Increasing laboratory learning responsibility by reflection and peer learning in larger student groups

(RHU project **156/G04)**

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Life Sciences and the fast development within the area prompt a modernized educational approach adapted to the current professional requirements. Our aim is to develop efficient learning strategies devoted to aspects of Protein Chemistry accessible only through experiments. It is well known that inquiry-oriented laboratory learning offers unique possibilities to deepen learning levels, especially with open-ness in the choice of problem and methods, and by allowing for unexpected results. However, with increased student numbers and lower budgets, this teaching strategy is difficult to adopt. We have developed novel approaches to make inquiry-based learning efficient in larger student groups by increasing student responsibility, motivation and level of learning by using active reflection as well as interdisciplinary aspects as driving forces. Higher-order cognitive skills in laboratory learning were achieved as judged by Perry evaluations, and higher levels of responsibility were taken by the students, who praised the new strategy for learning.

INTRODUCTION

Knowledge in Protein Chemistry - relating protein structure with function - is urgently required in research and industry as a result of the genomic screens, and the subject recruits students from various backgrounds. The interdisciplinary nature within Life Sciences and the fast development within the area prompt a modernized educational approach adapted to the current professional requirements. The Bologna treaty puts stringent requirements on the time frame in which to achieve proficiency and independence in Protein Chemistry on both professional and scientific levels (3+2 yrs MSc; 3 yrs PhD). With increased student numbers and lower budgets, educatory efficiency requires an altered attitude towards learning among students as well as among educators. This creates an inspiring arena for pedagogical development (Collins, 2002).

This application explores ways to enhance professional and scientific proficiency by encouraging increased student-learning responsibility, in ways that can be applied also to other subjects. A major goal has been to investigate the efficiency of different pedagogical strategies in laboratory learning in larger student groups. The multidisciplinarity of Protein Chemistry, together with our extensive research experience in this area of science, have been exploited when designing the pedagogic strategies.

Rationale for change

In the tradition of John Dewey, who argues that information does not become knowledge until one can use it, we argue that laboratory-based training at highly cognitive learning levels is essential for the understanding and mastering of Protein Chemistry. Indeed, the testing of a functional hypothesis requires accessibility to perform experiments on the protein in an experimental set-up. It is well known that inquiry-oriented laboratory learning offers unique possibilities to deepen learning levels, especially with open-ness in the choice of problem and methods, and by allowing for unexpected results (Schwab, 1962, Herron, 1971, Berg et al., 2003; Brauner et al., 2002). Thus, the ideal laboratory task in Protein Chemistry would seem to be that of investigating a protein as or within the research laboratory.

Despite the obvious gains in using a research-based, or inquiry-based, laboratory learning approach, this route has been more and more difficult to take in Protein Chemistry at university level, due to increased student numbers and lower budgets which do not allow the required high teacher/student ratio. A common and major challenge is therefore to adapt previous laboratory courses, which were often performed in the research labs, to 5-10-fold more students and with experimentally less challenging approaches. To reach this goal, simplifying the laboratory tasks to cook-book level is most frequent in Europe today (Séré et al., 1998), but the feeling of discovery and problem-solving essential for effective learning (Hegarty-Hazel, 1990) will then inevitably be lost.

In order to promote learning of higher-order cognitive skills in the laboratory, which is of critical importance for the development of professionality for students of Biochemistry, it is therefore essential to develop new strategies for laboratory learning.

Review of relevant literature

With larger student groups and the need to optimise resources, we need to find new ways to encourage the students to reflect efficiently on their own laboratory practice in order to deepen their learning, take increased responsibility and better advantage of lab time, and be better prepared for their tasks. To achieve deep learning in laboratory practice, students must be engaged in learning conversations with staff and other students. Presented by Dewey (1916) as an important part of learning-by-doing, reflection is crucial in loop learning (testing-experience-reflection-generalization-testing.) (Kolb (1984) which is essential to developing reflective practice (Schön, 1987; Barnett, 1992). Indeed, reflective practice is an essential component in doing research.

A major aim of the courses is to prepare students for their future role as experts in society, industry or research. It is well known that meaningful learning and student motivation is much elevated if the laboratory task is as authentic as possible and if the students are given an expert role (Coppola, 1995; Coppola et al., 1997).

