Report

# Making Informatics Work for Everyone
# Teaching Computer Competences for the Natural Sciences at ETH

**Author(s):**
Hinterberger, Hans

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Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Department of Computer Science
Information Technology and Education

# *Making Informatics Work for Everyone*

## Teaching Computer Competences for the Natural Sciences at ETH

Hans Hinterberger

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## ABSTRACT

This report has originally been presented to the Rector of ETH Zurich in March, 2008, as a white paper to discuss issues related to teaching basic competences required for the professional use of computers in the natural sciences at ETH Zurich. It describes how the challenges this raises have uncovered the need for novel approaches to realistically teach the use of computers. The report recounts how, with the support of funds from the Rector, it has been possible to address these problems and at the same time create novel and motivating teaching materials that are also useful in other educational environments. This report has been motivated by four concerns, raised by the teaching issues it discusses: awareness, continuity, synergy, and outreach.

**Keywords**: Education, didactics, pedagogy, computer competence, computer supported learning, problem based learning, tutorial learning, blended learning.

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## EXECUTIVE SUMMARY

In the 1990s, national research councils and other professional associations started to argue that teaching must adapt to a new social context and that the new challenge was how to more efficiently train professionals in *analytical*, *quantitative*, and *computing* skills required for effective problem solving. This request is still repeated today but it has become more specific and refers explicitly to competences in using the computer, the heart of information and communication technologies.

Computer competences build on informatics, a special field fundamentally comparable to those of mathematics and statistics; practically, however, capabilities in informatics are more *universally enabling*. All three have in common that they must typically be taught to large numbers of students at an early stage of their tertiary education, i.e. at a time when they cannot yet relate these topics to any future professional activities. This makes it difficult to motivate the freshmen to take these important courses seriously. Teaching them has therefore always required special efforts. Repeated calls by educational decision and policy makers to reform the teaching of mathematics, statistics and computer science indicate that this challenge has reached a critical mass.

### New pedagogy

This report discusses a new pedagogical approach and new contents for introductory informatics implemented at ETH in response to these new requirements. The new approach incorporates problem based instruction and tutorial learning into teaching materials that help more than 500 natural science and civil engineering students each semester to acquire application oriented computer competences. Starting in 2000, these tutorials were computerized and embedded in *blended learning* environments—a combined use of hardware software and brain ware—for which suitable didactical models and effective teaching procedures had to be found. The resulting research and development work is documented in the dissertation of Lukas Fässler [6].

ETH invested more than CHF 800'000 in the development and deployment of computer based tutors to teach computer competences. The result of this investment are 23 *E.Tutorials*®, productively used in 6 introductory informatics courses at ETH, providing problem-based, interactive learning environments for well over 1000 students each year.

### Outreach

These materials are also used at selected Swiss Universities of Applied Science and increasingly also at high schools and in industry where the trademark 'ETH' is of particular importance.

With the support of the North-South Center of ETH we are currently translating 6 *E.Tutorials*® into English so that they can be made available in developing countries (an initial request from Zambia triggered this effort). There are good reasons for these activities because people behind a number of international endeavors that address the problem called 'digital divide' started to realize that organizing a laptop for each child is not enough. Ultimately, the digital divide separates people based on their *ability to use* computers effectively.

We argue that computer based tutors can be an effective and efficient means to overcome the gap created by a lack in computer competence because they provide a format that makes learning materials highly suitable for distance learning and ideal for continued education.

### Future developments

This report wants to raise awareness to issues of *pedagogical practice* and show that ideas that depart from traditional patterns can be implemented successfully. It is also intended to provide background information to motivate the *continuation* of the new practice to teach computer competences at ETH Zurich, promote new ways in educational research and investigate marketing strategies for learning materials developed at ETH.

The pedagogical approach described in this report has the potential to positively affect many stakeholders; but it is expensive to implement and thus justifies building *synergies* that become possible when specialists in education, in informatics, in international relations, as well as potential investors cooperate. We also argue that with the funds that have been and still will be invested in e-learning projects, ETH continually creates a supply of teaching materials that could become an important part of its *outreach* strategy.

