36 Developing ICT based Learningware for Physics

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Abstract

As part of an ongoing investigation into digital learning environments and into organizing higher education for the knowledge society, a learning environment has been developed. The learningware has been specifically implemented for an introductory Quantum Physics course in a traditional large university classroom setting. It is however conceived as a generic instrument, suitable for all science courses. The WEB component of the learningware, called "Phys4All" (http://physics.rug.ac.be/Fysica), has been designed using generally available software, thus creating an inexpensive generic tool. A flexible database structure allows for easy adaptation to specific needs of both instructors and students. As instructors can upload the appropriate materials for each specific student group, or can select different learning paths as required, the technology is disconnected from the learning environment.

Keywords: e-learning, multimedia, learning environment

1. Introduction

The trend toward life long learning coupled with demands for more flexibility in when, how and where learning occurs is increasingly pressurizing the traditional higher education institutions into changing their methods and delivery of instruction. While adopting commercially available learning platforms may seem a straightforward solution, introducing new technologies is not sufficient. More conceptually there is also pressure on higher education to renew and refresh its vision of teaching and learning in view of the latest learning theories. At Ghent University, the Centre for Research and Innovation in Physics Education (CRIPE) has been established with the aim of finding the best ways of adapting the new ICT inspired technological capabilities to modern insights in these learning theories.

The choice of physics has not been fortuitous. While physics is recognized as relevant to all science and engineering related curricula, it is perceived by most students as conceptually difficult. At the same time, the overall knowledge explosion is being used worldwide as a pretext to reduce the time allotted to the traditional "Introductory Physics" course in curricula such as engineering, medicine, chemistry and life sciences. Moreover, physics teaching is increasingly being blamed to be inefficient. Indeed, while traditional lectures in introductory physics contain all the ingredients required for knowledge transmission, Physics Education Research (PER) instigated and conducted over the last decade by front-ranking physicists themselves has abundantly demonstrated that such lectures provide few ingredients to support knowledge reception, use, and creation [McDermott, 1991; Redish, 1999; Lenaerts, 1997; Lenaerts, 1998]. Much of the current curricular reform effort in physics is therefore based on the idea of interactive engagement of students in heads-on and sometimes hands-on activities which yield immediate feedback through discussion with peers and /or instructors. [Hake, 1998; Mazur, 1997]. One of the authors (W. W.) obtained very encouraging results by introducing (in 1997) Mazur's Peer Instruction as a more interactive teaching style for an electromagnetism course. Perhaps surprisingly, this approach failed completely for the Quantum Physics course taught by the same instructor to the same students. These somewhat contradictory results provided the main motivation to search for a combination of traditional but nevertheless successful low-tech lecturing methods with the use of technologically advanced network delivered immersion learning materials.

2. ICT assisted Instruction

Physics as a discipline requires learners to employ a variety of methods of understanding and to translate from one to the other - words, tables of numbers, graphs, equations, diagrams, maps. Multimedia are particularly suitable for this role. Physics requires the ability to use algebra and geometry and to switch from the specific to the general and back. This makes learning physics particularly difficult for many students. It is however clear that some unique capabilities of computers can be used to implement hitherto inaccessible and possibly better instructional strategies: the graphic capabilities of computers almost demand to be exploited to present powerful symbolic representations, including dynamic representations of time-dependent processes and to enhance spatial thinking. With careful design, computers can provide powerful environments

where students can explore new concepts actively on their own.

From the beginning of the computer age, physicists have been quick to adopt this new technology both for research and educational purposes, and a large body of physics learning software is now available. However valuable, most of this is "stand-alone", not integrated into a specific learning environment. On the other hand, existing learning environments are primarily text-oriented and while commercial authoring tools for producing Web-based learning environments have been available for some time, they were deemed unsuitable for our purpose. To begin with, commercial tools are expensive, being aimed at complete universities or at least at very large departments, and they often seem to be more concerned with administrative niceties rather than with sound pedagogical concepts. We wanted a tool that would allow easy inclusion of existing content, requiring minimal maintenance work for the lecturer and producing Web-deliverable materials for the students. We opted for a flexible database backbone for the instructor's input with an html output for the student's benefit. The database contains all "learning objects", which are very generally defined as digital or non-digital entities that can be used, re-used or referenced to during technology-supported learning [Wiley, 2000]. This allowed us to start up almost immediately, while fully exploiting the vast amount of legacy documents (lecture notes, exam papers, assignments from previous years, documentary slides, simulations etc) available in our physics department. By using all this material as learning objects a continuous and smooth transition from a paper-based towards a Web-based course was made easy. Requiring only a browser at the client side means no additional cost is involved for the students. The familiarity of our students with a browser environment is all the more important, as we had learned from previous experiences that many of them only reluctantly use course-specific software, however well designed. Although the WEB component could equally well be used for distance education we consider that coming to the campus in person remains important.

