E-Learning: Make it as simple as possible, but not simpler

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Abstract

This article summarizes our experiences trying to keep the instruction of computer sciences simple in an environment that is anything but simple. An analysis of the factors that contribute to the course's success shows that it is not the application of technology in various forms that is responsible but a careful instructional design based on sound pedagogical principles.

We developed course material that combines problem-based learning with e-learning to raise the motivation of natural science students taking an introductory information and communication technology class and to accommodate large classes

Introduction

Even though the amount of literature on e-learning is more than sufficient it is still difficult for the inexperienced to see the benefits of this educational technology or notice which pitfalls to watch out for when using computers to aid teaching. Reports such as 'The Future of Online Teaching and Learning in Higher Education' [1] make for interesting reading but are of little concrete help to someone faced with the challenge of establishing an online course.

This article summarizes the author's experiences over eight years of designing and employing e-learning classes for ICT and computer programming courses for natural science and civil engineering students at ETH Zurich. About 1000 ETH students complete these courses every year in a blended learning environment.

The materials we developed are also used complete or in part at other schools, and with the generous support of the North-South Center of ETH Zurich we are now translating the contents of the ICT course into English so that it can be used at a new research university in Zambia.

The observations I report here come not only from my work as an instructor, but reflect experiences I had during my four years as Head of Education of the Department of Computer Science. They also result from the numerous contacts I made while peer-reviewing the bachelor programs in computer science of many universities of applied science in Switzerland.

These contacts made it clear that in the context of e-learning it is particularly important for instructors to realize that they are exposed to many forces that result from priorities set and compromises made by those responsible for the educational system in which they have to function as teachers. The EDUCAUSE Current Issues Survey Report [2] summarizes some of these priorities. This survey, now in its eighth year, asks campus information technology leaders to rate the most critical IT challenges facing them, their campuses, and/or their systems.

Having said this, I begin this review with a sketch of the bigger picture before discussing the reasoning behind the design of our e-learning courses.

1 Stakeholders of an educational system

The history of e-learning goes back to the early sixties and the debate about how to use computers in schools has not stopped since. Whereas in the early days the field only attracted those interested in learning theories or in the commercial potential of computer-supported teaching, it is nowadays a topic with a life of its own, affecting almost everybody and particularly those involved in education. So why not first contemplate who the major players with a stake in e-learning are?

The ultimate stakeholder of a country's educational system is its *society*, represented officially by members of its *political body*. Responsibility at the operational level rests with the individual *school administration* which oversees its degree programs, each managed by a *program director*. The actual teaching is the domain of the *lecturers* and the *students*, possibly supported by *teaching assistants*. Thus one can readily identify seven levels of stakeholders, each with different responsibilities, their own expectations and consequently unique ideas about e-learning. It might be interesting therefore to wonder who takes the initiative for e-learning and how the others are affected by it.

1.1 Society

The interaction between society and technology has never been easy; it is mostly unpredictable and can be difficult to control. This point is clearly illustrated in the April 2007 issue of the ATDF Journal [3] where Victor Konde argues that the type of policies which a nation adopts to guarantee benefits from Information and Communication Technologies (ICT) can have profound consequences on the country's development. The situation with societies is also frequently ambiguous in that its individual members need not necessarily share the opinion the society expresses as a whole. For example, even though 20 years ago in Switzerland most would have agreed that computers affect everybody's life in one way or another, many individuals would not have seen the need to acquire the competences required to take advantage of this technology.

Even when Switzerland, together with many other so-called information societies, was flooded by the e-learning wave in the mid-1990s, it took a dozen more years for its students to use the PC as a matter of fact. Those who were too old to grow into it, namely most teachers, still have a hard time incorporating ICT into their teaching or learning activities. Societies, as a stakeholder in e-learning, must live with this generational time lag.

1.2 Political body

One of a politician's major responsibilities is to provide the conditions that ensure both a society's well-being and its future competitiveness. Since the youngsters are the primary asset of a nation's future, the society's decision-makers must set the goals for an effective educational policy and provide the budget necessary for its successful implementation. In most societies, though, national decision-makers have neither the time nor the necessary expertise to become involved with instructional or pedagogical details of citizens' education.