To provide a common platform for these activities it is strongly suggested that ETH establishes a multidisciplinary *Center for Computer Based Tutoring* [8], possibly under the auspices of the 'life science Zurich learning center'.

## 1. COMPUTER SCIENCE IS (MAINLY) FOR ENGINEERS

When universities were forced to consider the impact of computers on their curricula forty years ago, all that was expected from the schools' graduates was that they know how to program a computer. It therefore became the responsibility of *computer scientists* to teach these skills to all students, those in engineering as well as those in the natural sciences. It is important to realize that computer scientists are specialists in the branch of knowledge that deals with the construction, operation, programming, and applications of computers (Oxford English Dictionary); they are clearly members of an engineering discipline. Nevertheless, as long as the reasonable mastery of a relatively compact programming language is the only teaching goal, there is not much pressure to distinguishing between engineering and non-engineering students.

Today, society expects from the same graduates that they are competent to use computers as part of complex information and communication technologies. Much has been written to argue why this is so but little has been done to actually achieve it. This paper recounts how informatics at ETH has evolved to meet this expectation. The essence of these efforts can be summarized in one sentence: accept the fact that today's object of interest is no longer just the computer, it is *digitized information*, the representation, the processing, and the communication of this information in natural and artificial systems. Consequently, computer science must now be taught in the spirit of *informatics*, as defined for example in the International Encyclopedia of Information and Library Science and this implies the departure from a myopic view which reduces informatics to programming of computers.

Our discussions are restricted to teaching fundamentals of informatics to natural science students and civil engineering students. We will not talk about teaching students enrolled in mechanical or electrical engineering programs or in computer science. Nevertheless, even though there are strong arguments in favor of concentrating on traditional computer science topics in these degree programs, there is no question that these students could also profit from the teaching models that we have developed for the natural sciences.

To support my arguments I quote the first paragraph from the synopsis of the US National Science Foundation's $ 5 Mio. program 'CISE Pathways to Revitalized Undergraduate Computing Education' (NSF 08-516) for which applications are solicited in 2008: "Computing has permeated and transformed almost all aspects of our everyday lives. As computing becomes more important in all sectors of society, so does the preparation of a globally competitive U.S. workforce with the ability to generate and apply new knowledge to solve increasingly complex problems and understand human behavior. Unfortunately, despite the deep and pervasive impact of computing and the creative efforts of individuals in a small number of institutions, undergraduate computing education today often looks much as it did several decades ago."

## 2. REFORM PROCESSES TO TEACH FUNDAMENTALS OF COMPUTING

The availability of digitized information reached a critical mass during the early eighties when PCs, closely followed by the growing availability of the internet, swept across most of the northern hemisphere. The world's complexity all of a sudden appeared on everybody's desktop. The economically leading countries realized that this jeopardized their exclusive access to information and, as a consequence, correctly concluded that just having information is no longer a competitive advantage, but knowing what to do with it is.

**New pedagogy**

Many influential professional associations (e.g. in the United States the National Council of Teachers of Mathematics as well as the National Research Council), started to argue that teaching is taking place in a new social context and that the new challenge was how to more efficiently train professionals in *analytical*, *quantitative*, and *computing* skills required for *effective problem solving*. This triggered movements to reform the teaching of mathematics and statistics as documented in David Moore's article 'New Pedagogy and New Content: The Case of Statistics' [10]. Moore notes that the central idea of the new pedagogy is the abandonment of an 'information transfer' model in favor of a 'constructivist' view of learning: students are not empty vessels to be filled with knowledge poured in by teachers; they inevitably construct their own knowledge by combining their present experiences with their existing conceptions. We return to this topic in Section 3.

The decade of educational reform of 1990s coincided with a decade of economic volatility. This prompted the National Academy of Sciences, through its Center for Education in its Division of Behavioral and Social Sciences and Education of the National Research Council, to appoint a committee to explore how the various participants in the postsecondary sector were or were not changing their practices in response to these challenges. Its findings are particularly interesting for people involved in teaching informatics [7]. By the end of the decade, interest in ways to reform pedagogy in response to the information technology wave spread and started to include secondary schools [3].