Our major strategies for increasing higher-order cognitive skills have been to
- use active reflection on laboratory tasks
- use ‘real-case’ and/or interdisciplinarity as a driving force for active learning

For laboratory learning in Protein Chemistry, we have found very little, if any, literature related to these subjects, except for references already mentioned above which are mainly directed towards organic chemistry. In our participation in the international CDIO meeting in Linköping 2006, as well as in the continuous participation of prof Lena Tibell in international didactics meetings, we have met no one working with these approaches in Biochemistry or Protein Science – it appears to be virgin land. In writing up our results into proper manuscripts, we will do a deeper literature search extending into nearby fields.

Question(s)

We believed that by finding ways to engage the students more in preparing for the laboratory tasks, we would increase their level of learning when actually doing the lab. This was the hypothesis we set out to test. Critical to this hypothesis were questions such as
- Is it sufficient to just ask the students to ‘do their homework’ before the lab better?

- Does it increase learning if the students do their own lab recipes?
- How much difference does it make if the students are involved in choosing the question to be addressed? The method to be used?
- How do we encourage higher level of taken responsibility? How do we measure if this was indeed taken?
- How do we measure increased higher-level cognitive learning?

During the project, we also realised that we had to ask questions such as
- Do female and male students respond differently to our approach?
- How does group dynamics influence learning of our particular subject?

Importance of the project to us and why

We are committed to training our students to become high-level academic professionals, and to be able to use biochemical tools to address questions of high relevance. For our own sake, we want to do this as well as possible. There is great satisfaction to be gained both from having been able to train students we can be proud of, and great joy in being able to convey a scientific attitude. For us, the project has also been a journey-of-knowledge through the importance of active reflection, and how we can use this as a fruitful tool to increase higher-level cognitive learning.

METHODS

Students

Our students are majors in Chemical Biology and/or Protein Chemistry; thus, our subject is a major subject for them. Approximately half of them study for a civil engineering degree in Chemical Biology, whereas the other half study for a Master's degree in Chemistry, Biology or Medical Biology. In a normal year, we have a majority of female students (60-80%), the majority being 20-25 years old, less than 10% foreign students, all with a background of two years of university studies in Chemistry and Biology. Course levels are B-, C- or D, and the form of training more or less 'classical' when we started this project (including lectures, labs and seminars).

Innovation 1

During many years, the enzyme human carbonic anhydrase (HCA) has evolved as a common objective of laboratory study during our advanced courses. The knowledge of HCA is well anchored both in state-of-the-art textbook literature (e.g. Berg, Tymoczko and Stryer: Biochemistry) and in the research activities of the division of Biochemistry. Thus, in the first Biochemistry course, the students learn basic methods while purifying and characterizing HCA. In the Gene Technology course the students design an HCA mutant, which is further studied in subsequent courses Protein Chemistry and Protein Engineering, by biophysical methods. The courses are given over a 1.5-year period, which gives time for reflection between the courses, but still allows for development of familiarity with the HCA protein in a fairly continued way.

The Protein engineering course labs were originally designed for few students (5-10) closely linked to current research. Due to expanded undergraduate training in this field, the course needed to be given for up to 50 students, causing severe strain on economy and senior staff teaching load. To accommodate this change, we developed a novel teaching approach.

The advanced course Protein engineering is exclusively a project oriented laboratory course in connection to a theory course in Protein Chemistry. This laboratory course is now given for about 40 students. At the start of the course the students are divided into project groups of about 8 participants each and they receive an assignment. One of the group members has to coordinate the work. Usually this responsibility is circulating every week around the members. The course and project structure, which is explained below, is outlined in fig. 1.

