TRAINING MATHEMATICAL SKILLS FOR PHYSCIS BY MEANS OF A WEB-BASED TOOL

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Abstract

This article describes the use of a web-based course to enhance the learning of mathematical concepts and skills in a university Physics course. Both the coupling of a symbolic language (Maple) and adequate feedback enable to simulate in a computer program the way students should perform. The learning effect which is aimed for is to improve both concepts and skills. Moreover, this tool helps to correct possible misunderstandings or misconceptions.
Web-based training was offered in an electromagnetism course. The training consists of several exercises which focus on applying complex mathematical skills in the field of electromagnetism, one at a time.

KEYWORDS: web-based computer assisted instruction, Physics, Electromagnetism, mathematical skills, Maple.

Introduction

At the faculty of Applied Physics of the University of Twente, preliminary studies concluded that students do not master the required mathematical concepts and skills in a first-year electromagnetism course.

In such a course, mathematical complex cognitive skills are used constantly. On the one hand, concepts should be acquired, and on the other hand, skills and procedures should be automated [1]. To illustrate this, consider the calculation of an electrical field. By this stage of their studies, students should have automated how to calculate an integral, but that is not enough. They also need to understand what an integral is. They need to acquire some concepts such as that the integral being the addition of differential elements, and the limits of integration corresponding to the shape of the body which is being integrated.

Although most of the concepts and skills are taught in the mathematics' courses, students do not learn how to apply them to physical problems. The physical interpretation of these mathematical concepts and skills is therefore our goal.

In a regular physics course, lecturers have no time to train these skills and concepts because the specific subject matter for the course is already large enough. A web-based computer assisted course could supply the extra teaching that most students require.

Design

The design of the training is a critical point in order to get a positive learning effect. An effective instructional design is the base for a successful educational result. First adequate examples that illustrate the trained complex cognitive skill should not have additional complicity. Complex skills should be trained one at a time. In addition, students should approach physical problems according to a structured procedure. The web-based computer assisted instruction should simulate a real performance. This includes first an analysis phase where students plan their own solution route. Second, students have to solve the problem symbolically. Finally a numerical example is requested.

The program should be flexible enough to accept different kind of questions: true/false, multiple choice, and also open questions. In the computer assisted instruction that have been seen until now, open questions are limited to numerical questions. That is not, however, what is expected from a student when solving similar problems on paper. Students should therefore solve the problem in a symbolic form using the computer. As a last step, students may be asked to calculate a numerical example, but this is not the main goal of these exercises. The use of a symbolic language (i.e. Maple) allows students to get a general solution of the problem. The coupling of the symbolic computer language to the courseware is discussed in our previous work [2]. Briefly, the principle is to subtract (or divide) the students answer from the correct one, and if this yields zero (one), the student got it right. These enables intelligent answer checking, use of multiple coordinate systems, intelligent dimension analysis, etc.

In this entire process, students' performance should be closely monitored and specific feedback should be given in order for them to attain the right knowledge (for a review on feedback, see [3]). This means that standard errors should be coded in advance. In our opinion, feedback should be given to all answers, right or wrong. When a correct answer is given, feedback confirms students' answers with a short explanation. Sometimes students guess the correct answer, either by chance or intuition, and are therefore unable to provide a reason for it. In these cases, feedback adds the missing knowledge. Students who already have this skill or knowledge get a confirmation that what they think is right. When a wrong answer is given, feedback should explain in a positive way where the error has been made and correct the misunderstanding. Syntax errors, disagreement of unit, wrong dependencies, etc., are considered when giving feedback. In addition, there should be a hint given in the feedback to help students to continue.

Moreover, in almost all pages of the exercises, there should be a help page with some hints that student can consult before giving an answer. There they should be able to find some theory which is relevant to the exercise, a general case or some particular skills or concepts to consider when solving the problem.

Courseware Content

The electromagnetism course at the University of Twente is based on a textbook by Grifftith [4]. The mathematical skills and concepts required in an electromagnetism course can be mainly grouped in four topics: vectors, coordinates, differential calculus and integral calculus.

In addition to the electromagnetism courseware, some exercises have been included in the package which correspond to subject material which was covered in previous

courses. These mathematical skills or concepts should already be familiar to the student.

Figure 1 shows all the topics that have been treated. Unfortunately the computer version was not available for all exercises. A written version of some exercises was therefore offered.

Subject	Topic	Subtopics
Introduction to Mechanics	*Vectors*	Modulus , Unit vector , Dot product , Cross Product
	Integral Calculus	Integration constants[*]
Thermodynamics	*Differential Calculus*	Partial derivatives, Total differential, Physical and geometrical interpretation , Notation
	Integral Calculus	Line integral[*] , Physical interpretation[*]
Dynamics	*Vectors*	Dot product, Cross product
	Coordinates	Tangential and normal coordinates , Polar coordinates
	Differential Calculus	Differential of a vector
Electrodynamics	*Vectors*	Addition of vectors, Separation vector, Modulus, Unit vector, Component, Projection
	Coordinates	Cartesian, Polar, Cylindrical and Spherical coordinates , Transformation, Symmetries
	Differential Calculus	differential elements, gradient, divergence, curl
	Integral Calculus	Line/ surface / volume integrals, Integration limits
[*]It has been treated with a written version in the academic year 1999-2000		

Figure 1: List of topics offered.