**New content**

We restrict our discussion to the new content of informatics, a field for which possibly the most extensive investigation to find new content started when, in response to a request from the National Science Foundation, the Computer Science and Telecommunications Board (CSTB) of the National Research Council initiated a study in August 1997 to address the subject of information technology literacy [11]. The rationale for such a study was that the increasing importance and ubiquity of information technology in daily life make it essential to articulate what everyone needs to know and understand about information technology.

In 1998 the report of the CSTB was presented for discussion at the Computing Research Association's (CRA) biennial conference at Snowbird, Utah, a meeting that brings together the chairs of Ph.D.-granting departments of computer science and computer engineering, as well as leaders from U.S. industrial and government computing research laboratories.

The conference participants concluded after discussions that the CSTB's proposal was too much computer science oriented, too ambitious and that it contained too much material.

**New pedagogy for introductory informatics courses at ETH**

The reader perhaps asks herself or himself why we as computer scientists were getting involved in pedagogical issues. Should we not preferably have consulted the didactic center of ETH? The answer is yes, but at that time we could not get answers that solved our problem. It was a problem for specialized didactics (Fachdidaktik) and those people told us that we were on a 'mission impossible'.

Until 1996 the Department of Computer Science at ETH offered two traditional courses for the natural sciences: 'Informatik 1', offering introduction to programming and 'Informatik 2', covering software applications (i.e. concepts of operating systems and databases). The need for change became apparent in 1993 when several departments changed their curricula to the effect that the hours for informatics were reduced and exams were removed. Furthermore, in 1995 pharmacy as well as agriculture and human nutrition removed informatics entirely from their curricula. (Both reintroduced it after we redesigned the course in 1997).

As a consequence, the Department of Computer Science decided to focus on teaching applications and hired a commercial firm specialized in training computer users (with the blessings of the Rector). This experiment was stopped after two semesters when an entire class complained about the quality of the courses. In the fall of 1996 the author of this paper was asked to take over this teaching assignment.

Clearly, the department's efforts at a new pedagogy and new content had to be redirected. On the pedagogical side two revisions were due. First, teaching had to be based on didactical methods suitable for courses whose teaching goals are to empower students as problem solvers. To deal with this issue, problem based learning seemed to be a sensible approach. Second, because natural science students were less than excited to sit through two hours listening to someone talk about hardware and software, it stood to reason that we adopted the paradigm change 'from the sage on the stage to the guide on the side' and introduce tutorial learning.

**New content for introductory informatics courses at ETH**

When considering the learning goals for our lectures, another paradigm change became necessary: 'from the input of the teacher to the output of the learner'. In other words, do not dwell on what might be interesting from the point of view of computer science but instead ask yourself which competences are important to natural science students in light of their complete education (Gesamtstudium). What do they need to learn that will expand their scientific operational competence (Handlungskompetenz)?

As a first step we reversed the curriculum and started with the application of software to process information, and moved the teaching of programming to a later semester. Deciding on the contents of each course, however, was much less straight forward because the suggestions of the CSTB are of little concrete use and consulting the departments in which our students were enrolled was of not much help either. Nevertheless, the report of the CSTB provides a useful insight when they say that "Fluency with information technology requires three kinds of knowledge: contemporary *skills*, foundational *concepts*, and intellectual *capabilities*."

The last piece of the puzzle was the notion of an 'information workplace' (Informationsarbeitsplatz) which we introduced to structure the context needed to teach informatics. The idea is based on the fact that the workplace of today's natural scientists is no longer restricted to field and laboratory work, it also requires extensive information processing.

The categories of the CSTB, combined with an information workplace, provide the framework for our teaching materials: let students learn the informatics *concepts* and *skills* that will give them the *capabilities* to master an *information workplace*. Many highly abstract informatics topics can now be taught in a realistic and interesting setting. The challenge was to define a purposeful information workplace and to create an appropriate problem based learning environment.

