Beyond research based teaching: 
Teaching interdisiplinary research and pushing students beyond their training

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ABSTRACT: Interdisciplinarity involves using approaches and methods from different disciplines for solving the problem at hand. Based on our experience from interdisciplinary research we believe that this is most effective when researchers that are firmly rooted in their own discipline learn sufficient theory, methods and practice of other disciplines to communicate and work in teams doing research together. The course «Methods in PGP» focused on teaching sufficient methods to all students to solve the research problem to be worked on in «PGP case study». The methods should be sufficient for the research and the training should be sufficient for the students to understand the approach of the other disciplines. Thus geologists with no mathematics or IT training had to pose problems mathematically and solve them analytically and by computer simulation and mathematicians and physicists had to do field mapping and analyse minerals. The research problem was always chosen from the ongoing research at the CoE PGP and changed from year to year. Consequently, both courses had to be modified, developing new curriculum every year. «PGP case study» always had a real research problem where the teachers did not know the outcome or even fully the direction of the research at the start of the semester.

1 INTRODUCTION
To reach the ambitions to become one of the best research Universities in Europe, UiO through its strategic plan call upon innovation, creativity, interdisciplinarity and research based teaching. In spite of this, examples of true research based teaching and interdisciplinarity are few. There exist no formula for how innovation and creativity can be enhanced and it is questionable if at all students can be trained to become more innovative. We report here on 11 years of experience of interdisciplinary (Physics-Geology) research based teaching and attempts to train students to become more innovative. In this hindsight we will try to put our endeavour in context.

1.1 The development of an interdisciplinary research and education environment
In 1998 the Strategic university program “Fluid Rock Interactions” was initiated at the University of Oslo. A mixture of senior and young professors, PhD students and postdocs from the Geoscience and Physics departments started working together. Over the next 5 years a truly interdisciplinary culture was developing that came into full bloom with the award of the Centre of Excellence “Physics of Geological Processes” (PGP) in 2003. PGP was committed to forming a separate MSc program that enrolled the first students in August 2004. From this semester on all new MSc and PhD students at PGP had to take two 10 ECTS credit introductory courses cross-listed between the Physics and Geoscience departments: Fys-Geo 4200 “PGP Case study” and Fys-Geo 4300 “Methods in PGP”. The goal was clear from the outset: Students with basis in their own BSc discipline should learn by doing; engage in research themes central to PGP in the same manner as in all research projects at PGP: working together in interdisciplinary teams and employ all the five research methods: field observation, analytical measurements on rocks, experiments, theory and numerical simulation. The first two methods are traditional to Geology, the latter three traditional to Physics.

1.2 Interdisciplinarity
Interdisciplinarity is considered to be the key to future development of research and to societal development [1]. The recent Strategic Advisory Board report to the University of Oslo [2] commented that "At present, interdisciplinary activities mostly take the form of collaborations among participants from different disciplines, rather than the exploration of truly integrated interdisciplinary areas. ... At
*UiO learning and education appears not to be considered as a communal space constituted by criss-crossing investigations. … students are forced to choose a specific study programme right from the start. 'Crosslisting' of courses (...) is underdeveloped. … UiO should become considerably more interdisciplinary. Barriers between traditional disciplines should be removed without weakening standards of disciplinary excellence.’ We believe that the story we will now tell about the PGP introductory courses are an exception to this observation. Even if one does not have the goal (like UiO) to become a leading European research university one may recognize that in most industrial companies the science educated personnel are required to work in teams with personnel with a different background. So how do you teach true interdisciplinarity to students?*

1.3 Innovation
The Bachelor training in Sciences at most universities is focussed on basic knowledge and skills that are well established. Hardly a question is posed without the existence of a definite answer the professor can produce at will. The authoritarian culture installed in the students leaves little room for curiosity. On the other hand, the first steps towards learning innovation in research is to
- see that the world is full of open, unanswered questions,
- believe that the questions you pose may be of general interest and importance,
- trust that you have (or can acquire) the abilities and skills necessary to find answers to your questions.

This total break with the Bachelor training of the students was the starting point for our teaching.

1.4 Research (based) education
Research universities in Europe and USA developed from the notion of Wilhelm von Humboldt of unity of research and teaching [3]. This unity is also connected to Bildung (dannelse, the overall education of the individual, developing integrity and intellectual independence) as opposed to Ausbildung (utdannelse, training for employment). In the spirit of Humboldt the Norwegian institutions of higher education are required to give “research based education” (forskningsbasert utdanning) [4]. There is, however a wide range of interpretations of the concept “research based education” from “education in agreement with research” to the more Humboltian “training in scientific method in cooperation with a practising researcher” [5]. The latter interpretation that is close to our practise is mostly relevant at MSc and PhD level education although it has been used on BSc level with success as well [6]. The research training we describe in this paper is clearly a basis for a career as researcher, but we argue that the skills developed, the spirit of autonomy and method of enquiry are important to our future work force and the protection of democracy.