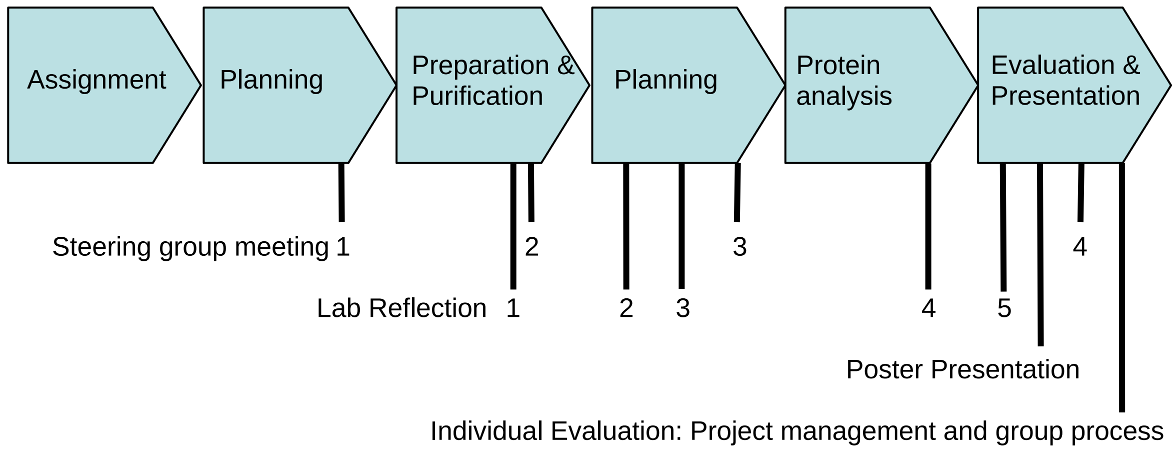

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Fig. 1 Course and Project Structure

The project planning process will proceed interactively through regular meetings between the groups and researching teachers. For this purpose we have organized a Lab Reflection Room. In this physical space, a lecturer will be present on scheduled time for discussions before, during and after the lab. Feedback can be given and received and the setting up of a hypothesis and the device of its testing can be discussed in more detail. A certain time in the Reflection Room will be compulsory for the students (Bennet et al., 1996).

The experimental work is done on genetically mutated human proteins cloned in bacteria. The origin of the mutated proteins is ideally proteins that have been mutated by the students in an earlier course in gene technology or can be provided by the research group. A mutated protein is produced and purified in all projects. Subsequently, the effects of the mutation on the characteristics of the protein, such as on stability or enzyme activity, are studied. The preparatory work is carried out with guidance of published method descriptions, whereas the groups have to organise the operation of the work. In this part of the project the whole group is cooperating to produce homogenous protein enough for the following analyses. When planning the characterisation of the mutated protein variants, the groups are to decide what properties to study and how this should be tackled experimentally. They base their decisions on through literature search and reading, in combination with discussions with teachers in the Reflecting Room. As a result of these discussions, tasks are divided by the group members. The group is usually divided into 3-4 subgroups that are focusing on different aspects of the project.

After planning and designing the experiments, the measurements are performed on instruments at the research and education departments, e.g. fluorimeter, circular dichroism spectropolarimeter (CD), differential scanning calorimeter (DSC) or spectrophotometer, which have to be booked in advance by the students at times when the instruments are to their disposal. After having carried out the analyses, the students should independently evaluate their experimental data. Also during this phase, researching teachers are available for reflecting discussions.

In order to make the project work as realistic as possible we have a close collaboration with a separate course in project management, which is studied in parallel with the Protein engineering course. Having this opportunity is of course a great advantage, although it is not an absolute prerequisite for caring out this kind of a project course. By this approach the project work can, however, be deepened and include moments like project scheduling, resource planning, project administration control and monitoring, as well as group processes and group dynamics.

To mimic project organizations in professional life, the groups report regularly to a steering group, which is constituted by teachers acting as “senior managers”. At these occasions the students are expected to give brief oral presentations of their progress. The whole project group participates in the meeting, but only two students give the actual presentation. Throughout the course four such steering group meetings are held, at which different aspects of the project work are presented and discussed, e.g. choice of methodology, obtained results, aim achievement, labour time, economy etc. Since different group members present at different occasions, all project members will present at least at once.

The students are also encouraged to record all thoughts, ideas, evaluations and conclusions as well as experimental planning, observations, calculations etc in a personal Laboratory Notebook to educate the students the value of recording all data and observations. Furthermore, Blackboard Learning System- Basic Edition has been used as a tool to facilitate communication between the group members. Blackboard is mainly used by the students as a discussion platform and/or for sharing data files and results. Additionally, teachers use Blackboard to give the groups instant feedback after each steering group meeting.