Sometimes, however, local politicians cannot resist the glamour of powerful corporations, which can lead to dubious activities. Back in 1997 for example, the then Swiss Minister of Finance promised to donate 30,000 old Federal Government computers to schools in the following years. This effort was to flank the promise of Bill Gates, who offered to donate, free of charge, 5000 Windows licenses, including internet browser and introductory courses for teachers. The project was then downsized to 2500 computers and eventually cancelled, as only 450 schools expressed interest and only 120 computers were delivered.

Education is a complex system that cannot be controlled at the stroke of a pen, like rubberstamping a budget. Budgets are of course also an important part of the system and how important they are can be estimated from the numbers mentioned in the following paragraph. Considering that the amounts mentioned cover only some of the more important projects of only one university, the political body is an important stakeholder indeed.

1.3 School administration

A school's administration, controlling the distribution of the organization's resources, is in a position to decide how its funds are used, which makes it perhaps the most influential stakeholder in e-learning.

At ETH we have been fortunate in that the administration decided as early as 1986 to systematically support the use of ICT in teaching and learning via a five-year project with over $40 million at its disposal. In 1996 the school started a project called 'Network for Educational Technology' (NET) to specifically support lecturers in the use of new educational technologies. NET was institutionalized in 2002 and today it is the competence center for e-learning of ETH, with 6 full-time staff positions.

Most important, though, is that since the year 2000 the Rector has had between $1.5 and $2.5 million per year at his disposal to finance innovative teaching projects (Fonds zur Finanzierung lehrbezogener Projekte – FILEP). Needless to say, much of this money has gone into the development of e-learning materials. The author has also benefited: five of his requests to fund e-learning projects were approved (amounting to a total of over $660,000). Without these generous grants it would not have been possible to develop the e-learning materials that we can now offer to other non-profit institutions of higher learning at no charge.

It can be said without hesitation that at ETH the school administration has been instrumental in providing a fertile ground for e-learning, and I am certain that at other schools this organizational unit is also a key stakeholder. Unfortunately, however, the approach chosen does not assure sustainability, for the following reasons. When institutionalizing a service such as the NET, a school freezes funds for technology support, creating permanent positions taken by people who are competent in technology but are not involved in teaching. Without this commitment to teaching it can be difficult for the service staff to advise lecturers on the usefulness of certain technologies. For lecturers, however, content comes first, and the suitable technology to deliver it comes second. A teacher's adoption of e-learning methods can mean that a rework of his/her materials – and often the redesign of an entire course – is necessary to make them computer-compatible.

To those who teach actively it comes as no surprise that developing new course material can take many semesters and improving quality is a never-ending process. And yet it is precisely this crucial work which is supported only by impulse financing, typically with funds for a two- to three-year project. After that it is up to the lecturer to figure out how to maintain the course.

1.4 Program director

The job of program director at ETH is usually assigned on a rotation basis to a faculty member for the duration of two to four years. The position is embedded in a strictly democratic environment, which means that the director cannot implement procedures without the consent of a majority of his/her colleagues. The director cannot decide independently that an entire program be supported by e-learning, but might complement the support given by the rector to members of his department. All in all, not a stakeholder that matters greatly for e-learning at ETH.

This might be different at other schools, however, because a program director faced with budget cuts might decide to stretch resources by substituting regular lectures with e-learning materials.

1.5 Lecturer

If e-learning is reduced to the presentation of lectures using an electronic learning platform, one could argue that the role of the lecturer in e-learning is secondary compared to that of the school administration. If, however, the goal is to improve the effectiveness, efficiency and sustainability of teaching by harnessing a computer's strengths, then the lecturer becomes the prime stakeholder. His (or her) focus is teaching, he is responsible for the material he uses and he must find the necessary hardware and software for support in this effort. If he does not ask what e-learning can do for him he runs the risk of putting technology before content.

Once a lecturer adopts e-learning as a method for presenting course material, he or she must be prepared to face a whole range of consequences. First of all, the material must be complete, because students interact only with the computer during long stretches of the learning process. If the material is flawed, frustration and anger result, both of which will not raise confidence and trust in the instructor. Second, provision must be made enabling students to verify that they are on track. Third, the role of the instructor typically changes from 'the sage on the stage to the guide on the side'. The pedagogical consequences are far-reaching.