1.5 Differences between Geology and Physics
Geology is traditionally a descriptive science based on systematic field observation and analysis of rock samples from the field when back in the laboratory. Since the observed patterns are petrified remains of several very slow processes that occurred inside the Earth’s crust there is an important creative element to infer what has happened. The qualitative descriptions of sequences of events leading to the complicated present day observations are seldom well constrained. Geology has traditionally had strong links towards chemistry with the development of the field geochemistry by Goldschmidt 1926[8]. However many geological processes, such as mountain building, fracturing, earthquakes and avalanches can only be understood by applying physical principals and laws.
Physics has, since Gallilei focused on picking apart the complicated Nature and describing the simple constituents in universal laws in mathematical form that have predictive power. As the fundamental laws are now known, physics today applies the same reductionist approach to complex systems with interaction of many forces and processes.

The BSc training at the Geology department at UiO has until now not required any mathematics or computer science whereas the physics BSc at UiO has 50 ECTS credits mathematics and computation and only 10 credits physics during the first year. Thus the BSc training of the two main groups of students starting the introductory PGP courses was extremely different.
2. CONTENT AND FORM OF THE COURSES AND THE PHILOSOPHY BEHIND

Many introductory courses are constructed to give a broad overview of the field. Since this was an introduction to interdisciplinary research we quickly realized that it was better to focus on a single topic per year and the limited the number of theories and methods to those necessary to solve the problem.

2.1 The topics of the case study
The topic of the case study changed from year to year and was chosen based on the following criteria: We were looking for research avenues that were in the developing stages internationally or that we could sense would become important in the nearest future and thus where we could play a leading role. Since the project work was based on field data we were looking for topics where we could draw advantages from Norwegian nature and climate. The project should contain problems that could be addressed through geological and physical working techniques and principles. The annual change of topics and field areas, although challenging for the lecturers, were fundamental to keep the innovation up both for students and teachers not to fall into traditions and repetitions. The topics chosen spend a wide range from “Fracturing and alteration of the oceanic lithosphere, exemplified by the Leka and Røragen ophiolite complexes”, “CO2 sequestration in ultramafic rocks”, “Green concrete”, “Ice wedging of surface fractures” and “Friction melting in deep earthquakes”.

In the methodology course we restricted the choice of fundamental processes involved so that learning the necessary theoretical concepts did not take too much of the students time. The key processes of fracturing and transport and reaction were kept throughout the 11 years because they were fundamental for much of the research in PGP at the time and to allow development of good and effective exercises.

2.2 The organization of the teaching
The semester started with 2-6 weeks of teaching an introduction to the field area and the topic of the year was given together with exercises in methods followed by a field camp for 3-4 days at the chosen field area. We looked for accommodation where we could stay together also at night to continue discussions and learning. The case study field camp was fundamental to collecting field data (rock samples, maps, images, and measurements) to be used in the subsequent part of the course and in the Method course. The field camp was also used to create a group feeling and as many of our students where from abroad, they were given the first taste of Norwegian nature and wildlife.

Each group treated the field data during the field camp and afterwards and handed in a field report 2 weeks after the camp. The rest of the semester each group had weekly (or more frequent) meetings with the teacher and other research staff to discuss the scientific questions and how to proceed with analysing rock samples from the field and how to do modelling, experiments and finding relevant literature. In parallel there were more methods exercises that were often relevant to the case study. All the methods teaching was performed in the following manner: 2-4 hours introduction, 1-2 weeks individual and group work on practical exercise and group report writing. Reports from each group were commented and a revised report was handed in and commented.

The students were organized in groups of 3-5 persons. Each group should have at least one member from each discipline geoscience or physics/mathematics. This was critical for the learning outcome of the students because the exercises were so demanding that the students had to teach and help each other to solve them. Because there were methods from both geology and physics all students would both help and be helped at various times during the semester. A few years there were not enough students from one discipline or the other. Then we had to modify some exercises and lower the standards. In the methods course the groups were changed deliberately to ensure that students interacted with many different students and to aid the evaluation of each student’s contribution to the reports. In the case study the students decided during the field camp which topic they would focus on and thereby groups were formed that lasted the whole semester.

Both the case study and the methods course required several teachers/researchers to be involved since they involved both geology and physics and application of research methods from several specialities
(theoretical physics, numerical simulation, experimental physics, field geology, geochemistry and optical and electron microscopy). No teacher was allowed to simply lecture about their own favourite research. Through thorough discussions about content and form the teachers decided on an exercise (for the methods course) that would be practically realizable in a week. For the case study the students, the responsible teacher and other researchers all took part in discussing what the interesting questions were and which analysis, simulation or experiment would be pertinent to perform. Then the student group and the expert researcher would enter an intensive period (1-4 weeks) of teaching necessary theory and methodological issues and performing the analysis, simulation or experiment and finally treating the data and writing about it in the final report. Each group would go through several such rounds of discussing the observations in field and in samples brought from the field and employing new methods in their investigation of the central processes of study.