## 3. PROBLEM BASED TUTORIAL LEARNING

Problem based learning (PBL), as a proven pedagogical strategy, is no longer restricted to medical and professional schools which developed it thirty years ago to teach students about clinical cases and financial analysis for example. Today, Princeton University, for instance, adopted it to get a grip on problems with their introductory science education by effectively moving instruction from the lecture room to the lab where students spend their time to solve realistic problems under the guidance of tutors from different disciplines (http://www.princeton.edu/pr/pwb/07/0312/1a.shtml). The expertise of the teacher is no longer made available through lecturing but through tutoring.

Tutorial learning refers to learning with a highly skilled tutor and one student or a small group of students. Learning is totally active for the student, making it an ideal environment for problem based learning. Students will continue to work with the tutor until the material is fully learned, essentially keeping the amount of learning constant and varying the time required for it. The situation in a traditional lecturing system is the other way around.

After analyzing our situation in 1996 we were convinced that tutoring, combined with PBL was the model to be used for our introductory informatics courses. It is arguably the best way with which our students can learn the skills required to work effectively with computers and become motivated to deal with the informatics concepts underlying the various software applications.

One critical aspect of tutoring, however, is the shortage of good tutors. This forced us to use written instructions, similar to 'Leitprogramme' (Karl Frey, Angela Frey-Eiling: "Allgemeine Didaktik", 17. Auflage 2004). In order to assess the tutorials effectiveness, we added an important additional step as follows. After completing the task specified by the instructions of the tutorial, the students are asked to independently solve a new, related problem where they apply the informatics concepts just learned.

Working through a tutorial and the subsequent assessment takes on average six to ten hours. Given a semester of fourteen weeks we have time for six to seven tutorials.

Problem based learning materials are costly to develop because embedding problems into a given, realistic context is time consuming, but it makes the tutorial accustom made product. Nevertheless, we felt that this effort was worth the while, given the large number of students.

**Tutorials for introductory informatics courses**

To modularize the new information processing course with tutorials we defined an information workplace based on the following activities: *communication*, *data processing*, *data analysis*, *data management*, and *application programming*. Table 1 shows the topics chosen for six PBL-based tutorials with which students learn the skills, concepts and capabilities required to solve complex problems.

Table 2 shows the structure of the syllabus for the programming course based on Pascal and Delphi (a Pascal-based, visual program development environment). A similar course exists for Java.

This modularization of the syllabi not only made the preparation of the tutorials more manageable, it also provided the flexibility to accommodate different student populations. We were able, for example, to conveniently adapt our course to the needs of a civil engineering class by simply revising the definition of an information workplace to include scientific computing in place of data analysis. This led to a new tutorial with which students can learn basic principles of numerical methods while they practice how to use Matlab, a numerical computing environment.

| Topics for an Information Workplace | Tasks for PBL-based Tutorials |
|---|---|
| Communication | Internet publishing: designing and installing a webpage |
| Data processing | Simulation using spreadsheets |
| Data Analysis | Visualizing multivariate data using different graphics |
| Data Management | Managing data using lists; pivot tables |
| Data Management | Managing data using relational databases |
| Programming | Writing macro programs in VBA |

**Table 1** Topics that are relevant in the context of an information workplace and the corresponding tasks for the associated PBL-based tutorials. The concepts and skills taught with these tutorials are not restricted to these tasks; they could be learned just as well in other contexts.

| Topics for Programming | Concepts for PBL-based Tutorials |
|---|---|
| Fundamentals | Variables, data types, conditional execution, compilation |
| Repeated program execution | How to program repetition; debugging |
| Data structures, Procedures | Declaration of and working with arrays |
| Object oriented programming | Graphical objects, methods, events, modules |
| Parameterization | Scope and lifespan of variables, value and variable parameters |
| Processing data files | Reading and writing text files, program development |
| Processing bitmap data | Structure of digital pictures, reading and manipulating bitmaps |

**Table 2** Concepts that must be mastered by competent programmers and the corresponding topics covered by the PBL-based tutorials.

A course can be modularized into several individual tutorials in different ways. The important criterion for this design process, however, is that the result must lead to a course during which students learn how to solve a variety of problems using information technology and thereby develop skills to apply different methods when tackling a complex task.