Ideally, it is the lecturer who decides whether or not to employ e-learning, in cooperation with the school's administration. If this decision is one-sided, with one party being forced into it, the outcome is most likely to be dissatisfying.

1.6 Student

For better or worse, students are the stakeholders most affected by e-learning. E-learning can give them the opportunity to learn wherever and whenever they want, without the restrictions of an agenda. They typically benefit from the advantages that the internet offers, but they also suffer should this service not be available when they need it most.

Before e-learning, students just had to cope with the different teaching styles of their instructors. Now they are also exposed to the teachers' technological preferences, which could mean that they have to become fluent with many different learning platforms unless the school's administration (or at least the program director) prevents uncontrolled use of ICT systems to deliver and support teaching.

Normally students can influence the development of e-learning only indirectly by deciding either to sign up for such courses or to avoid them. Whichever option they choose can depend to a large extent on how successful a course has been in motivating students in the past.

1.7 Teaching assistant

In many courses the large number of students can only be managed efficiently by appointing competent teaching assistants. These people have the task of helping students understand the material that is presented during a given course. They are often responsible for creating suitable exercises, correcting the work that students hand in, and also for generating exam questions.

E-learning obviously affects the work of teaching assistants in a fundamental way. First, there are no exercise classes because students work on their own, each at his or her own speed. Second, exercises have to be restructured so that they can be presented electronically and the students' work be corrected automatically. Third, many of the student problems requiring help have to do with teaching technology, and not with content.

In consequence, lecturers must analyze their e-learning courses to find out where students need help and how, under these new conditions, they can incorporate teaching assistants into their work. Perhaps the biggest challenge we have encountered is how to train teaching assistance so that they can help students learn with the new materials without interfering in the learning process: in other words, how to prevent a teaching assistant from taking the mouse in her own hands when helping a student at the computer.

Summary

When considering this by-no-means-complete list of issues in connection with stakeholders, one can see that an educational system is indeed a complex one. And, of course, each key player in this system wants to use technology to his advantage. So, how can we as lecturers cope with new technologies and remain unscathed? I have learned to summarize the insights that have emerged over the years in one sentence: *Do not ask what you can do for e-learning; ask what e-learning can do for you*.

2 E-Learning to support problem-based learning

All natural science students at ETH must complete introductory computer science courses. Ideally, in such a course students not only hear or read about computers but become competent in using computers to solve problems. Computers are complicated tools that demand from their users not only skills but also a strong motivation 'to keep at it' throughout the semester. We have observed that motivation wanes rapidly if the learning objectives are reduced to memorizing facts or going through routine drills with application software. This is understandable, because it is difficult to detect sense in material that is presented as a collection of loose fragments.

2.1 Concepts as teaching objectives

To embed our courses in a stimulating framework, we make *concepts* rather than a compilation of facts the center of our teaching objectives. Concepts can provide structure and thus help students to see the course content in a meaningful context; but to be useful during the learning process concepts must be 'connected' to useful skills. Combining concepts with skills requires an instructional design and pedagogical preparation that leads to a course in which students learn more than the sum of the concepts taught and acquire new capabilities. By this we mean that a representative set of concepts must be embedded in a process that guides students through increasing levels of 'computer competency'.

Instruction that relies on *problem-based learning* (PBL) supports this process best, because learners come into contact with the concepts through their own activities and thus can better differentiate between them. This differentiation lays the ground for a perception of the underlying ideas that enables students to construct the concepts by themselves, to successfully apply them, and do this while they are in control of their own learning process. The crucial point, however, is that the problems which guide them through this process must be interesting, relevant, realistic and, if at all possible, also entertaining. We have learned that these are the primary ingredients for instruction that motivates. But we also quickly realized that PBL is easier said than done, because for it to work it is imperative that the chosen problem's difficulty is adapted to the student's level of competence.