Implementation

The courseware has been developed in such a way so that it can be distributed over the World Wide Web (WWW). It is based on HTML, adding the intelligent behaviour by means of JavaScript. There is a coupling with Maple V5 [5] on the server side in order to be able to evaluate symbolic answers. At the University of Twente, Maple is part of the first year curriculum of Applied Physics, so students are already familiar with it. Due to the Maple license, the courseware is strictly limited to on-campus use. Students' answers are registered in an MS Access database, by means of ODBC technology. This means that students' performance may be studied or monitored. On the one hand, students were given a bonus for doing some exercises, so the database was used as a register of participation. On the other hand, by studying the performance the courseware could be improved (formative evaluation), and new

misunderstandings could be detected, which could lead to the development of new exercises.

The layout of a typical page is shown in figure 2. The left upper frame contains the navigation menu. The right frame includes the exercise student is asked to complete. The left lower frame is the feedback that student gets to his answer. If students press the Help button, they will obtain an information page with the needed Maple instructions.

Figure 2: Example of a differential calculus exercise for electromagnetism.

Experiences with the courseware

The course offered in 1998-99 included a pilot experiment involving computer exercises. Two exercises were developed in an earlier version of the courseware where the coupling with Maple occurred on the client side. Students liked the flexible HTML structure because they could return easily to previous pages. The main disadvantage of this version was that students had to install some software on their own computers, and most of them were not willing to do this.

Since the academic year 1999-2000, Maple operates on the server. This means that students only need a browser to do the exercises on-line. The courseware has been included in the above-mentioned Physics courses. Participation in this part of the courses is voluntary. In two of the courses (dynamics and electromagnetism), students are rewarded with five bonus points (on a scale of hundred) if they participate.

73 students started to study Applied Physics. Some of them dropped out during the first months. 60 students started the Electromagnetism course. All of them, weak and good students, were offered the computer training. However, the ones with the weakest mathematical skills, were particularly advised to participate.

During the first two courses (introduction to mechanics and thermodynamics) and due to the WWW server not being operational, the courseware could only be offered locally in the computer room. In spite of this, 17 students did the computer exercises on mechanics, whereas a smaller amount did the written exercises (no computer version was available). At this stage, most of the students had trouble using Maple. The Maple course takes place in the next term. A help page therefore was developed with some rules and examples. In this first course only simple calculations were required. During the first exercise students were mostly getting acquainted with using Maple. A short questionnaire was given to participating students. In general, they were pleased with the courseware. They considered that it had a positive learning effect. Several students asked for an on-line version so that they could do the exercises at home.

In the thermodynamics course, none of the students chose to do the computer exercises on differential calculus. Unfortunately, for organisational reasons, students were informed too late of the existence of the training. Later it did not make much sense to ask them to do these exercises because they would no longer have been simultaneous with the course. 7 students did the written exercises on integrals.

In the dynamics course, 30 students completed all the exercises. Although the participation was much higher than in previous courses due to the reward, it was noticed that students did the exercises not simultaneously with the coursework, but close to the examination. In our opinion, the training will probably be more effective if it is completed earlier and simultaneously with the use of the skills during the course.

In the log file it was observed that sometimes students were making syntax errors, but the feedback they received only told them that the result was wrong. In the exercises on electromagnetism a function to detect syntax errors was included. Students appreciated this, because it was easier to find the error.

53 students completed the training on electromagnetism. In addition to the mathematical problems four physical applications of integral exercises were included. Some exercises were scheduled during the practical part of the course. A few exercises had to be done in the students' own study time. Some deadlines were imposed in order to ensure that students performed the exercises when these skills were introduced in the course.

Conclusions

Web-based courseware presents a wide range of advantages with respect to classical teaching or stand-alone courseware. It can be used as a tool to train skills and concepts which are required in courses, but which are in fact not a part of the course. Students can get feedback on their performance, and therefore learn.

The on-line version has several advantages. Firstly, the system can be easily updated. Errors that are detected can be redressed. Secondly, because there is only one source of information, there is no need for a distribution network (CD branding, distribution to students). Finally, the courseware can be followed at any time and in any place. Students, particularly the ones living on the campus (they have a free connection), appreciate this flexibility to plan their own study time.

Nevertheless, the computer training should be seen as a complement, and never as a substitute of a lecturer. Some parts of the process such as linking concepts can not be substitute by the computer. In addition developing computer training is a high time consuming process. Finally, all the technical work (set up and maintenance of servers) behind such courseware should not be underestimated.

Our study showed that mainly good students did the exercises on voluntary basis. Weak students saw these exercises as an extra task, but not as a learning tool. The reward encouraged students to do the exercises. As noted earlier, students have the tendency to do the exercises at the last minute. Deadlines should be set to force students to do the exercises simultaneously with the application of the skills or concepts in the course to enhance the learning effect.

Concerning the courseware, in our opinion the coupling with Maple enables the student to perform the computer exercise in a similar way as in the written version. It gives both flexibility to students in writing the answers and simplicity to programming the function that checks the answer. Moreover, adequate feedback takes care of the learning process by explaining wrong answers, giving hints to solve the problem, reinforcing positive answers, and detecting syntax errors.

Discussion

Although the systematic evaluation of the courseware is presently coming, improvements on mathematical skills and concepts have already been notice by the four theoretical and practical leaders of the electromagnetism course. Concerning the systematic evaluation, two tests were given, before and after the electromagnetism course, to evaluate the learning effect. This information was collected during two academic years. The first year there was almost no treatment (only few written exercises plus the pilot experiment). The second year the training explained in this paper was available. The results of both years will be compared. These results were not available at the time of writing this article, but the authors expect to have them soon. It is also planned to survey students' opinions about both the courseware and the learning effect.

In addition, next year the courseware will be enlarged with some more exercises. A computer version of the exercises so far only available in written form will be developed. Analysing the students' performance on the database, feedback will be improved when required. With all these changes, it is expect to enhance the courseware and students' performance in physics courses.

Acknowledgements

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