The flexibility provided by our instructional model allows for motivating the brightest students, while at the same time taking care of the less well-prepared students. The attention for these very best students is intentional, as we feel very strongly that pedagogical innovations often fail to take into account their specific requirements.

One of the most robust observations of cognitive research is that attentional focus is crucial to learning. Students often fail to learn in an educationally rich environment, because they fail to attend to the right things. Therefore the interface display of a learning environment should be optimized to direct the user's attention to the more essential features. The content is subdivided in small portions to prevent cognitive overload. We provide students with a learning path that represents a hierarchical structure; however students can bookmark their own path if they so prefer. The amount of material on the web

gives the students the opportunity to create their own organization. Throughout the material questions and small assignments are provided that can be used either during the lectures or, alternatively, for Just-in-Time Teaching (JITT) [Novak, 1999]. JITT is a pedagogical strategy that successfully exploits a fusion of high-tech and low-tech elements. The WWW is used to deliver multimedia curricular materials and to manage electronic communications while the interactive classroom environment is maintained. The JITT system is built around Web-based preparatory assignments. The students complete these assignments individually, at their own pace and submit them electronically. The (traditional) lecture can subsequently be targeted to remedy the specific problems of that student group, thereby increasing its efficiency.

3. Physlets and simulations

One aspect of learning where computer technology has a major advantage involves Web-based interactive problems and animations. To be an effective tool they must foster an interactive-engagement approach so task setting becomes a very important element of the instructional design.

Browser technology now readily supports JAVA applets, small programs written in Java and embedded in HTML documents allowing interaction with the user. Such applets are ideally suited for physics instruction, allowing animation, changing of parameters, taking measurements etc. Combined with a scripting language like JavaScript JAVA applets provide us with very flexible interactive programs that can be adapted to various pedagogical activities. To emphasize the physics content of such script enhanced "physics applets", Wolfgang Christian [Christian, 1998] coined the term *Physlets*. Physlets are easy to use since they are based on standard non-proprietary Internet technologies. Depending on the degree of sophistication, they are also fairly easy to develop. Moreover, many physics instructors are making available downloadable versions, free for non-commercial purposes, so even those without JAVA skills can benefit. Using Physlets allows for better insight in the theory and creates opportunities for presenting to our students new types of problems that would have been awkward to formulate in printed versions. The use of JavaScript allows one to adapt a Physlet to the desired learning model and to the appropriate learning environment. This way the technology is disconnected from the learning environment and can be used by different instructors, creating a generic instrument. Physlet problems can be programmed is such a way that students must determine what they need to know in order to solve the problem before they even attempt a solution. This prevents students from fall back on the often successful but pedagogically counterproductive "guessing" strategy. Physlets can also be programmed to allow students to take readings of different instruments, thus simulating "real" measurements. As in real labs, students can be instructed to arrange and structure these measurements in tables and