The final experimental results are presented in a formal laboratory report, in the form of a technical article with sections like introduction, material and methods, data, results, and conclusions. Technical writing experience is helpful for students as they will most probably be writing scientific articles in the future. The students also present their results via a poster session, which teaches the students to present their data in a clear but scientifically distinct way, and to orally explain the results to teachers and course-mates.

Innovation 2

A major aim of university training is to prepare students for their future role as experts in society, industry or research. During a master's education, it is thus important that the students are encouraged to practice entering the role of a professional in their field of training. However, in the learning situation, students are used to the teacher being the expert, which hinders them to act in this role. Furthermore, it is well known that student learning is related to the method of examination. We thus need to provide the students with a situation during the examination where they are indeed the experts. To this end, we have designed a part of the final examination of the course in Biomeasurement Technology for engineering students in Chemical Biology as an oral presentation for an external examiner with medical expert training. The students are expected to present a research plan on a protein studied by the visiting expert, but using course methodology, which is usually not familiar to a Medical Doctor. The aim is to encourage the students to confidently enter the expert role by putting them in a situation where they have to explain their expert knowledge in a way understandable by non-experts.

Student participation in innovations

During the course of this project, the students have been involved in several ways. These include continuous student evaluations of the courses (both through our own project-directed evaluations and through course evaluations directed from the student council), student interviews where feedback on the courses could freely be given and received, dialogue with senior students who had taken the courses as to the importance of the courses for their professional development, and through written course evaluations as part of the courses. Linköping University has a tradition of active student engagement, which actively contributed to facilitate student participation in the current development project.

Procedures (how)

To evaluate the effect in student learning, in particular when it comes to cognitive and meta-cognitive levels, we have used a variety of evaluations:

- Inquiry of cognitive learning according to Perry (1981). To evaluate improvement of deep knowledge and complex use-of-knowledge on synthesis level we have used a modified inquiry with 19 questions developed by Bergendahl & Tibell (2004).
- Motivation. We have evaluated motivation by asking for a 'top-3' out of thirteen tentatively motivation-increasing factors in a range of teaching situations.

- Degree of responsibility. We have asked students and teachers to rank their level of engagement on a six-degree scale in the categories: propose a problem, plan, do, evaluate, and propose further applications (Sutman et al., 1998).
- Open questions with free answer space
- Interviews and student discussions
- Formal exams where certain questions were designed to be possible to evaluate from a Bloom-perspective

In the first three evaluations, we have evaluated both before and after the course was given, in order to be able to judge whether learning was affected by the teaching. Interviews and free questions have almost always been administered after the course, as has the exam.

RESULTS

Innovation 1

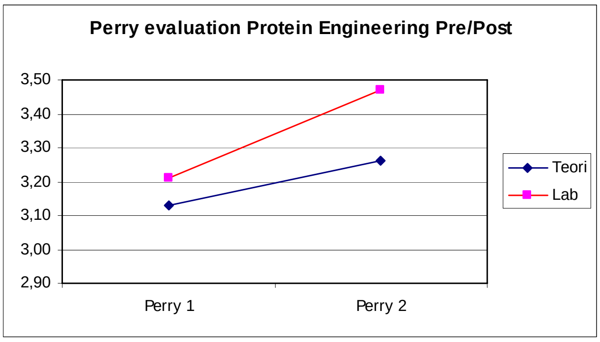
With larger student groups and the need to optimise resources, we need to find new ways to encourage the students to reflect efficiently on their own laboratory practice in order to deepen their learning, take increased responsibility and better advantage of lab time, and be better prepared for their tasks. Furthermore, there is a need to prepare the students for a future professional life, which often to a large extent will entail working with assignments in project groups. Our course has been designed with this in mind, encouraging the students to take responsibility for planning and execution of their laboratory work while simultaneously offering support for a reflective discussion with teachers.