**Competence-oriented didactics with the four-step model**

The tutorials help our students develop computer-skills independently and at their own speed. Ultimately, however, we were looking for a comprehensive pedagogical approach that integrates skills, concepts and capabilities, leading to effective competences in information technology as proposed by the CSTB. To this end we developed a didactic model consisting of the four steps SEE, TRY, DO, and EXPLAIN. During the SEE-phase the student is introduced to the concepts to be learned. This prepares her or him to try to apply these concepts actively with appropriate guidance through the tutorial as part of step two. In a third step the students DO it, meaning they apply the skills and concepts learned in the previous steps independently while solving a realistic problem. Finally, to verify their competence, they EXPLAIN their solution to an instructor.

The sequence of these four steps, with our tutorials as step TRY, provides a learning environment in which students not only can become competent to manage the complexities of an information workplace, they can also acquire the other nine intellectual capabilities for a fluency in information technology that are listed in the CSTB report [11]. These are the capabilities to engage in sustained reasoning, to test a solution, to manage problems in faulty solutions, to organize and navigate information structures and evaluate information, to collaborate, to communicate to other audiences, to expect the unexpected, to anticipate changing technologies, and to think about information technology abstractly.

These learning goals exceed by far the traditional notions of information literacy which typically call for a minimal level of familiarity with technological tools.

The interactive tutorial learning approach forces an author to pay close attention to *content*, both in terms of substance and structure. Our experiences have taught us that if this work is not done very carefully, then tutorials are unlikely to succeed. This is in line with the arguments of Elsbeth Stern, Professor for teaching and learning research at ETH Zurich when she says that content counts more than method [13].

Teaching informatics with tutorials is a prime application for e-learning simply because computer supported learning brings a student directly into the environment where the skills and concepts to be learned apply. The costs to develop computer based tutors, however, far exceed a lecturer's resources so that when in 2000 the Rector of ETH introduced 'Filep', a fund to support innovative, teaching-related projects, an opportunity to realize computer based tutoring presented itself. The next Section summarizes the results of several Filep-projects that were started in that direction.

Didactics based on the four-step model is not restricted to informatics, but, regardless of where it is being applied, its success stands and falls with the quality of the tutorial's content. For this reason it is important that the tutorials are designed by competent teachers in the particular area of specialization.

## 4. BLENDED LEARNING ENVIRONMENTS COURTESY OF FONDS FILEP

The idea to develop e-learning materials for our tutorials was convincing because if we use a computer based tutor to teach how to work with computers, we will effectively create a *virtual laboratory for informatics*. This is in sharp contrast to all the efforts that use the computer simply to transfer information.

We grabbed the chance to develop an e-learning system in the summer of 2000 by submitting a proposal to Filep for a three year project entitled *Information Processing for Domain Scientists* with the goal to develop software for the delivery of tutorial learning, so-called *E.Tutorials*®.

This project was challenging in several ways. First, there was no literature to document tutorial e-learning for informatics. Second, we decided to take an engineering approach to the development of learning materials and allow for development cycles. Third, we had no environment for prototyping; our materials saw active duty with classes of 250 students and more right away. Fourth, we wanted our materials to be easy to use, easy to maintain, and to be independent of any proprietary software.

Writing computer based tutorials was only half the story, the other half was embedding these learning materials into the instructional process. We quickly learned that computer based tutors are of little value when they are not part of a *blended learning* environment—a combined use of hardware, software and brain ware. This turned our project into an endeavor to understand and apply principles of educational engineering, namely developing and implementing suitable didactical models and effective procedural sequences and refining them until evaluations and results of process analyses proved that our new pedagogy worked.

The dissertation of Lukas Fässler [6] describes the technical details of this approach. The experiences the author has made while developing and applying these e-learning materials are summarized elsewhere [9].

### Results

ETH invested more than CHF 800'000 in the development and deployment of computer based tutors to teach information processing and programming competences. The result of this investment are 23 *E.Tutorials*®, productively used in 6 introductory informatics courses at ETH, providing problem-based, interactive learning environments for well over 1000 students each year. Just for comparison: learning materials developed at the UK's Open University figure in the Mio. $ range for a single course [2].

