Evaluation of teaching in environmental engineering

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Abstract This paper describes the effect of changing course content and teaching methodology for an introductory course in Environmental Processes. Student evaluations were used both to monitor the effect of the changes, as well as to change the course structure and the didactics. The result of the change was a better average score at the examination, and higher student satisfaction. The paper illustrates the usefulness of course evaluations in course development.

Keywords Environmental engineering; examinations; costs; course development; student evaluations; teaching

Introduction

The study system at the Technical University of Denmark (DTU) is based on a flexible modular system, where students select courses according to their own preferences and qualifications, only restricted by the regulations of the study programme they are attending. The 28 departments at DTU offer more than 700 undergraduate and graduate engineering courses annually, covering traditional study programmes in mechanical, electrical, chemical and civil engineering, and newer programmes in energy, informatics, applied physics and environmental engineering. All the traditional ways of instruction or combinations of these are employed, but the major form of instruction is lectures. The large degree of freedom in the study system has many advantages, but it also poses problems in relation to the continuity in the studies and to the varying background of the students following a given course. Most of the 700 DTU courses are small, equivalent to three weeks of work and five ECTS credit points (see e.g. Larsen, 1999 and DTU, 1999a). The number of students following each course varies from five students to 600, the high numbers for basic courses in mathematics and physics, the low numbers for highly specialised courses in areas with less student appeal.

In 1998 DTU decided on a new strategy that aims at changing its course structure from the many small courses to larger courses, and at the same time improving the transfer of the content of the courses to the students (DTU, 1998). As a consequence of this strategy, the Department of Environmental Science and Engineering (IMT) has adopted an active policy of revising the course structure on a triennial basis, matching the three-year teaching contracts between DTU and the department. The most important basis for revising the course structure is thoroughly going through the courses and adapting their technical content based on deep insight into the technical details and knowledge of the international standard within the different fields. However, more formal procedures are also introduced, as the demand for increasing productivity and quality is expected to increase in the future. Having students evaluating the courses, the course materials and the teachers’ performance is an important instrument when revising courses, and the evaluations can be assessed in combination with examination results and a statement of the resources spent in running the courses. Some recent experiences with course evaluations at the IMT are outlined in the following, using a basic course in Environmental Processes as an example.
Example course: Environmental Processes

This course is one of the key courses in the first years of environmental engineering studies at DTU. It is run every spring semester and the students typically follow it in their second or third year. The number of students following the course is 80–100 each year. The course gives the theoretical background for the processes studied in advanced courses such as Water Pollution, Water Supply, Wastewater Treatment and Soil and Groundwater Pollution. The course content is a classical basic course containing a mixture of selected elements of chemical reaction engineering, aquatic chemistry and geochemistry. Updated details of the course can be found on the DTU homepage (DTU, 1999b).

Owing to the introductory level of the course, it is based on a Danish textbook (Harremoës et al., 1994) and course notes. More detailed coverage of parts of the elements can be found in textbooks like Levenspiel (1962), Stumm and Morgan (1996) and Reynolds and Richards (1996). The course is taught in Danish, but the advanced courses following this course are all taught in English, typically with numbers of students ranging from 40 to 120.

In accordance with the department policy, there is a course coordinator who is responsible for coordinating the course content and the teachers contributing to the course, and for managing the logistics. Between three and five teachers who specialise in different fields undertake the major part of the teaching, assisted by instructors during the exercises. The reason for having several teachers involved in one course is to increase the professional level and inspire the students; however it requires strong coordination to ensure a homogeneous progress of the course.

Originally this course was developed to qualify civil engineering students for further study of wastewater treatment and water pollution. However, the student profile has changed during the past 15 years, and now most students study either environmental engineering or chemical engineering as their major field. This development has led to changes of the course content over the years.

Evaluation tools

In order to manage and to ensure continuous quality improvements of the great number and variety of courses at DTU, an evaluation system is required that allows both for subjective judgements (expert opinions) and more objective evaluation tools. Apart from thoroughly going through the courses and adapting their technical content based on insight and knowledge of the international standard within the different fields, three formalised measures of evaluating courses are discussed and partly used at IMT:

• student evaluations, where students comment on the courses, the course material and the teachers’ performance,
• examination results where teachers evaluate the students’ performance, and
• estimates of the resources spent in running the courses.