We have found that by focussing on practical exercises with very directed introduction the students were able to perform tasks and master methods they never imagined. This is one aspect of pushing the students beyond their training. Physics students that had hardly been out in nature would map patterns and structures observed in the field and analyse rock textures. Geology students that had never programmed or studied mathematics since high school programmed numerical simulations and developed image analysis programs in Matlab. For example: The introduction to Matlab was done in a classroom with PCs where 2 and 2 students entered exactly the commands the teacher entered on a PC displayed by a projector. After 1 hour of general commands the teacher would spend 2 hours to introduce concepts like: how an electronic image is formed, how it is represented by a matrix of numbers, how operations like changing contrast and brightness can easily be represented mathematically, the mathematics of converting colour images to grey scale and black and white, concepts of image segmentation of image correlation etc. Then the instruction in front of PCs continued with applying all the concepts to a few example images. Then the students had to perform an experiment, collect images and develop Matlab programs to apply similar sequences of analysis to the series of images from the experiment.

2.3 The response of the students to research based teaching
Students were often frustrated to start with by the teamwork as opposed to working and being assessed individually. All students did quite quickly realise that collaboration was the only way to complete the tasks given. Another source of frustration at the onset of the semester was the lack of clear answers that they had got used to in their bachelor training. The professor answering “I do not know, but we can try to find out together” pushes the students beyond their training and into a real innovative mindset necessary for real research.

2.4 Research achievments – scientific and applied
The results obtained through our two interdisciplinary courses have paved the way for new larger research project funded by Norwegian Research Council, Horizon2020 and oil industry providing funding for PhD and master students. Following the more planned results the curiosity based research also led to important unexpected discoveries. For example: The mineral pyroaurite, which is know as an environmental mineral that can adsorb heavy metals from contaminated water, was discovered in one of the studied area. A master thesis carried out in order to test if naturally formed pyroaurite had the same environmental effects as the experimentally produced pyroaurite used in water purification today. In the studied sample pyroaurite was coexisting with the mineral dypingite that unexpectedly turned out to be a much stronger adsorbent than pyroaurite. This new adsorbent may represent a potential industrial product for water rinsing and as such a subject that may be patented.

2.5. A future multi-interdisiplinary approch totally devoted to research and innovation
In retrospect we can see that nature is so rich on interesting interdisciplinary problems that we could also have pick a field area and develop the project from the observation we made. This however would have made the preparation and introduction to the course difficult. It is evident that the involvement of additional sciences (modern chemistry and biology) would have been beneficial to solving some of the problems we were addressing and probably created new interesting interdisciplinary research fields.
3 EVALUATION
In both courses we announced that 75% of the grade was based on reports handed in and 25% based on a final exam. Because all reports were written by a group, the assessment of the contribution of each student was the most difficult. The role of the final exam was to assess if the students were able to explain the content of the reports that were handed in. In the methods course the students would have to answer questions about one of the reports randomly drawn. The random choice of report could often be hard on a student that got a report on a method from another field (for example for a geology student who would have to explain how to use the theory of fractals to make a mathematical model of hierarchical fracturing). If the student had great difficulties with one topic they would get some questions about other topics to assess if the student was generally weak or not. In the case study course the oral exam was started by the student giving a presentation about some part of the case study and then he/she was examined about the report. The examination would often take the form of a scientific discussion between good students and the examiner.

Almost all reports that were handed in in both courses were of high standard and the starting point for all would therefore be a C or a B. We would sometimes get a spread in grades from A to E within a single group. This could be argued to represent more than 25% weight of the final exam. This deviation from the stated weight is problematic. On the other hand, also the students knew that there were large differences between them and it would be unfair to give both the student who had done everything and the student who did nothing the same C. Oral exams are difficult and require very good preparations by the examiner. We have seen several times that we could have been more systematic in our examination and following assessment. We found that using the same sensor for both courses every year has helped us in maintaining a stable grade level and keep the assessment relatively fair. Some students however have felt unfairly treated during the exam and by our grading of the exam.

4 CONCLUSIONS
The two 10 ECTS courses developed to train new students to take part in the interdisciplinary Centre of Excellence “Physics of Geological Processes” gave in depth introduction to interdisciplinary research in accord with goals of Norwegian higher education and the strategy of the University of Oslo. We judge the training to have been very effective at pushing the students far beyond their basic training and into an innovative mind-set.

REFERENCES
[1] Documents of all three pillars of excellent research in Horizon2020 (ERC, MSC and FET) refer to interdisciplinarity as fundamentally important.