By the summer of 2003 we had developed 6 operational *E.Tutorials*® for the topics listed in Table 1, to be used as part of the following courses, offered in 10 different degree programs:

- *Einsatz von Informatikmitteln* (251-0839-00), an information processing course offered in the fall semester, 270 students from environmental sciences, earth sciences, and agriculture and food sciences.
- *Informatik I* (251-0845-00), an information processing course offered in the fall semester, 210 students from civil, environmental, and geomatic engineering.

- *Informatik (für Biol./Pharm. Wiss.)* (551-0432-00), an information processing course offered in the spring semester, 280 students from pharmaceutical sciences, biology, human movement sciences and sport.

During the four years following their introduction, the first six computer based tutors have been refined based on results from our process analysis and extended so that they can also be used in connection with OpenOffice software (Filep-project 337, '*E.Tutorials*® Erweiterungen und Updates'). As part of this project we also developed a template to support authors who write *E.Tutorials*® and made it available free of charge to non-profit educational institutions.

In 2006 the course Informatik I was complemented with an *E.Tutorial*® on scientific computing using Matlab.

By the spring of 2005 we started to employ 7 new *E.Tutorials*® for our introductory programming course in Java, developed as part of a Filep-project, managed by my collaborator, Dr. Bettina Bauer-Messmer (Filep-project 'Computergestützter Programmierunterricht für Informatikferne Studiengänge'). Originally oriented towards natural science students, these learning materials were extended so that they could also be used with civil engineering students (Filep-project 'Computergestützter Unterricht am D-BAUG'):

- *Anwendungsnahes Programmieren* (251-0840-00), an introductory programming-course in Java offered in the spring semester, 180 students from environmental sciences, earth sciences, agriculture and food sciences.
- *Informatik II* (251-0846-00), an introductory programming-course in Java offered in the spring semester, 210 students from civil, environmental, and geomatic engineering.

Also in 2005 we decided to restructure our Pascal-based programming course by introducing computer based tutoring. The following course was originally restricted to 4 *E.Tutorials*®, which were used during the first half of the semester, the second half was held traditionally, with lectures and exercises only:

- *Programmieren und Problemlösen* (251-0846-00), an introductory programming-course in Pascal and Delphi offered in the spring semester, 25 students from environmental sciences, earth sciences, and agriculture and food sciences.

It turned out that this approach—half tutoring, half lecturing--needed more research and so we decided to extend the computer based tutoring to include the complete course (Filep-project 'E.Tutorials in der Fachvertiefung Informatik').

When in the fall of 2006 the Department of civil, environmental and geomatic engineering requested that the course Informatik II cover object oriented programming more extensively, we developed 2 computer based tutors on this topic. (Master thesis of M. Guex: *E.Tutorials*® *für Grundlagen der objektorientierten Programmierung in Java*).

Some of these materials are also used at selected Swiss Universities of Applied Science (Zurich, Winterthur, Basel, Luzern, Chur) and increasingly also at high schools. With the support of the North-South Center of ETH we are also translating the 6 *E.Tutorials*® into English with the aim to make them available in developing countries (an initial request from Zambia motivated this effort).

There is strong interest to use our materials for training programs in industry. We are currently developing a prototype in cooperation with Corporate Management Accounting, SBB Cargo, to train financial controllers. Industry contacts have shown that when dealing with managerial persons responsible for continuing education, the trademark 'ETH' is of particular importance.

## 5. FUTURE DEVELOPMENTS

Even though the learning materials that we have developed during the past 10 years are now being routinely used by over 1000 students at ETH and many more at other institutions, we see that further work is necessary in the following areas:

- review the pedagogical principles in light of design-based research
- integrate the resulting insights into the 'new pedagogy'
- deal with institutional barriers that are impediments to interdisciplinary educational research

- problem-based e-assessment
- more in-depth work on process analyses
- offering contributions to the problem known as 'digital divide'

**Design-based research**
As mentioned in Section 2, in the absence of what we considered suitable didactic models, we proceeded pragmatically and started working on a new pedagogy for informatics instruction, an effort that has raised our interest in educational research. We have recently found that our practice of continuous cycles of design, enactment, analysis and redesign is an integral part of an educational research paradigm called 'design-based research' [12]. Design-based research seems so far to be the most promising approach to study instructional strategies.