Student evaluations

Several types of student evaluations have been in use at IMT during the past decades. This made it possible to tailor questionnaires to individual courses and direct them towards identified problems where information on the students’ opinion was required. IMT decided a few years ago to make the results of the student evaluations publicly available, thus making it possible for students and student organisations to check and criticise the way evaluations are handled at the department.

During the past 2–3 years DTU has centralised the use of student evaluations, and it is no longer permitted to tailor questionnaires to specific needs. Approximately four weeks
before the end of a semester a standard questionnaire is distributed to all students on each course. The questionnaire is divided into three parts.

(a) Questions about course prerequisites, teaching methods, technical content, teaching materials and student attendance. Gives an impression of the students’ overall satisfaction with a course.

(b) An evaluation scheme to measure teacher performance, one for each teacher, including assistant teachers.

(c) Students’ improvement proposals (praise, criticism, suggestions).

Each question in part (a) and (b) includes 3–5 optional answers, that can be quantified on a scale from 1 to 5 for later enumeration and statistical treatment. The students have to select one of the possible answers. An example:

I found the teaching material to be:

- [ ] Bad
- [ ] Fair
- [ ] Acceptable
- [ ] Good
- [ ] Excellent

The DTU Study Office enumerates the completed parts (a) and (b), and returns the result and statistics to the teacher in charge of a course (the course coordinator). The result of evaluating part a) is then displayed and discussed with the students during one of the last lectures in the semester. Parts (b) and (c) are only used internally in each department to further develop and improve the course, while part a) also is used by the DTU study committees responsible for the different study programmes and for the requisition of courses from the departments.

The evaluation system has been criticised for being an administrative burden for the teachers and suffering from a lack of flexibility. A fixed standard questionnaire may be applicable in some courses and gain useful information, but not appropriate in another course. It often depends on the type of course and the form of instruction used. From our point of view, a standard questionnaire was not the best choice, as several different forms of instructions are combined in several courses at IMT, including the renewed course in Environmental Processes which is discussed below.

The way the departments at DTU handle and reflect upon the evaluations in practice is indeed individual. At IMT a summary of all three parts is carefully assessed by a Teaching Committee, which is an internal body responsible for the overall course coordination, the department’s teaching profile (which courses should the department offer?) and the allocation of teaching resources. The teaching committee assesses all courses offered by the department, including the involved teachers’ comments and suggestions for improvements, after the result of the examinations are known.

In case a course repeatedly achieves unsatisfactory evaluation scores, the teaching committee takes action. In close collaboration with the teachers involved an appropriate plan is made in order to solve the identified problem. Mostly, however, the teachers involved are fully aware of problems long before the teaching committee notices them and have already taken the necessary initial steps to solve the problem. It is considered of major importance that the course coordinators reflect on the student evaluations at the end of each semester and reacts on the conclusions when planning the course for the following semester.

Evaluating students’ performance

Student performance is measured by the Danish Grading Scale with scores from 0–13, where 6 and above means passed and 13 is given for an exceptional and independent student performance; however in some courses students either pass or fail without getting a more detailed evaluation. The Danish Scoring system is compared with the scoring system built into the ECTS system in Table 1. Further details of the ECTS system can be found in Larsen (2000).
Monitoring resource consumption

A system for monitoring teaching resources used in each course has been developed at the department during the past three years. The system has several purposes, but in this context the main purpose is that it measures the costs spent in running a course. The cost data generated by the system can easily be combined with the results from examinations and evaluation results, cf. above, thus providing information on productivity per invested cost. The system is built on a basic “teaching unit” which corresponds to the time spent by an “average teacher” when giving a normal lecture with only minimum preparation requirements. Several teaching units or only fractions of a teaching unit are given for different teaching elements (lectures, exercises, correction of written examinations, development of course material etc.) based on a fixed key, which is upgraded from time to time based on the experiences gathered.

The majority of teachers should preferably regard systems like this one as fair, particularly because they can be used for measuring individual teachers’ workload in addition to the resource consumption. Such issues can bring up severe disagreements at university departments where the working environment is usually relatively unbound, but where staff often spend more working hours than they are paid for when teaching, carrying out research or working with administrative matters. The system is considered a necessary tool for meeting future demands for improving the efficiency of teaching at IMT; however, it still needs improvements.

