*.
Professor Carl Wiemann (CW) *Department of Physics and Graduate School of Education*, Stanford
Professor Hermundur Sigmundson (HS) *Department of psychology*.
Professor Øyvind Sandbakk, Frode Moen (ØS, FM) *Center for elite sports research*.
Kjetil Knarlag, Elinor Olausen (KK, EO) *Universell*.
Trond Aalber *NTNU Drive*

One post doctoral fellow (NN), experienced in educational development, will be included in the project and will be responsible for the progression of the projects together with the project manager (ML). This core group will be supported by two TAs as well as several student assistants to develop new learning materials for the courses. *NTNU Drive* along with student assistants will provide support in deploying the contest-web system. Bi-monthly project meetings with all the partners will be conducted to inform about progress and receive feedback. The expertise of the project partners will otherwise be used as needed.

C.2 Evaluation and impact

The first year of the project will focus on development of new learning activities and measuring baseline data with the current instructional paradigm. The effect on learning in EM1 will be tested with the BEMA concept inventory [19] where we already have baseline data. For EM2 we will develop a new concept inventory based on questions from old exams[20]. There is not time within the project to perform a thorough check of reliability of this inventory *a priori*, but these checks can be applied after the test has been deployed to check that it meets reliability criteria. The learning effects of the reformed courses based on the framework will be assessed by these concept inventories.

In addition to improving disciplinary knowledge we expect that the targeted education aimed at the requirements of the individual as well as the focus on developing a collective mentality among the students will have a positive effect on attitudes of the student population. We will investigate this using the Colorado learning attitudes towards science survey [21]. We already have baseline data of this survey from the student population in questions[22]

The scientific evidence that more active learning methods provide more learning is overwhelming[1]. As Freedman et al. points out, if the comparison between the traditional lecture and more active learning techniques was a medical study it would be unethical to continue the study as the effects are clear. Yet, the adoption of modern learning activities are still scarce and the traditional lecture prevails. There are probably several reasons for this, the most prominent being that current teaching format is deeply embedded in the current culture, that individual teachers places much pride in the way they have taught over the last 20 years, and that there is very little individual incentives to improve teaching.

Changing this culture is a long term project but through this study we want to test the effect of several potential mechanisms:

- By providing a local comparison of different instruction methods, the results will be more difficult to ignore than if they are from a different cultural context.
- Through focusing on *optimizing* the learning activities we hope that significant learning gains can be achieved that might have a greater impact.
- By design courses so that the teachers time is most efficiently used as an expert and all administration is delegated to TAs, we hope to show that significant learning gains can be achieved with no additional time from the faculty.
- By providing an easy to use framework for optimal course development, it will potentially be easier to adopt research based learning activities.
- By incorporating a system for educational development, faculty will acquire a larger knowledge base on which they can further develop their courses.

The *Department of physics* will implement the Teaching practices inventory (TPI) [4] in the fall of 2017. At the completion of this project, we will measure the TPI score for the department again, to determine whether this project has led to an increased adoption of research based teaching.

C.3 Dissemination

The results of this project will at the local level be disseminated at the Department of physics teaching seminars. For a wider audience we will target the Faculty's seminar series on innovative education.

The framework (WP 1 / WP 3) will be designed specifically for the NTNU educational administrative system, and as such transferable within NTNU. We aim at making an expandable design, which can be transferable within NTNU with ease, and adopted by possible future external partners.

The results from the project will be published in peer-reviewed journals and at national and international educational development conferences (Læringsfestivalen, MNT-konferansen, CDIO conference).

The aim of the project is also to develop sufficient competence and experience, to carry an SFU with focus on active development of a learning culture. The proposal is part of the ΔQ project which has aims to disseminate results on how to transform faculty to focus more on quality in education.