Our work fits perfectly into this paradigm but it must be complemented with sharable theories that help communicate relevant implications to practitioners and to other educational designers. Furthermore, additional work is necessary to account for how our design functions in its particular setting. Successes and failures must be documented and our understanding of the learning issues involved must be refined. We plan to become active in this community with the goal to formulate a theoretical foundation that can account for how our design functions.

**New pedagogy**
Teaching and learning informatics are problematic because they are inherently constructivist activities. Informatics teachers who attempt to implement learning programs designed from predominantly behaviorist perspectives quickly find that these are less effective. For almost ten years now there has been a call for a new pedagogy that goes beyond a cookbook approach [3].

We have shown how a constructivist approach can be implemented successfully but need relevant results from design-based research that can provide us with a basis to integrate our approach into the new pedagogy.

**Institutional barriers**
Another challenge that must be addressed is the fact that our design is well accepted by the students but that many instructors see its advantages, are convinced of its effectiveness but shy away from redesigning their courses accordingly. They hesitate to adopt the paradigm change and step down from the stage.

Design-based research requires an interdisciplinary environment including specialists in teaching and learning, practitioners who teach in a particular context and researchers in didactics interested in the interplay between the teaching of generic competences and competences embedded in a specific context.

**The digital divide in the context of e-learning**
When reflecting on the digital divide it is convenient to let the term refer to the gap between those people with effective access to digital information technology and those without access to it because then the divide corresponds to the world's economic divisions. Efforts to overcome this global digital divide have led to many initiatives such as the United Nation's *Global Alliance for Information and Communication Technologies and Development* (GAID), the *World Summit on the Information Society* (WSIS), organized by the International Telecommunication Union or the *Digital Alliance Foundation*.

Participants of these international endeavors have realized that organizing a laptop for each child will not be enough because the digital divide has a moving target: first it meant ownership of a computer; later access to the internet; most recently it centered on broadband access; but in the end it also refers to the imbalance that exists amongst groups of society regarding their ability to use computers effectively. Others, concerned with this problem, believe that the open content, free software, and open access movements can help equalize access to digital tools and information.

Technology is by definition central for information and communication technologies, but when it comes to the ability to benefit from technology then education is probably the most important issue. Unless people can operate an information workplace, all the computers and networks in the world won't be of much use. Seen from this angle, a digital divide that separates those who are able to use computers from those who are not, no longer coincides with socio-economic boundaries, it runs across all societies because it is no longer a problem of technology but one of education and training.

We address these issues because our computer based tutors can in many ways contribute to overcome the gap created by a lack in computer competence by providing a format that makes learning materials highly suitable for distance learning and also ideal for continued education.

This claim is supported further by the success we observe with the large number of our own students and by the broad range of institutions that expressed interest in our e-learning materials. They include different universities of applied science, high schools, the chief controller of the cargo division of the Swiss federal railways, and a group who initiated efforts to found a private research university in Zambia, Africa. All of them were looking for educational materials that support active learning based on sound concepts embedded in a realistic context. Most e-learning materials on the market cannot live up to this demand as they are suitable for information transfer only and therefore totally lack the necessary ingredient for interesting interactions.

As an aside to this topic we note that by using learning materials to support activities such as the United Nations' Global Alliance for Information and Communication Technologies and Development, ETH could make a productive and sustainable contribution to the 'Plattform für Nachhaltige Entwicklung (BNE)' of the 'Schweizerische Konferenz der kantonalen Erziehungsdirektoren' and by doing this broaden its global visibility.

Having said the above, we must also realize that education has become a global industry, the extent of which has been impressively documented with a study commissioned by the World Bank [14]. ETH could and possibly should grab the chance to become a player in this market. We would be glad to help.

