Environmental engineering education at the Swiss Federal Institute of Technology in Zürich

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Abstract  A revised ten-semester curriculum in environmental engineering was introduced at the Swiss Federal Institute of Technology in 1998 which is based on 10 years of experience with a previous less focused curriculum. The scope of the new curriculum is rather broad and includes sanitary engineering, water resources management, soil pollution control and resource and waste management. Air pollution is not fully developed yet. Based on broad basic studies (first four semesters) the professional studies (semesters 5 to 9) require the students to choose two out of four possible areas of specialization. These studies are followed in credit groups which combine advanced courses and extensive project work designed to reach scientific depth in an exemplary fashion. There is an exchange of teaching units between Environmental Engineering and Environmental Natural Sciences but the two curricula are quite different and lead to significantly different professional profiles.

Keywords  environmental engineering degree; sanitary engineering; water resources engineering; soil pollution control; resource and waste management; Swiss Federal Institute of Technology; curriculum

Introduction
From 1988 the Swiss Federal Institute of Technology (ETH) in Zürich offered a nine-semester curriculum (including diploma semester) which related to environmental engineering. In 1998 a new redesigned curriculum was introduced together with an MS degree in environmental engineering (dipl. Umwelting. ETH). This paper relates to this new curriculum which was developed based on ten years of experience with the previous, less focused education.

In the context of a major reorganization of ETH the faculties responsible for three curricula were united in the Department of Civil, Environmental and Geomatic Engineering. In this context four previously existing curricula (civil, environmental, rural and surveying) were restructured into three new ones (civil, environmental, and geomatic engineering). At the same time a concept was defined which allows for more flexibility in the choice of the degree discipline:
• Semesters 1 and 2 are close to identical for all three disciplines, making it possible to defer the choice of the final discipline until even after the first year of study.
• Semesters 3 and 4 of the studies in environmental engineering provide the base and the whole breadth of the discipline, making it possible to choose the lines of specialization only after the second year.
• In the professional studies (fifth to ninth semesters) case studies, projects and professional practical training make up 40% of the curriculum. This allows for interdisciplinary collaboration across the three (and possibly more) disciplines.

Professional profile
In the Anglo-Saxon world environmental engineering has a rather long tradition with its roots in sanitary and civil engineering whereas continental Europe is still struggling to find a well defined niche for this “new” engineering discipline. Several varieties of “environmental engineers” exist, some relating more to technology (environmental process engineering) and others dealing more with the management of the interface of artificial and...
natural systems. Therefore many areas of overlap with established, traditional disciplines are inherent and may cause "academic" problems (seemingly touching on disciplinary property rights) in building up a new discipline and relevant curricula. In Switzerland it took nearly 10 years until a degree in Environmental Engineering could be awarded.

Our environmental engineers are meant to develop concepts and to design, realize, optimize and operate installations for the management of vital resources such as water, soil, air, biomass, minerals and metals, the disposal of waste solids, air and water, and the rehabilitation of contaminated soil and waters. Research and education are committed to the concept of sustainable development.

In their education and professional work environmental engineers combine knowledge, concepts and procedures from ecology, physics, chemistry, biology, microbiology and soil sciences with the more engineering-oriented techniques from process engineering, geomatics and civil engineering.

Environmental engineers have a good command of a great number of demanding analytical and experimental methods in the laboratory as well as in the field. Complex mathematical models are required (and understood) to develop new methods, procedures and concepts. The transfer of these concepts into practical application requires a convincing public appearance and thus good knowledge of social, economic and political processes and a great deal of communication skills.

The professional activities of our environmental engineers include the following:

• consulting engineers for public and private institutions (communes, state and federal level) concerning systems for urban water management, handling of resources and solid waste, protection and rehabilitation of waters and soil;

• process engineers specialized in the design of pilot experiments and prototype facilities and processes for water and wastewater treatment, handling of solid waste, in situ soil and groundwater remediation, off-site treatment of contaminated soil;

• engineers specialized in the development and application of pilot and field experiments, models, tools and software for the simulation of complex systems (groundwater, receiving water, urban drainage, treatment processes, etc.);

• engineers responsible for the management and the quality assurance of raw materials, products and waste streams in larger industrial enterprises;

• executive officers and managers in the administration and operation of water supply, urban drainage, wastewater treatment, solid waste collection and handling systems of larger communes;

• experts in risk engineering and risk analysis under special consideration and monitoring of the threats to the environment (often in collaboration with insurance companies and banks);

• research and marketing.