Our course is structured as follows. A biweekly two-hour lecture covers major topics of ICT and their underlying concepts. To complement theory, every two weeks our students start a new set of problem-based exercises originally handed out as printed tutorials, to be worked through at a student's own pace. The tutorials – on average about 15 pages long – guide a student step by step through a problem that he or she solves using a given software application (e.g. a database program). At the end of each tutorial, students are required to solve a different, but related problem independently and then demonstrate and explain the solution to a teaching assistant.

Each student must complete a total of six tutorials, covering the following topics: internet publishing, simulation with spreadsheets, visualizing multivariate data, managing data with spreadsheets, managing data with a relational database, and macro programming.

2.2 Supporting teaching activities with *E.Tutorials®*

When we started to redesign the ICT course for the natural science students at ETH eight years ago, we had the following goals in mind: incorporate active, problem-based learning for the reasons mentioned above; teach large classes without sacrificing individual support; provide the means for student controlled learning. We also set out to investigate the potential of e-learning to support these goals.

Intuitively it seems clear that a computer can be of great help to provide individual support. The large number of students, however, forced us to apply instructional concepts which can provide a maximum of support – particularly for less experienced students – with limited personal resources. But we also had to come to grips with the problem that such a course's content has both to challenge students already experienced with computers and avoid overtaxing those who lack these skills. Student controlled learning can help to keep the balance on his pedagogical tightrope walk.

Even before the development of the World Wide Web and the e-learning wave that followed, complaints were voiced that students are acquiring extensive theoretical knowledge but that they cannot use this knowledge outside of school or university. Trusting in problem-based learning to tackle this problem, we created written tutorials to guide students through six conceptually different application programs while solving a well-defined task. At the center of this effort is the problem-solving process, not the operation of the software.

As it turned out, using electronic media to deliver the PBL tutorials helped us solve the problems we faced, particularly the stubborn qualitative problem of inactive knowledge. We have called the learning material based on this combination *E.Tutorial®*. Tutorials for an ICT course are natural candidates for e-learning, because when guiding people through a software application with written instructions it stands to reason that the instructions themselves be presented together with the application on the same computer screen.

The user interface of an *E.Tutorial®* is shown in the center of Fig. 1. It consists of an application window (e.g. a spreadsheet program), in which learners are led step-by-step through small problems via instructions that are displayed in an instruction window. In a separate verification window students can check whether or not they are on the right path in the problem-solving process. The guidance in the instruction window must be structured in such a way that learners are neither overtaxed nor under-challenged.

Producing the e-learning materials was one thing; embedding them successfully into the teaching process was quite another. This embedding should not be simpler than the requirements dictated by sound pedagogy. After many attempts, an instructional design we call the four-step model finally emerged.

3 The four-step model

We have found that instruction is the most effective and efficient if it makes the learning process 'brain-friendly' by breaking it up into four discrete steps [4]:

See: students must be given the opportunity to ***see*** the concepts

Try: students should have the chance to ***try*** to apply concepts actively with appropriate guidance