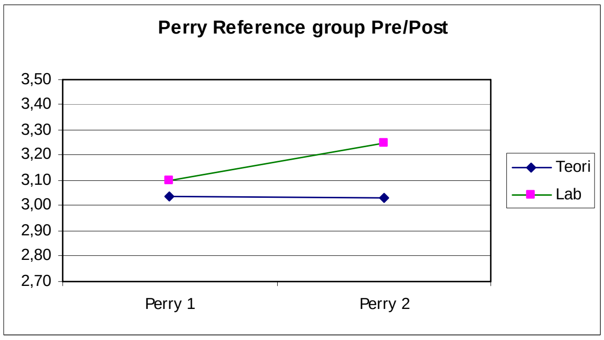
Critical to the course was the utilization of the 'Lab Reflection Room', and student responses to this concept have generally been very positive. Typical student responses include

- "woke interesting questions which led to that we wanted to investigate further properties in the protein"
- " we have trained to conduct a scientific discussion"
- "now one understands how it all goes together"
- " it gave a deeper understanding"
- " one could appreciate the laboratory parts better after having done all the preparations one self"
- "self-confidence during the laboratory task was increased"
- "it was much more fun to do laboratory work in this way"

The project structure, including regular progress reports at steering group meetings, provide a sense of reality as well as ample opportunities to practice oral presentation. In combination with instant feedback from the teachers via Blackboard, this facilitates collective learning processes within the groups. A significant progress both in terms of structure and content of the presentations, and also enhanced self confidence among the students giving the presentations, was often readily observable.

So, did learning levels increase? As judged by Perry evaluations, they did. As a comparison, we were fortunate to have a group of students who performed similar laboratory tasks in a different course, where we had even more students (~100). In this course, the lab tasks had to be performed in a directed manner due to space- and time constraints. We used these students as a control group to the students in the Protein Engineering course. In this comparison, we could see a significant increase in higher-level cognitive learning both as judged by the questions related to laboratory learning and the learning of theory for the students in the Protein Engineering course. For student in the control group, we could also see an increase for the lab-related questions, but not as large, and for theory, the level of learning was not increased.



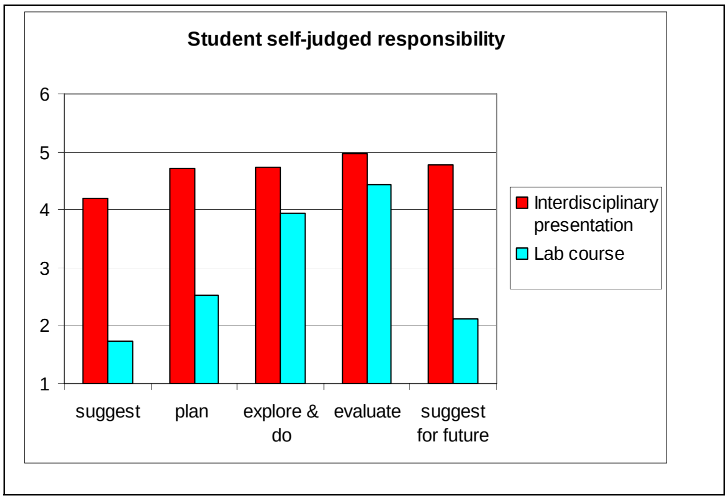


Invention 2

In this project, we want to encourage the students to take increased responsibility for their own learning. One strategy can be to put them into situations where increased responsibility is implicitly required. It is well known that students learn according to how they are examined. We want the students to train to become experts within their fields, but if the examining teacher is already an expert, students are hindered to practice this role.

The real-life situation where our students end up as professionals is often in the interdisciplinary cross-interface between chemistry and medicine. Medical doctors know little about biomolecules but need to use such knowledge to cure patients. On the other hand, our chemistry students know little about disease but a lot about (bio)molecules. By creating a situation where our chemistry students were asked to suggest a research project to a medical doctor, we put the students into a situation where they were indeed the experts. The invited medical doctor was asking the questions, while the 'ordinary' teachers were sitting at the back of the room, taking notes on the performance with respect to learning on different Bloom levels according to a developed scheme of evaluation.

In analyzing the evaluations of the course, we asked the students in free text to identify positive and negative factors regarding how they felt in the situation of this examination. Positive factors included: Increased preparation, Increased clarity, Reduced feeling of stress, Increased feeling of competence, Challenging, Professionally related and Unexpected questions. Negative factors were few, but included Examination criteria unknown, More difficult to prepare, Unexpected questions and Increased feeling of stress. It is interesting that most students experienced a reduced feeling of stress, although for some students, the stress factor did increase.