graphs and to produce lab reports. These traditionally important skills can therefore be trained outside a laboratory setting. Used in this way Physlets present a very cost-effective way of training laboratory skills. We found these virtual instruments to have another benefit: contrary to real instruments, students do not find them "intimidating" and seem to be more willing to experiment freely, probably because they cannot do anything wrong with them. Moreover, while Physlets can simulate experiences from the real world, a number of real life annoyances, e.g. all kind of noise signals, can be left out, thereby allowing a more focused approach and allowing to create the exact experience the teacher requires. By manipulating the model through changing parameter values, the learner can control step by step how the Physlet is indeed a model for a real situation. Specifically, the option to choose non-significant values for the parameters, which cannot be done in real experiments, often contributes to a much better insight. The animation possibilities of Physlets allow a degree of insight in real problems that is unattainable with static texts or graphics, certainly not for inexperienced learners. less worried about making mistakes they seem more willing to experiment. Many interesting physical processes can't be properly visualized in printed form, e.g. many time dependent phenomena. For others the three dimensional world has to be reduced to a number of two-dimensional cross sections from which only the more gifted students can reconstruct the whole picture. Physlets allow us to give far more realistic representations, which can be manipulated in space at will. Since we first introduced Physlets to our students we had only very positive reactions, and we consider this aspect of our project to be highly successful.

As a cautionary note, we would like to stress here that Physlets can never displace real-life laboratories, and students should eventually be allowed to use real instruments. Familiarity with the appropriate Physlets will then smoothen the learning curve and increase the effective use of prime-time laboratory work.

4. Technical aspects and production tools

4.1. Database structure

Taking into account the pedagogical issues discussed above, a fully-fledged learning environment has been created and baptised Phys4All [Lenaerts 2001]. While all elements are accessible over the internet, for some of them the access is restricted by password or other protection systems. The core element is the database, therefore a lot of effort went into the choice of the most appropriate software. We finally selected FileMaker Pro, now in version 5.5, because it works very intuitively and it produces excellent html material without further user intervention. This last aspect was crucial for our choice and at the start of this project (in 1998) it was not easily available with other database software. In fact, Filemaker Pro contains a Web server so that setting up a dynamic database

on the Web is an easy process. It also has a very powerful scripting language that allows communication from the Web between different databases.

The learning environment itself consists of a number of separate but related database files for course material, students, instructors and evaluation. These databases can be connected to the other existing databases like the departmental library and applet database. At any moment new databases can be added by simply setting them up and linking them to the existing ones. E.g. we recently added a "physics lab" database which allows the student to prepare the laboratories at home more efficiently. Filemaker Pro can produce XML output or be linked with other databases through ODBC making it an open tool for future evolution.

Access to the data is governed by both a user profile and an access mode, the main access modes being the "instructor mode", "student mode" and "general user mode".

4.1.1 Instructor mode

Instructors can access all databases, the most important one being the course database which contains the actual learning objects. For security reasons, the "instructor mode" is not only password protected but uses IP control to restrict access to specific computers. The opening screen of the course database, as shown in Figure 1, allows for a number of hierarchical choices ranging from adding a "new course", a "new chapter", a "new paragraph" or a "new file". Additionally, the learning objects can be attributed to one of three "levels". The main or course level corresponds broadly to the curriculum requirements of a specific student group, while the advanced level includes introductions to more difficult and rapidly developing topics (e.g. quantum computing, Bose Einstein condensation) and makes liberal use of advanced mathematics, e.g. Maple worksheets. The introductory level (not yet fully implemented) could be used for a non-science course, and also provides inadequately prepared students with the necessary background knowledge. Clicking the "add new file" button creates the link to the Web site where the document should be transferred to. The Web address is automatically generated and if so desired a preview of the Web page can be copy-pasted in the right half of the screen. Simultaneously the database updates a text file providing the necessary parameters to create a (collapsible) tree view of the course content on all Web pages. This procedure results in a neatly ordered Web site.

In instructor mode, any kind of material can be added or changed quickly and efficiently. Several authors can easily collaborate on the same course and there is no need for a prospective author to acquire any knowledge about the database software.

To allow for reliable updating and easy "recycling" of the learning objects, e.g. using the same file for different courses or different student groups at different levels, the learning objects themselves are not stored in the database, only

pointers to the place holding the actual Web pages are generated. Instructors have also access to a special section of the database where announcements can be posted about important physics related topical matters and current events, e.g. background information about the Nobel prizes, new technological breakthroughs, historical and philosophical perspectives on the ideas of physics, social and economical aspects.