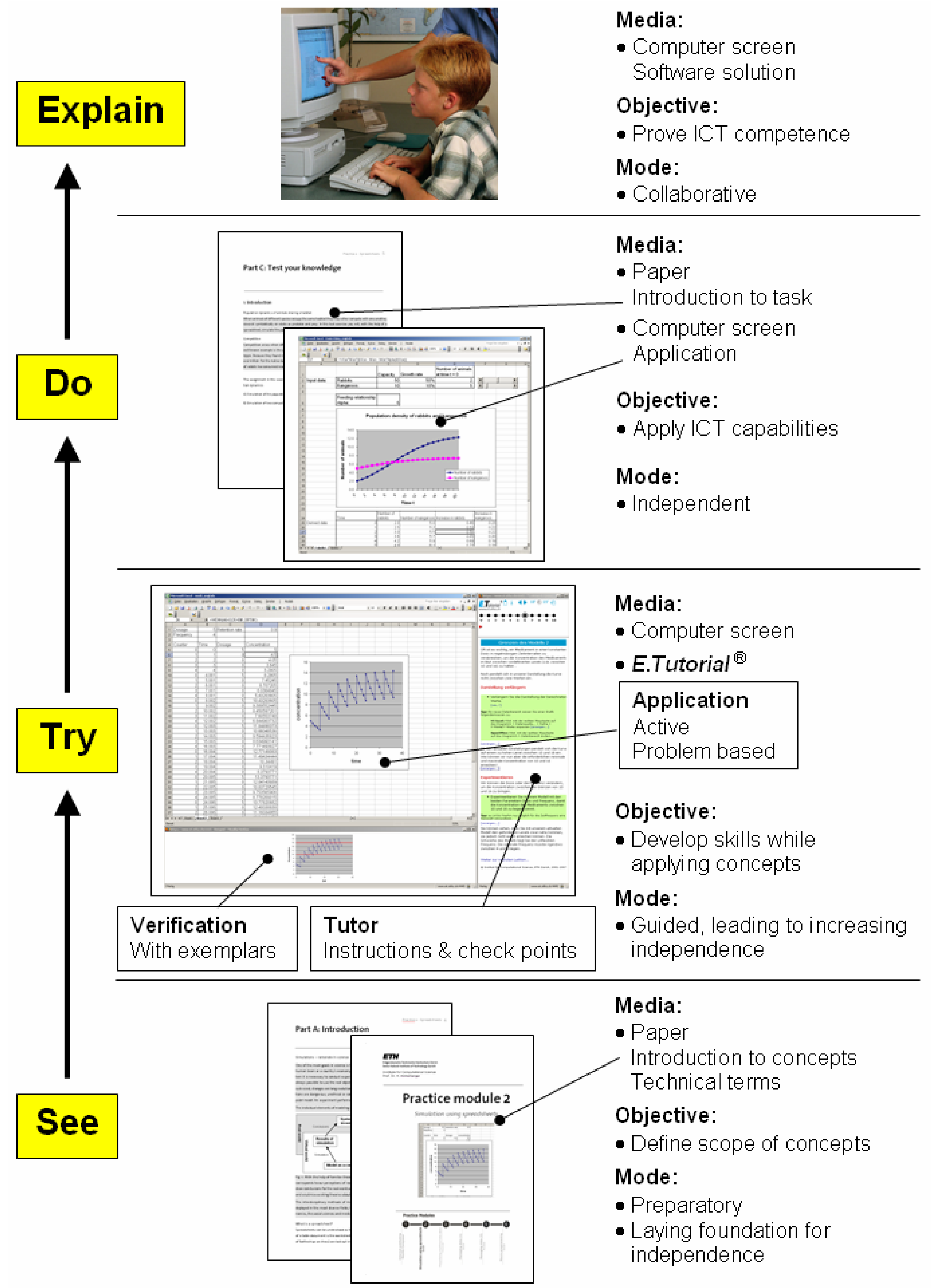
Do: then they ***do*** [apply] them independently

Explain: to verify their competence, they ***explain*** their solution to an instructor

All the tasks of our introductory courses are organized around these four steps. Figure 1 illustrates how *E.Tutorials®* are integrated into the blended learning environment in which students complete the four steps mentioned above. For each step we have chosen a medium that best suits its purpose and content.

In the first step, the concepts and technical terms involved are briefly introduced on paper (See). They span the space of the learning process and lay the foundation for the second step, in which the concepts will be applied when students work with the *E.Tutorial®* (Try). The Try step combines PBL with constructivistic methods in an e-learning environment. It is during the second step that knowledge becomes active and learners become increasingly independent as they progress through the learning material. We count on this independence dur-

Figure 1. The instructional design based on the four-step model used to organize an e-learning environment with *E.Tutorials*®. See text for details.



ing the third step, when they have to solve a new problem on their own (Do), applying the knowledge and the skills learned while working through the *E.Tutorial®*. The fourth step concludes a learning unit with a short oral presentation (Explain), in which students are given the chance to show what they have learned and an instructor can evaluate the learning outcome. At this stage students typically interact with the teaching assistants, whose task is to verify authorship of the results and confirm that concept and theory have been correctly understood and applied in the right context.

This four-step model with its explanations, check points and discussions provides a scaffolding to help our students feel that they are in control of a learning process during which they acquire skills that they can confidently apply. Both this sense of control and their self-confidence motivate them to learn more about computer science.