D Documented quality in existing education

D.1 Input factors

The *Department of physics* has conducted several projects aimed at implementing innovative educational methods. Examples are more project-oriented and open-ended laboratory exercises[23], flipped classroom (TFY4102), peer-learning (TFY4125, FY1001), and instructional videos (TFY4125).

The *Department of physics* is the only department in Norway to lead two SFFs (Center for excellent research). In addition, we participate in one more SFF and two SFIs (Center for excellent innovation).The teachers in the courses in questions (EM1 and EM2) have agreed to participate in the project and provides the necessary disciplinary expertise. The teacher of EM1 (Jacob Linder) is part of NTNU's Outstanding academic fellow program (stjerneprogrammet). CW is a Nobel laureate in physics and has led multiple large scale educational transformation initiatives in the US[24]. Students are deeply involved in the departmental research through master projects. The *Department of physics* and partners thus form a strong research environment in where to develop research based education.

The head of department (EW) is part of the project management team and the departmental deputy head of education (ML) is the project manager, ensuring the necessary project management competence as well as strong departmental support. The project is also supported by the faculty. The strong departmental support ensures that project outcomes will be incorporated into departmental structures.

The project members have led several projects within NTNU toppundervisning.* The project partners includes experts from cognitive psychology (HS) and physics education research (CW, RJP). This ensures the projects educational expertise. The director for the Center for elite sports research (JS), which is an internationally renowned institution for performance research, is participating in the project. *Universell* is the national center for universal design in Norway and has recently led an EU project on universal design for learning[25]. This center provides key knowledge in how to optimize learning activities for the heterogeneous student population.

The project will include a full-time post doctoral fellow, with a background in educational development, as well as two TAs and several student assistants which provides the necessary resources for completing the project. The involvement of science education specialists was highlighted as an important factor for success in a recent educational development effort[26].

D.2 Process factors

This project is part of the existing educational development center ΔQ[2]. The primary aim of this project is to study and develop a culture for quality in higher education. ΔQ is funded jointly by the Faculty of natural sciences and the Department of physics. The center aims to position itself for status as Center for excellent education in the next round of calls.

The project will be an integral part of the current revisions of the study programs within physics. Starting with the EM courses allows for swift implementation of the results to other courses, and in the end to full study program.

* *'Video for Kvalitet'* and *'Å gjøre det åpenbare: aktivisere studenten'*.

One of the projects of ΔQ is to improve the connection between courses and that there is an efficient transfer of information to the next teacher. This project will be greatly enhanced by the current proposal where a system for such transfer will be developed and studied.

The *Department of physics* is actively working to integrating effective use of teaching areas designed for different didactic approaches, and is currently refurbished large teaching areas that will be designed for more active and collaborative learning. This area will be a key ingredient in realizing the ambitions described in the work packages. A part of this project, called *Fysikkland* is part the NTNU project to develop areas for innovative education[27]. The methods outlined in WP3 will be invaluable to find optimal ways to use these spaces. Through our collaboration with CW at Stanford university we are aiming for an international benchmarking of our education. ΔQ has a project were we want to use exchange students and their international learning experience as an inspiration and benchmarking of our curriculum

NTNU as recently introduced a incentive system for excellent teaching. This has been highlighted as central to developing the standing of education and increase quality[26].

D.3 Result factors

The department of physics is responsible for four study programs, in total about 200 students per year. In addition, the department of physics teaches physics for about 1300 engineering students every year as well as programs in continued education for high school teachers.

The study program in Physics and Mathematics at NTNU is one of the hardest programs in Norway to get into (GPA of 59 in 2017). The completion rate is high and has been increasing (average 87% for students starting 2013-2014). The 2013 NTNU candidate survey conducted showed that 81% of the MTFYMA had permanent positions after gradutaion. An evaluation of the study programs in 2016 is being followed up in the current revision process. It focuses primarily on optimization of teaching methods, as well as a closer association with industry as two key goals.

The *Department of physics* with associated partners thus provides a solid foundation for developing the innovative ideas described in this proposal.

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