Scope of environmental engineering education at ETH

At present environmental engineering at ETH covers five different fields, four of which are fully developed.

• Sanitary engineering grew out of the civil engineering curriculum and concentrates on urban water management. It includes water supply, urban drainage and wastewater treatment. Courses traditionally taught for civil engineers were significantly expanded for the new curriculum in environmental engineering.

• Water resources management has been introduced only recently. It combines hydro-mechanics, hydrology, water resources and groundwater management. This part of the curriculum has been introduced with the new curriculum and is presently being developed. The first diploma students will leave ETH by the year 2003.
• Soil pollution control grew out of a previous curriculum for “rural engineering” where the main topics were soil conservation and land use planning. Today protection and rehabilitation of polluted soil are in focus.

• Resource and waste management (including materials flux analysis) was developed some years ago specifically for the previous environmental engineering curriculum.

• Air pollution control is not fully developed and is only introduced in its basics. Teaching relies on teaching assignments to external and internal experts from other departments.

The first four fields offer full Environmental Engineering credit groups. Each student must choose two out of these four and may follow a third one in the context of electives. In these credit groups it is our goal to reach sufficient scientific depth such that the students gain the analytical, experimental and modeling expertise necessary for creative concept and design work.

Basic courses in information technology (IT), spatial information systems (GIS), decision support systems (DSS) and environmental planning are compulsory for all environmental engineers. These courses are designed to link environmental engineering to its sister discipline, geomatics, which provides important background in order to deal with large scale spatially distributed infrastructures and information.

In the second half of the curriculum a series of elective credit packages (courses which preferably are taken as a package in order to reach sufficient depth) are offered: noise, vibration (to be developed), risk analysis, process control, energy systems, water pollution control, business administration, etc.

Goal of education
According to the guiding principles of ETH Zurich, the education at our school aims to impart knowledge and know-how to the students, fostering their understanding of ethical and cultural values, and helping them to grow into responsible, independent members of society, who are able to orient themselves in a complex and rapidly changing world.

In particular we try to live up to the following principles:
• promotion of interlinked and system-oriented thinking and acting with explicit consideration of social implications of our work as engineers;
• development of creative, independent thinking as opposed to traditional concepts of receptive learning by communication and absorption of facts;
• support of inter- and transdisciplinary work and teamwork, complementary to individual learning capabilities;
• creation of modular and flexible curricula in order to be able to adapt to changing boundary conditions set by technological and scientific advancement and the development of this new profession;
• problem-oriented case studies, requiring teamwork, communication and project management skills, rather than striving for completeness in conveying detailed procedural and fact-oriented knowledge.

The education must be broad and deep at the same time, which creates a conflict of interest. Broad knowledge and perspectives are the basis for collaboration across the disciplines, depth is required for successful scientific work and the development of the profession.

Environmental engineering core faculty
The environmental engineering curriculum was built up only recently and had to rely heavily on existing faculty. Today the environmental engineering core faculty is distributed over three organizational units.
• Institute for Hydromechanics and Water Resources Management (on campus):
  Prof. Wolfgang Kinzelbach (hydromechanics, water resources and groundwater management);
  Prof. Paolo Burlando (hydrology, water resources management);
  Prof. Willi Gujer (sanitary engineering), with research facilities located at EAWAG (Swiss Federal Institute for Environmental Science and Technology, Dübendorf) 10 km from the campus;
  Prof. Peter Baccini (materials flux analysis, resource and solid waste management), with research facilities located at EAWAG;
  Prof. Rainer Schulin (soil pollution control), with research facilities located at the Institute for Terrestrial Ecology of ETH, located 10 km from the campus.