4.1.2.Student mode

Basically the student database keeps all records about a student, i.e. personal data, study path and problem solving performance. A question database linked to the student database is available for surveys and for evaluations or, with the right feedback, for self-evaluation. The question database can accommodate all conceivable kinds of problems: simple multiple choice, multiple choice-multiple answer, multiple choice-open ended answer etc. Questions can be randomized and the database can generate series of questions to fit a certain student profile. Questions can also be interactively related to Physlets, and by generating some random numbers Physlet assisted problem scan be individualized. Every evaluation of the student is stored in a separate evaluation database. A FAQ database based on student's e-mail questions is also available. Recently we introduced the possibility for students to compose questions containing mathematical constructs using simple TeX commands. While students can still avoid TeX by typing e.g. "sqrt x", most prefer using it to produce $\sqrt{x}$, especially after we added an on-line TeX-command help file.

Using the problem solving environment instructors can introduce questions and students can provide answers via the Web. As instructors can monitor the results at all times, this is an excellent instrument to assist lecturers using "Just In Time Teaching" as explained before.

At the start of each semester a password is issued to every student allowing him or her access to the relevant parts of the databases as the course progresses.

4.1.3. General user mode

The Web page http://physics.rug.ac.be/fysica is the entry point to the freely accessible general user mode. In this mode most of the learning objects are available for viewing or downloading. Although all materials were produced with the traditional browsers Netscape Navigator and MS Internet Explorer in mind, we do not have the resources to guarantee 100% compatibility or to keep abreast with all browser developments. Therefore Netscape 4.7 or IE 6.0 are recommended. While Netscape 6.0 gives poor results the recently released Netscape 7.0, preview release 1, seems promising. Presently course material is available covering Thermodynamics, Electromagnetism, Quantum Mechanics and Statistical Physics. A search tool covering the whole Web site is also available. At the start of the semester, students can purchase both a course text and a Cd-Rom. The Cd-Rom is an

image of the website at that particular moment, of course without the surveys and the test bank. Most students still find it important to have a "traditional" printed copy of the course text and they appreciate the Cd-Rom because at the moment many of them have only a slow (and expensive) telephone line to access the internet.

Some typical Web pages are reproduced in Figure 2. The tree view at the left of these figures gives an overview of the content of each chapter and can be made floating or minimized to allow a more efficient use of the screen. This tree view applet helps students to keep an overview on the course at all time, since in contrast to the fundamentally linear character of a traditional book, hypertext learning objects are non-linear, requiring users to make choices in searching for information. Pictograms reproduced at the bottom of each Web page assist an easy navigation through the Web site. All figures can be expanded separately to full page format. Icons indicate the availability of Java applets and advanced (level 3) material.

4.1.4. Production of learning objects

Mathematical symbols and equations present a particular problem in a html based environment. Converting them into pictures, e.g. in gif format, may be acceptable in short documents but rapidly becomes unwieldy for an extensive project. We therefore decided to adopt another approach, using the IBM TechExplorer software based on Latex and also adopted by symbolic programs such as Maple and MathCad. At the client side, this software, now in version 3.3, is freely available as a browser plug-in allowing easy viewing of mathematical symbols in Web documents [TechExplorer, 2002]. The use of TechExplorer guarantees beautiful mathematical typesetting as illustrated in Figure 2. Because TechExplorer is based on MathML, an xml implementation, the mathematical symbols load just as quickly as regular html text

While some instructors involved in this project produce documents directly in Latex, most prefer to use MS Word for text and MathType for equations. To facilitate the translation of these Word files into Latex a Visual Basic script has been written. As this procedure still required frequent interventions by a skilled technician the excellent commercial translator package Word2Tex has recently been adopted [Word2Tex, 2002]. For audio and video files any format accepted by standard browsers can be used.