As judged by the quantitative evaluations, this moment of examination really turned out to challenge the students in a positive way. Indeed, this single event increased contextual - relativistic ratings with up to 12% (comparable to entire Protein Engineering lab course). Significantly increased motivation parameters included ”Perform something with a function”, ”Joy of discovery”, “Challenge” and “Real problem”. Importantly, the students took a lot of responsibility, more than we had expected. In particular, the possibility to themselves suggest the approach and future applications greatly appealed to the students.

Of particular value to us was the fact that the students felt that the examination was highly professionally relevant and of use for their future. Indeed, we have met students who participated in the examination several years ago who still vividly remember the project and recite how much they have benefited in their life as professionals from this experience.

Gender perspective

During the course of this grant we identified an overlooked factor that greatly affected our thinking about the results. It turned out that when analyzing our material with respect to gender, we found that the responses to our teaching strategies were substantially affected by the sex of the students. In particular, we identified the following most prominent critical factors:

Male/female teacher vs. male/female students: A higher responsibility level in the laboratory task was obtained if the lab teacher was of the same sex as the student. In particular, this was highly apparent in the higher levels of learning – interpreting results and putting them into perspective (metareflection).

Gender distribution in groups: We found that the learning outcome in the Protein Engineering course was greatly affected by whether groups were homogeneous (all male or all female), 50-50 or had a minority of men/women. The most unbalanced learning profiles were obtained when a minority was present. These results are coherent with similar results obtained at Chalmers

University of Technology, but with female or ethnic minorities. We find this very interesting and would like to investigate this further.
To take a task – self-chosen or ad-hoc? We found that in the group dynamics of the courses, women had a much larger tendency not to actively take their role but to passively let the situation decide for them what role they would take. Since we want to train men and women equally, we find this very disturbing and would like to find situations where this could be redeemed. To spend four hours in the lab in an active or passive way must make a great difference in achieving higher-level learning.

DISCUSSION

Since our funding was only available for two years, we decided to use this time to as far as possible reach results on a practical level that would be applicable to the students, and meanwhile collect as much pre- and post evaluations in these situations as possible and relevant. Looking at the project in this way, we have achieved excellent results. The Protein Engineering course has received top-ratings among courses given at the Faculty of Technology (4.8 out of 5.0), and was this spring considered as the 'jewel in the crown' by students in Chemical Biology. The Interdisciplinary Examination has attracted a lot of attention and continues to engage students not only at Linköping University but also at Karolinska Institutet. Indeed, we have started to apply selected parts of the pedagogic inventions also at the larger Protein Chemistry course (~100 students) with excellent student feedback. Thus, we have reached our goal to engage students in self-directed laboratory tasks with high responsibility also in larger student groups. In addition to the inventions described above, we have also applied increased reflection to the course in Gene technology, as well as in Lessons in Biomeasurement Technologies, with excellent feedback from the students. We are fortunate to have been able to set time aside to develop these strategies.

In a didactic perspective, we are making good progress to reach our goal to scientifically evaluate our results. We have sufficient data to describe the learning outcome both quantitatively and qualitatively, and our preliminary analysis show that indeed the learning outcome has increased in several ways – space is too short to describe all this in detail here. However, the material we have collected is huge, and although we have made a lot of progress we are still evaluating the data collected throughout the project. Indeed, we have realized that we may need to engage a graduate student and/or postdoc in didactics to fully profit from all our collected effort, and we are working on several strategies to receive such funding.

To spread our results, we have presented our work on the international CDIO meeting in Linköping in June 2006 (www.cdio.org). Our presentations were greatly appreciated, in particular since our work is focused in a novel field for the Conceive-Design-Implement-Operate model. We were therefore asked to present our results in the same meeting series at MIT in June this year. Unfortunately, none of us could go due to teaching obligations and family considerations. Our aim for the fall of 2007 is to put together at least two

manuscripts on our results. In doing so, we will gratefully acknowledge the Council for the Renewal of Higher Education for distributing the supporting grant.

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A warm thanks is extended to associate professors Rachel Fisher and Ewa Ehrenborg, Department of Medicine, Karolinska Institutet, who participated in the interdisciplinary examination.

Our sincere thanks also goes to Dr Thomas Magnusson, who took part as teacher of Organization Theory in the Protein Engineering project.

Financing for the project during 2005-2006 was obtained from Rådet för högre utbildning [*in English*: The Council for the Renewal of Higher Education.