The crucial parts of this process from an instructional design point of view are steps two (Try) and three (Do), because with PBL the right problem for each competence level must be found. Our approach is that for both steps we first define the level of competence required before we construct a problem that represents the concept in question. Next we divide this problem into a set of smaller tasks that allow step-by-step instructions for the Try phase and that facilitate continuous verification to provide the learners with checkpoints on their journey through the *E.Tutorial®*. Establishing the subject matter of these steps typically requires several iterations until a satisfactory design has been found. Each ICT application has its own individual *E.Tutorial®*, but all are conceptually embedded in the same four-step model.

4 The difficulty of keeping it simple

Our e-learning materials are technically as simple as can be: text documents and hypertext documents. The only software needed is a browser ('as simple as possible'). The content of the documents, however, is anything but simple, and neither is the pedagogical environment in which they are used, as illustrated in Fig. 1 ('but not simpler'). The technical simplicity evolved over time as a consequence of keeping our focus on instructional effectiveness, student motivation and just common sense.

Designing and implementing the six *E.Tutorial®*s of the ICT course based on the paper tutorials took approximately one year. But we then spent more than two years refining the course to improve its quality. This section discusses some of the issues that arose during this process. Please note that the comments made in this section relate strictly to our work; certain techniques that we found inappropriate for us might very well be useful in other e-learning applications.

4.1 Learning platform

When selecting the operating environment for our tutorials we also considered learning platforms, as these seemed to be the epitome of e-learning. Upon closer examination none of the reasons why one might want to use a learning platform corresponded to our needs. These systems help students to manage their e-mail, their agenda, their files, their contacts, and other office-type functions. Students have already automated these tasks as part of their daily lives; if there is anything they do not need it is one more system to do this.

Learning platforms were also unable to provide us with support in managing our content, namely to organize the problem-based learning materials in a way suitable for application-oriented instruction. In the end we decided to use the simplest web technology and design an interface consisting of three windows using HTML and JavaScript. The technology needed was (and still is) available free of charge, we were not bound to any proprietary standards, and it made the software open.

For our purposes a learning platform would be more of a liability than an asset. Nevertheless, anyone who operates a learning platform can easily incorporate our material into it.

4.2 Collaboration

Another buzz word in e-learning is 'collaborative work' and lecturers are repeatedly encouraged to use software to support it. We also felt obliged to provide our students with a service that would allow them to share their thoughts and their work easily with each other and the teaching staff – but not one student used it. Instead, they engaged in lively discussions in the computer room and during the lecture, sharing experiences in solving the problems of the exercise.

Early in this project we noted that students collaborate on their own if the course content encourages this type of exchange among peers. Unfortunately, at the beginning it is often unclear what exactly fosters collaboration and therefore it is important to observe how students behave during e-learning.

4.3 Electronic textbook

Once we decided to use hypertext documents, it seemed a logical extension to also create an electronic version of the lecture notes and link its content with the tutorial and the glossary. We learned, however, that availability of information in itself is not a major problem when instructing. Linked hypertext pages and text databases with search facilities provide novel access simply, but they do not reduce the complexity or place the abundance of information in the right context. The information presented in detail in a textbook is too remote from the information which students require to solve their immediate practical problems. Theory must therefore be reworked into smaller units that relate to a concrete problem and become part of the instruction.

4.4 Animations, videos

To visually support the step-by-step instructions of the *E.Tutorial®*, we first experimented with short video sequences. When we realized that animations and videos are instructor-centered and do not support the student's activity, we dropped them altogether. Evaluations showed that the students did not miss them. As soon as learners themselves can control the learning process, they no longer view animations and videos. We observed that illustrations that show intermediate results (Fig.1, 'Verification' in step 'Try') are much more effective, and that they are greatly appreciated by learners.

4.5 Time management

Since we started using a problem-based approach combined with *E.Tutorials®*, students spend more time on the learning materials than before, they are more motivated, and they work less superficially. E-learning therefore does not reduce their workload during the semester; but because they must work continuously their learning process is complete at the end of the semester. This frees up the time they previously spent on exam preparation.