Structure and content of example course before change

The content of the course “Environmental Processes” has gradually changed during the years, however, the basic elements have always been:

- basic hydraulics of reactors and environmental systems
- kinetics of chemical and biological processes (0. and 1. Order, Monod)
• water–air equilibrium and mass transfer processes (dissolved gases)
• classical chemical reactions
  – chemical equilibrium
  – dissolution/precipitation
  – complexation
  – redox
• important buffer systems e.g. the carbonate and sulphide systems
• biofilm processes.

In recent years more emphasis has been put on heterogeneous processes such as sorption and cation exchange. The focus with respect to compounds has also shifted, to include xenobiotic organic compounds in addition to nutrients and “environmental” dissolved gases (oxygen, carbon dioxide).

Before significantly changing the course in 1997 the students had two lectures per week, 23.55 minutes each, and one afternoon with exercises (calculations). Instructors advised the students, but written solutions to the exercises were also handed out. The students were awarded 5 ECTS credit points if they passed the examination. The examination was a traditional 4 hour written examination solving problems, with access to books and other materials. The teachers and an external examiner evaluated the solutions from the students.

**Structure and content of example course after change**

The motivation for changing the course in 1997 was many-sided: the students considered the workload of this course to be significantly higher than for average courses at DTU and the percentage of students passing the course was also relatively low. Furthermore, after establishing a study programme in environmental engineering the students tend to follow this course earlier than before. Part of the motivation was therefore to adapt the course to the changing target group (younger students with a different background) and to revise the content in view of the many subsequent courses on advanced topics that have been developed recently.

After carefully inspecting the content of the old course and the interactions with subsequent advanced courses the wish from the department was to upgrade the course. This was done partly by including specific topics that were part of several advanced courses but could be taught on a common general basis, and partly by excluding other specific topics that were used only in few of the following courses. The content of the course was slightly changed:

• biofilm theories were left out
• separation processes were included
• basic hydraulics of pumps was included
• transport in pipes and porous media was introduced
• air–water equilibrium for xenobiotic organic compounds was included

After these changes the course content was considered to give a good theoretical basis for most of the advanced courses at IMT. The number of credit points was increased from 5 to 10, to give a better balance between the workload and the credit points granted. This also allowed an extra afternoon per week (the original afternoon exercise was unchanged), where we introduced various new elements in the teaching. Based on the evaluation, several changes were made to the course:

• an excursion to a Test Centre for pipes and pumps
• two practical exercises:
  – an experimental introduction: the carbonate system
  – demonstration and hands-on: pumps for environmental technology
The example course was revised between 1997 and 1998 and student evaluations were made both years. Part of the data from the completed questionnaires has been grouped in four main categories as shown in Figure 1. Interestingly, the evaluations have worsened with respect to the two categories “attendance and workload” and “overall teacher assessment”, whereas they have increased with respect to the categories “teaching materials” and “form and content”. The average student satisfaction has, however, increased after the change. The revised course was offered for the first time in 1998 and further improvement of the student evaluations is expected in the future. It should be noted that the students made their evaluation before the examinations.

The result from the examinations in 1997 (old course version) and 1998 (new course version) are shown in Figure 2. For comparison, the relation between the Danish and the ECTS grading scales is shown in Table 1. The grades improved considerably from an average 6.4 in 1997 to an average 8.8 in 1998 and the number of students passing the examination increased from 60% to 90%, see Table 2.

Although the number of students following the course went down from 78 in 1997 to 66 in 1998 the resources (teaching hours) invested in running the course increased from 516 hours in 1997 to 728 in 1998. This is primarily due to the new teaching elements introduced in 1998, focusing on practical excursions and exercises. The resources invested per student following the course increased from 6.6 hours per student in 1997 to 11.0 in 1998 as a direct consequence of the increasing teaching effort spent on a decreasing number of enrolled students. However, the resources spent per student passing the course only increased from 11.0 in 1997 to 12.1 in 1998, due to the increasing number of students passing the examination.

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**Figure 1** Main results of the student evaluations for the years 1997 and 1998. The course content and form were revised between these two years.
When focusing on the number of ECTS credits granted it appears that the teaching efficiency has actually increased (0.82 ECTS credits per teaching hour in 1998 as compared to 0.46 in 1997). This is, of course, due to the doubling of ECTS credits granted for the course and the increased number of students passing the course. The implications are clear: the students are allowed to spend twice as much time to achieve learning goals that have only increased moderately, resulting in better scores at the examination.