The positions of Assistant Professors are scarce at ETH, therefore all three institutions must rely heavily on their senior scientists in their teaching activities.

Laboratory space in the downtown location of ETH is scarce; this resulted in the fact that some institutes are located in the surroundings of Zürich. In environmental engineering the separation of research facilities from the teaching environment has grown historically and is today a severe handicap in building up a “home base” for this newly emerging discipline. Students lack the direct contact with motivated young scientists (Ph.D. students) in a lively scientific environment.

Strengthening and consolidating the existing activities with additional faculty on an Assistant Professor level was recently favored over further dilution by expanding into air pollution. Three Assistant Professor positions will become available in the next few years in order to complement the existing activities. This is in disagreement with a recent evaluation of the faculty by invited peers: they recommended expansion into air pollution.

Curriculum

The Swiss university system does not allow for any numerus clausus (except in medicine). We have to accept all students sufficiently qualified to perform university studies (Matura certificate).

One of the politically defined goals of ETH is to maintain short curricula and to achieve short student residence times. This leads to rather strict predefined curricula which are followed by most of the students. In addition the exam structure of ETH is rather strict too.

• The first comprehensive examination which covers most courses of the first two semesters is typically taken after the first year. Passing this is a prerequisite to pass any other examination. Two trials are possible and approximately 75% of the beginners finally pass this examination (approximately 60% in the first trial).
• The second comprehensive examination, which covers semesters three and four, is taken after the second year. Passing this examination is a prerequisite to gain credit in further semesters. Approximately 85% of students passing the first examination finally pass the second.
• In the higher semesters credit must be gained by either examinations or other graded contributions, reports, etc., as specified by the responsible lecturer of each course.
• In final oral examinations the students demonstrate broad comprehension of the field and the electives chosen. Most students pass these final examinations which may be repeated once.

In environmental engineering about 50% of the students finish their studies within the minimum time possible (today eight semesters plus diploma semester). Most of the other 50% interrupt their studies for one year (typically after six semesters) in order to gain some practical professional experience (and to travel) and finish their studies after ten semesters.
plus diploma semester. With the introduction of the new curriculum we introduced a required professional practical training of four months. We expect that this will lead to a negligible extension of the average duration of the studies because it will now become possible to interrupt for only one semester (nine months including semester breaks).

The structure of the curriculum is outlined in Figure 1. It is based on 26 contact hours per week. In the first four semesters (basic studies) this means about 18–20 lectures of teaching and 6–8 lectures of exercise classes, where teaching assistants or tutors are available. Computer-assisted learning is increasingly practiced in the lower semesters.

**Basic studies: fixed curriculum**

The first three semesters cover a multidisciplinary basic education in mathematics as well as natural, social and engineering sciences. In the fourth semester the full scope of environmental engineering is covered in introductory lectures; all five fields are introduced with a basic course, excursions and some field work. This in order to provide the students with sufficient background to choose their majors (credit groups) in the following professional studies.

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**Figure 1** Outline of the curriculum of Environmental Engineering at ETH in Zurich. CH = Contact hours
It is surprising, but possibly typical for many continental European technical universities, that students must choose their discipline rather early. At ETH it was impossible to design even a first common year for the three sister disciplines which actually have a common faculty (civil, environmental, and geomatic engineering). Table 1 indicates the major differences between the three curricula in the first year. It is however possible to keep at least two options open until the end of the first year if additional courses are followed.

### Table 1 Major differences between the three sister disciplines in the first year

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Major course</th>
<th>Minor courses</th>
</tr>
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<tbody>
<tr>
<td>Environmental Engineering</td>
<td>Chemistry I and II</td>
<td>Ecology</td>
</tr>
<tr>
<td>Geomatic Engineering</td>
<td>Geodetic Metrology I and II</td>
<td>Mechanics I</td>
</tr>
<tr>
<td>Civil Engineering (Construction)</td>
<td>Mechanics I and II</td>
<td>Geodetic Metrology I</td>
</tr>
</tbody>
</table>