Learning physics at an advanced level requires considerable mathematical expertise. Ghent University has a campus-wide license for Maple and our engineering students get introduced to Maple during their Calculus and Algebra courses, therefore we also adopted this package for the advanced level of the course. Maple allows exporting complete worksheets in HTML format, and can therefore be easily integrated in our project. An example of such a Maple worksheet is given in Figure 3. Students are issued a free copy of Maple, so they can use these worksheet to study the influence of different parameters. Such worksheets allow even users without any knowledge of

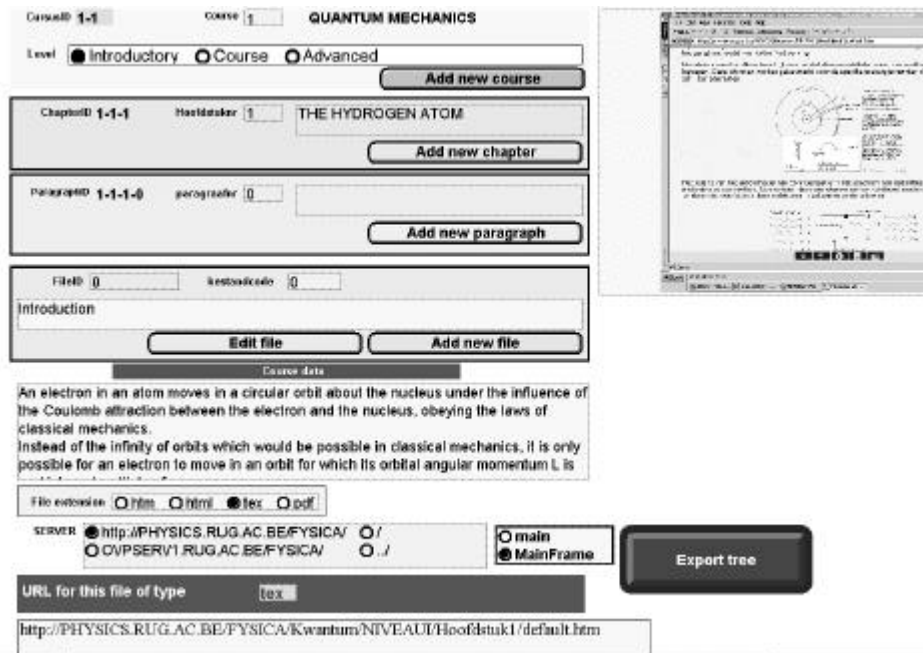Maple programming to produce parameter-defined graphical representations.

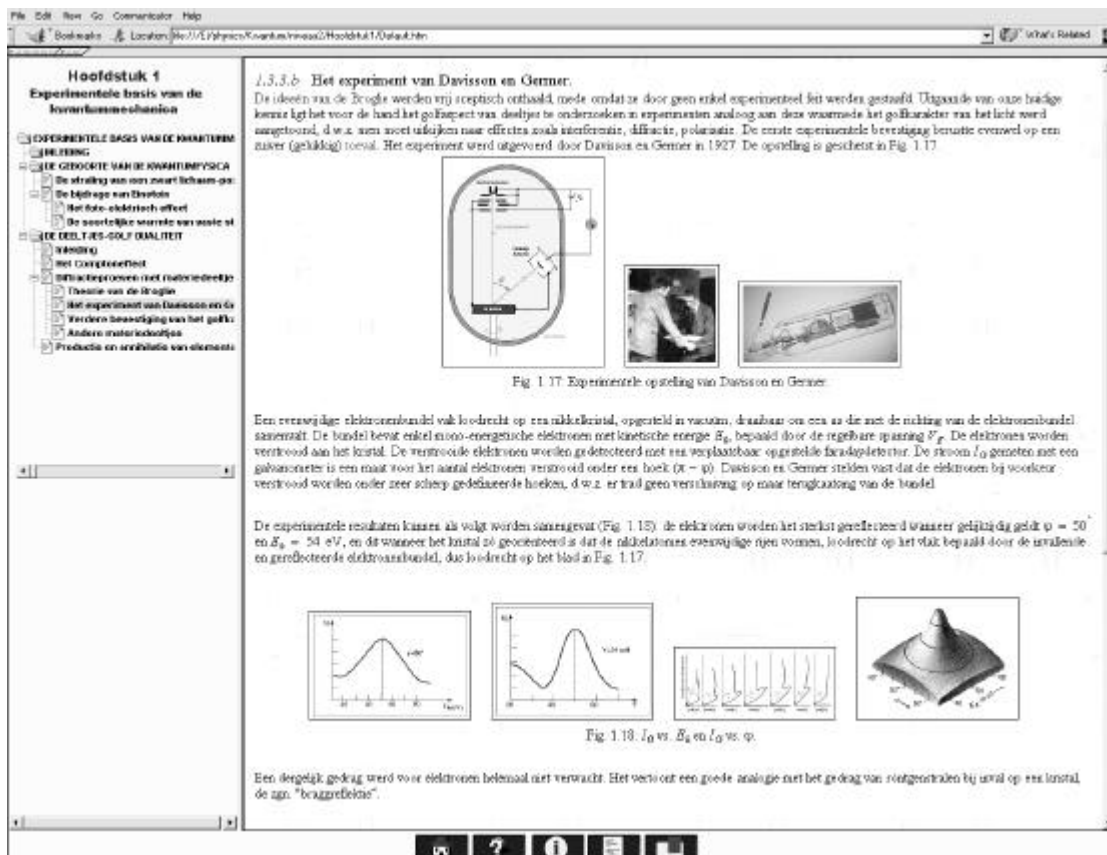Figure 1: Opening screen of the Phys4All Quantum Physics course in instructor mode