Problem-based learning allows us to distribute activities such that time is more effectively utilized.

4.6 Media

Because studies have shown that for reading longer texts most people prefer paper over computer screens, we have chosen to hand out detailed information on paper. Figure 1 shows that this is preferred when a new topic and its technical terms are introduced (step 'See'), and for describing the problem students have to solve independently (step 'Do').

Any electronic medium can be used to store the hypertext files of the *E.Tutorial®*. We make them accessible over the web, on CD-ROM and more recently on USB memory sticks. Memory sticks have the advantage that students can save their work together with the e-learning materials on the same medium so that their activities are not tied to a particular computer anymore.

Interestingly, if given the choice most students prefer the memory stick over the web even when they have free internet access in the school's computer rooms.

4.7 Teaching assistance

Even though our students have the option to work anytime, anywhere, we organize teaching assistants during fixed hours. This allows students to build a relationship with real persons, which anchors the learning process in the real world. As mentioned in Section 2, the role of the teaching assistant has changed from information broker and example problem-solver to that of a coach who can answer technical questions, observe the learning progress and provide feedback.

Working in a computer room dedicated to the purpose animates students to help each other out more frequently and collectively answer many small questions themselves. This makes other mechanisms to encourage and support collaborative work superfluous.

4.8 Assessment

A potential side-effect of PBL is that learners indeed understand the problem but may have difficulty disengaging from it to reach a level allowing generalization. To verify that students achieve this level of competence, we introduced oral presentations during which they summarize in their own words what they have done (Fig. 1, step 'Explain'). The assistant's feedback on this presentation becomes a reward for a student's efforts which counts more than the credit points at the end of the semester.

Assessments are, in general, limited to providing data for a grading process which typically takes place at the end of an instructional unit. Grading often fails to include the instructional process as a whole. Instructors want to give a good and interesting course, but they also have to separate successful students from unsuccessful ones. To be of any value, the selection must take place at a cognitive level that corresponds to the cognitive level of the instruction. For this reason, our students must also pass an hour-long application-oriented exam at the end of the course.

5 Assuring quality

We have argued in Section 2 that an educational system has many stakeholders, each with his own goals, priorities, constraints and means. But, no matter how diverse their opinions on e-learning are, they surely would agree on one desideratum, namely that no matter who delivers education and regardless of the method chosen, it must be of the highest quality. Traditionally, schools try to control quality by having their classes evaluated. We also think that evaluations are important, but to be meaningful they must include the assessments.

5.1 Evaluation

That teaching is a complex system became clear to us when we realized that we were spending more time optimizing our e-learning instruction than we had spent putting it in place originally. To guide our optimization we evaluate the course in such a way that we can observe how the entire process behaves. First, course acceptance is evaluated regularly with questions concerning the lecture, the *E.Tutorials®* and the exam. Second, course effectiveness is assessed via an application-oriented test at the end of the semester. This provides us with a realistic estimate of what students have actually learned.

The most useful feedback, however, is the set of results from the 10-minute verbal assessment session at the end of each tutorial (Fig.1, step 'Explain'), during which students explain to a teaching assistant how they solved the problem that follows the *E.Tutorial®* (Fig.1, step 'Do'). These assessments show that our students not only became more motivated, but that they now also learn more. This observable output has become our dominant quality criterion.

5.2 Assessment

In traditional courses students are often required to solve application-oriented problems during an exam even though they never really applied their knowledge during instruction. The resulting failure rates often tempt the instructor to fix averages by adjusting the grading scale accordingly. PBL-oriented instruction reduces this side effect. We have become convinced that if instruction and assessment are to be effective, both must be designed to operate at the same cognitive level.

In another project we are examining methods for administering exams electronically, with individualized tests that include application-oriented questions. The underlying database of questions will also be accessed during the course, allowing close coupling of instruction with assessment so that students can verify their progress. First experiences are reported in [5].

Summary

E-learning systems must be simple, otherwise they cannot be incorporated into a complex teaching environment without dominating it. To guarantee high quality in teaching, however, an e-learning system must not be simpler than the complexity that results from combining a sound didactic model (PBL) with an effective instructional design (4-step model).

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