### Table 2 Composition of the required credit units (CU) in the professional studies (5th to 9th semester) of Environmental Engineering at ETH

<table>
<thead>
<tr>
<th>Component</th>
<th>Credit Units (CU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Environmental Engineering Credit Groups</td>
<td>40</td>
</tr>
<tr>
<td>2 Environmental Engineering Projects</td>
<td>30</td>
</tr>
<tr>
<td>Environmental Engineering Laboratory (I and II)</td>
<td>14</td>
</tr>
<tr>
<td>Geomatics I and II</td>
<td>4</td>
</tr>
<tr>
<td>Free electives</td>
<td>24</td>
</tr>
<tr>
<td>Electives in Humanities</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>120</td>
</tr>
</tbody>
</table>

### Professional studies: credit system

**Credit System:** 120 credit units (CU), equivalent to four semesters of full-time study, must be earned after the fourth semester, according to the composition indicated in Table 2.

**Environmental Engineering Credit Groups:** Each student must choose two out of four available environmental engineering credit groups (see earlier). The basic courses offered in the fourth semester are an important basis for their decision. Figure 2 indicates the content of the credit group in sanitary engineering as a typical example.

**Environmental Engineering Laboratory:** We are presently building up the environmental engineering laboratory (profiting from North American experience, AEEP 1988). We will teach a first laboratory course in the fifth semester, concentrating on chemical analytical methods oriented towards problems from the entire field of environmental engineering. A second laboratory course in the sixth semester will relate to the two credit groups chosen by
the students. It will concentrate on design of experiments, unit processes and unit operations and writing of reports.

**Professional Practical Training:** During the seventh semester a professional practical training of 4 month duration is compulsory. We expect that the students will gain insight into the constraints of professional surroundings, will gain motivation for their final year of studies and will improve their ability to get involved in scientific experimental and field work in view of their final diploma thesis. Public and private institutions, engineering companies, administration, plant operation, etc. are expected to employ the students for a nominal salary for practical training. We will maintain quality control and will assist the students to find reasonable training opportunities in Switzerland as well as in foreign countries. Foreign language experience will be specifically supported.

One of the incentives for introducing this practical training was that environmental engineering as a discipline is not well known in continental Europe. Traineeships are one possibility to make contact with potential employers and to make them aware of potential future human resources.

**Project oriented studies:** In the eighth and ninth semesters the students choose a project which relates to either of the two chosen credit groups. In each semester we expect the students to spend 50% of their time in project work. Most projects are designed as group effort with the goal of fostering team work and project management capabilities. Written and oral communication of results is an important aspect of these projects. We anticipate offering projects where multidisciplinary collaboration (civil–environmental–geomatic) will be necessary. In some teams we integrate students from environmental sciences, further fostering interdisciplinary collaboration.

An important aspect of successful project work is that we allow for sufficient free time without any competing lectures for direct communication within the project groups and in order to place workshops for the introduction of new methods and computer programs, or field measuring campaigns etc. Typically one and one half days per week are reserved without any other activity than project work.

Typical project topics in sanitary engineering are:

- Evaluation of existing data, fixing discharge requirements and redesign and optimization of a wastewater treatment plant. Field work would be necessary in order to determine a choice of tracer information, characterization of aeration equipment (off-gas analysis), sedimentation properties of activated sludge, calibration of some measuring systems, evaluation of receiving water quality, etc.

- Development of an urban drainage concept in view of holistic concepts of receiving water requirements, drainage comfort and urban hygiene. Increasingly we deal with modern information technology, the development of data management and decision support systems, programming of methods, etc.

Introduction of these rather large projects into our teaching concept goes back to 1975, when an experiment with project-oriented studies was conducted at ETH. It is a very successful scheme where in the second half of the semester we typically have to make sure that the students still follow the rest of the “theoretical” courses.

**Electives:** In the professional studies we allow for 24 CU, i.e. 24 contact hours, (20%) of totally free electives from either the ETH or the University of Zurich. However we do make suggestions for reasonable combinations of electives (credit packages) which will be placed with priority in the timetable. In principle it would be possible to use 20 CU of the electives in order to follow a third environmental engineering credit group, however we do
not encourage this possibility. In addition ETH requires all students to follow at least 2 CU of humanities in each semester which result in an additional 8 CU of electives.