Figure 2a: Screenshot of a typical Phys4All Web page, with the (collapsible) navigational tree at the left
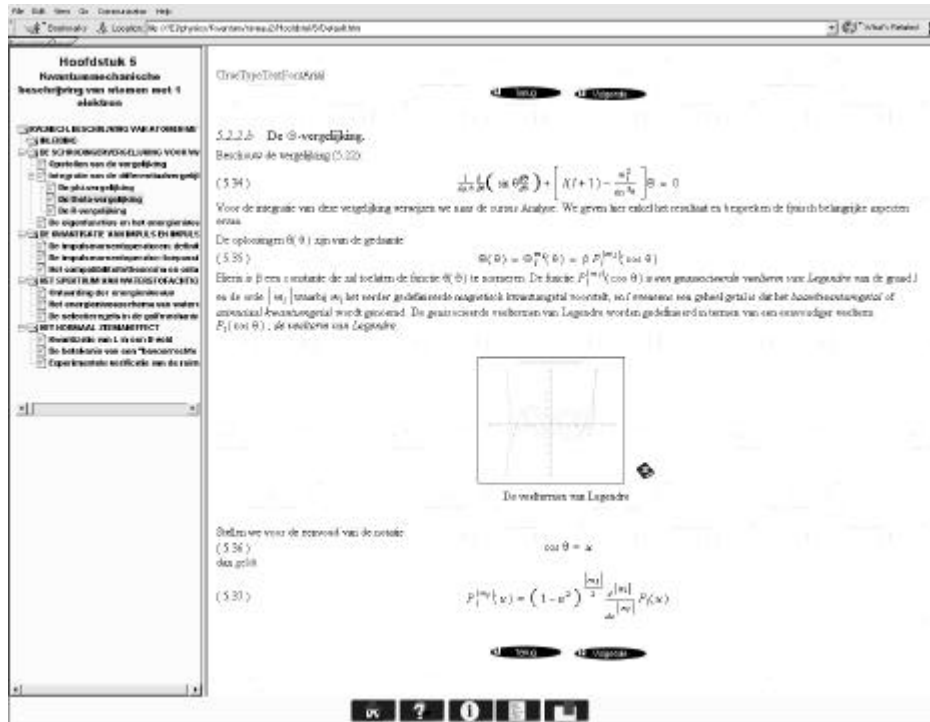
Figure 2b: Screenshot of a typical Phys4All Web page, with the (collapsible) navigational tree at the left
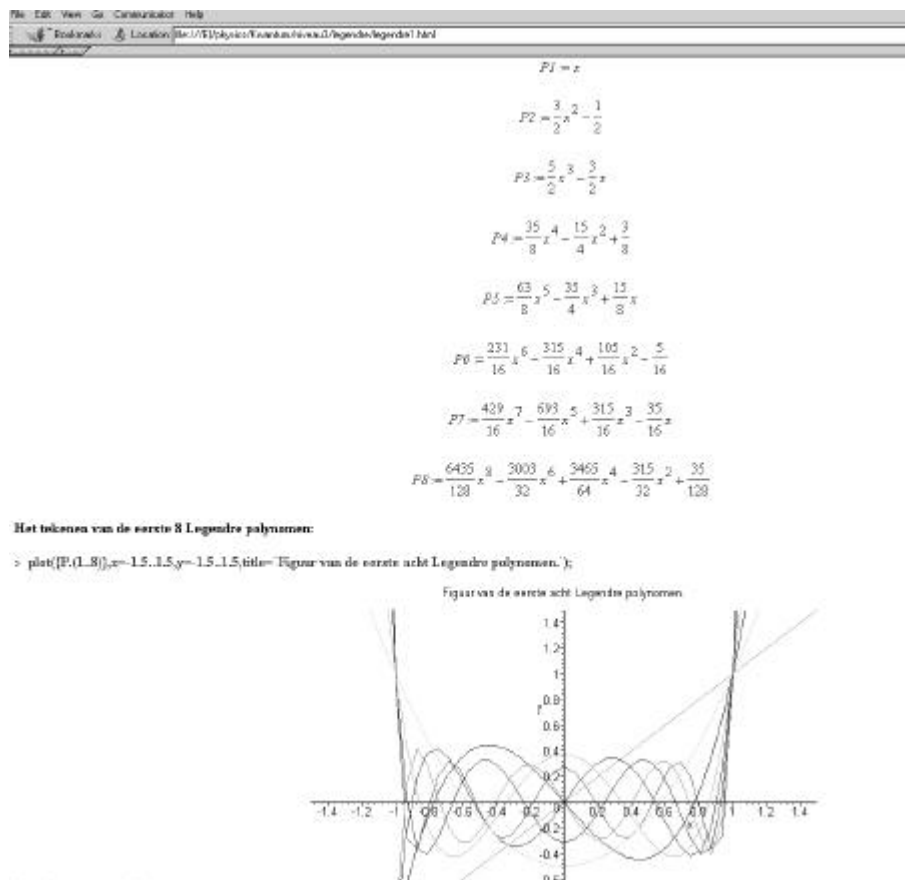