**Problem-based e-assessment**
Instructing large numbers of students with PBL is one thing, assessing them is quite another when we want to test more than memory and understanding of concepts (levels 1 and 2 in Bloom's taxonomy of educational objectives [1]). We had to apply new methods that allowed us to assess to what degree we were successful in promoting active knowledge in our students (Bloom's level 3 and higher). This called for problem-based assessment.

We also started to work on a database to store exam questions which would allow individualized online exams that could be written anytime, anywhere, providing instant results after automatically correcting the tests. We are close to completing the first project in this direction (Filep project: 'K3+ basierte, elektronisch gestützte Leistungskontrolle').

While developing the software for problem-based e-assessment we became aware of the importance to integrate assessment into the learning process. As a consequence, our students are assessed verbally after each DO step of the four step model. Furthermore, each *E.Tutorial*® contains a typical exam question at the end, to be solved online.

**Process analyses**
By bringing the type of assessment in line with the type of instruction and having data on the results available electronically we can readily analyze the performance of our learning system ([4]). This analysis includes also the students' motivation which we deduce from a process analysis based on questionnaires that the students complete online at the end of each *E.Tutorial*® ([5]).

## 6. ENDNOTES

The motivation to write this report has been fourfold.

1. **Awareness**. This report describes how we perceive the need for change in pedagogy at the teacher's level and it shows that ideas which depart from traditional patterns can be implemented successfully. The document illustrates that the necessary commitment must be solid, that the willingness to allow major changes must be persistent and that the price is high, increasing the risk that sustainability considerations are left behind.

   The report also wants to demonstrate to those who have become conscious of the need for pedagogical change that even though much has been written about reform, quality control, support in technical and didactic matters etc., there is also inventiveness required to actually get something done.

2. **Continuity**. Courses taught in a traditional way can be passed on to the next generation lecturer without paying much attention to the new person's didactical attitudes as she or he will continue

teaching it using the same pedagogy, possibly with minor modifications. This is not so with courses that part with tradition.

The author of this report will retire in October 2010 and would naturally like to see a continuation of the new practices introduced for the information processing and programming courses at ETH. This is more likely to happen if the reasons and the history that led to the new pedagogy are documented. Evaluation and assessment results speak for themselves and are convincing arguments to maintain the current pedagogy ([15]).

3. **Synergy**. We have learned that computer based tutoring systems, the way we implement them, can only work satisfactorily in an output-oriented sense when they are incorporated in a blended learning environment. Because of their modular character, tutorials can be and are used in many different educational settings, raising many interesting questions as to how different teaching and learning methods can and should be combined. Answers to such questions can be found more effectively when expertise from different fields can be combined.

   In order to put the new pedagogy to teach computer competences for the natural sciences at ETH on a sustainable footing and to make progress in the areas that require further research, we need a place where synergies can form that involve: psychologists specialized in teaching and learning, specialists in didactical methodology, specialists in informatics, people with connections to political bodies, development agencies as well as potential investors. See also [8].

4. **Outreach**. Last but not least we think that it would be profitable for ETH to capitalize from the resources invested in its fund Filep which continually creates a supply of teaching materials with a potentially high market value, if not to generate cash then to use it as a public relations resource. Maybe the teaching materials could be used to support the activities of the United Nations mentioned above. At any rate, the term *E.Tutorial*® has been registered as a trade name for ETH.

   A trade name is only of value, however, if the quality it implies can be continuously guaranteed. Because other institutions have started to produce computer based tutoring materials based on our concept (some of them with our support), we propose that a multidisciplinary **Center for Computer Based Tutoring** be established at ETH. The reader is referred to [8] for details.

   To the author's best knowledge, the teaching of computer competences, both applied and theoretical, is not organized systematically at any educational institution in Switzerland. Many efforts had been started over the years to remedy this situation, all following top down directives, an approach which could quite likely be the basic problem behind the state of affairs we see today. Should political or educational decision makers decide at one point to try to solve the problem bottom up, then ETH could take a leading role. The experiences it made and the teaching materials it has at its disposal could be a starting point. This would be a tall order, but perhaps a worthwhile one for ETH to take on.

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