Diploma Thesis: Diploma work lasts exactly 4 months. For didactic purposes we define a deadline for the submission of the thesis at the beginning of the diploma work. Frequently diploma work consists in collaborating with a Ph.D. student, it may include some laboratory or field work and combines problem analysis, design of experiments, analysis and integration of results, developing models and working with modern system analytical tools (simulation, model identification, sensitivity, etc.). Again communication of results is important – in addition to the thesis and a possible seminar the students must supply a poster which will be used for an annual exhibition of diploma thesis projects. Grading this poster contributes to the grade of the diploma work.

Problems
Establishing a new “discipline” is always connected to substantial problems. Scarce resources, academic tradition, occupied gardens, etc., are some of them. More important for the students are the following.

Developing a market: In Switzerland the market of potential employers of environmental engineers consists of many small to very small engineering enterprises which can sometimes afford to keep only one environmental engineer in their company. The resulting professional isolation is not a good environment in which to establish a new discipline. At present it appears that some engineering companies outsource environmental engineering expertise by collaborating with more specialized enterprises.

Lack of professional organization: The future professional development of academics depends to a large extent on the availability of a professional organization which maintains the bridge between research and application and provides a framework for continued education and information exchange. Today professional associations within Switzerland are organized along the traditional lines which are mirrored in the international associations: water supply, sanitary engineering, solid waste, etc. No association covers environmental engineering as a whole. Under such circumstances it is difficult to establish a new discipline.

Lack of acceptance: It is surprising how long it takes until a new discipline can establish itself in the market. It appears that engineers are hired primarily based on tradition (because civil engineers have always worked on these topics) rather than based on education and background. We hope that the compulsory practical training will help to introduce this new profession and give it a broader industrial base. Further with an increased number of environmental engineering graduates entering responsible positions we expect that they will prefer to hire their peers.

Lack of doctoral students: Environmental Engineering is in my opinion a discipline where doctoral studies should be followed by a very significant fraction of the students. Whereas 27% of environmental natural scientists remain in a university environment (Frischknecht 2000) less than 10% of environmental engineers prefer doctoral studies over leaving the university and starting to solve “real problems” (which of course was our major goal).

Collaboration with environmental natural sciences
Besides environmental engineering ETH maintains a separate curriculum in environmental natural sciences (Frischknecht 2000). Whereas the engineering faculty is associated with
civil and geomatic engineering, environmental natural sciences consist of a separate department and faculty. However there are ties between the two curricula: common basic natural science courses and common advanced courses as well as an exchange in the frame of electives lead to many contacts of students and faculty. In addition, research of course supports collaboration.

Graduates
From questioning our environmental engineering graduates of the last five years in the context of the evaluation of teaching at ETH we know that:
• less than 3% are unemployed;
• about 80% work in private companies, predominantly in consulting engineering (60%);
• for 80% the present employment relates directly to their education;
• their education was up to date and allows them to solve professional problems, although creativity was not sufficiently enhanced;
• evaluation of the previous (not the revised) curriculum is positive, deficiencies being identified in areas such as languages, project management, business administration, communication and humanities;
• there is a feeling that the number of contact hours with traditional teaching should be reduced, whereas seminars, laboratory, case studies, project work, acquisition of information etc. should be extended;
• sufficient team work abilities have been acquired.

Conclusion
Environmental engineering at ETH consists of a full five-year curriculum and not only of a graduate programme as observed in many American universities. This allows for a rather broad education. Being a young discipline some problems with acceptance remain but the survey of our graduates indicated that within the first years after graduation most of our students find a satisfactory professional position.

In our revised curriculum we have given more weight to some of the deficiencies identified from questioning our graduates: contact hours have been reduced and more emphasis has been put on laboratory, field and project work as well as seminars. Whereas we can include communication as an important aspect into our teaching, we will try to support the development of skills in management and humanities in the frame of electives.

References