**Discussion and conclusion**

Although a high student satisfaction and high scores in the examination are considered an advantage, this is not the major goal of course development at IMT. The students' under-

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**Figure 2** Distribution of marks in the example course in Environmental Processes in 1997 (78 students) and 1998 (66 students). The course content and form was revised between these two years.

**Table 2** Main statistics of the student evaluations, examination results and resource consumption for the years 1997 and 1998

<table>
<thead>
<tr>
<th></th>
<th>1997</th>
<th>1998</th>
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<tbody>
<tr>
<td>Average student satisfaction (scale 1–5)</td>
<td>3.5</td>
<td>3.6</td>
</tr>
<tr>
<td>Average marks obtained</td>
<td>6.42</td>
<td>8.80</td>
</tr>
<tr>
<td>Number of students enrolled</td>
<td>78</td>
<td>66</td>
</tr>
<tr>
<td>Number of students passed</td>
<td>47</td>
<td>60</td>
</tr>
<tr>
<td>Percentage of students passed</td>
<td>60</td>
<td>90</td>
</tr>
<tr>
<td>Resources invested (teaching hours)</td>
<td>516</td>
<td>728</td>
</tr>
<tr>
<td>ECTS credits granted per student passing</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Resources per student enrolled (hours)</td>
<td>6.62</td>
<td>11.03</td>
</tr>
<tr>
<td>Resources per student passed (hours)</td>
<td>10.98</td>
<td>12.13</td>
</tr>
<tr>
<td>Resources per ECTS credit granted (hours)</td>
<td>2.20</td>
<td>1.21</td>
</tr>
<tr>
<td>ECTS credits granted per hour invested</td>
<td>0.46</td>
<td>0.82</td>
</tr>
</tbody>
</table>
standing of environmental processes and their ability to handle the knowledge gained during the course are considered more important. We strongly believe that the new course structure provides a better basis for the students to attain these qualities but it cannot be taken for granted that the examination results as shown in Figure 2 reflect this. The examination form was not changed and is still primarily based on testing the students’ ability to calculate simple examples. To measure more precisely whether there is an improvement of the students’ understanding it would be necessary to restructure the examination. Such tests have recently been carried out for 10 DTU courses including one IMT course on “Air Pollution and Environmental Effects” (Clemmensen and May, 1998).

Nowadays, the number of students passing their examinations directly influences the funding of Danish universities. This means that it is economically attractive for a university to let a reasonable number of students pass the examinations. When looking at the ECTS credits granted per teaching hour it becomes clear that the change of the example course between 1997 and 1998 is economically advantageous for DTU. However, there should be a balance between the ECTS credits granted, the teaching resources invested and the number of students passing the examination. Although part of the motivation for changing the course was too poor a student performance at the examination in 1997 and previous years, 90% passing with an average score of 8.8 is considered too good. Thus, changes to the course format are foreseen in the future.

As can be seen from the preceding information, the changes made to the example course in Environmental Processes impacted on student satisfaction and the examination results for the course. This illustrates the success of the change, but it is emphasised that further details need to be considered to assess in a complete manner the effects of changing the course content and structure.

Of further interest would be monitoring the course for more years and evaluating how the changes affect the advanced courses that take this course as a starting point. This is difficult owing to differences in the student population in the basic course and the advanced courses. The advanced courses have a side-stream of foreign students entering. These students have a mixed background in aquatic chemistry and chemical reaction engineering. Some of them get a quick update in these topics in a 24 h course given in English. As a result of these inhomogeneities, it has not until now been possible to monitor the effect on the advanced courses of the changes made to the example course dealt with in this paper.

The conclusion of this example of course development based on student evaluations is that it is possible to some extent to improve transfer of teaching elements to the students. The tools are more practical elements in the course and a variety of teaching elements. However, the example also shows that course evaluations are difficult to perform and assess afterwards. To evaluate teaching in environmental engineering in an objective and transparent manner requires an effort comparable to that usually employed in environmental research projects, and this may be difficult to ensure generally. However, formal procedures for evaluation of courses are necessary to maintain focus on continuously improving the quality and productivity of university teaching.

**Literature**


http://www.adm.dtu.dk/studier/index e.htm.