Figure 3: Maple worksheet (Phys4All advanced level 3) for calculating the Legendre polynomials mentioned in Figure 2b

5. Conclusion

In today's technology-driven world, more students than ever before should become familiar with the basic concepts, reasoning, and critical thinking of science. Unfortunately, all evidence points to the fact that students learn less than we intend them to and that bringing about conceptual change requires the introduction of new teaching (and learning) habits. We therefore developed Phys4All, a learning model and learningware based on the judicious use of ICT. Great emphasis has been put on the design and development of ICT-based media consisting of non-linear hypertext, Physlets, laboratory simulations, tests, FAQ and e-mail communication as a solid basis for research on student's understanding of physics and the use of new technologies for teaching and learning. Phys4All has been in development for three academic years and has been extensively tested in a large classroom setting and evaluated through a number of surveys. While most of the data have been collected using the authors' students as a test group, Phys4All is also being used by lecturers at other universities, not connected in any way with the development of the Phys4All project.

Students' use of Phys4All has been monitored and analyzed using Web server log data [Burton, 2001]. These data, together with results from surveys and interviews show that students clearly realize Phys4All offers a lot more than just "another course on a website" or a collection of tools, and they appreciate the added value. Test and examination results for the Quantum Physics course have significantly improved since the introduction of Phys4All. The overall outlook is therefore very positive, indicating that a judicious explicit integration of the use of new technologies can greatly benefit students as well as lecturers.

The database structure set up for Phys4All provides a generic instrument, adaptable to all physics courses, or even all science courses and to each lecturer's preference. As a learning environment tool, it is easily transferable as proven recently by colleagues from the Department of Mathematics who used our Phys4All learningware template to produce a new Web-based course for discrete mathematics in a very short time (http://cage.rug.ac.be/~vo/DiscreteWiskunde/ NIVEAU2). Moreover, recently this mathematics course has been smoothly integrated into a Blackboard (http://www.blackboard.com/) environment, proving its is future proof.

Because by law the teaching language of Ghent University is Dutch, most of the material is - perhaps unfortunately for wider distribution - in that language. Nevertheless, anybody interested in using this material for educational purposes is invited to contact the authors for further information.

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