Main problems for incoming U.P.M. students in physics and mathematics: selecting and drawing up interactive didactic materials.

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Abstract
This project aims to implement interactive and multimedia didactic materials for mathematics and physics in the pre-university courses offered at the Polytechnic University of Madrid. These one-month courses are given in the Technical School of Engineering in order to complement students' knowledge in certain subjects (mathematics, physics, technical drawing and chemistry). The interactive materials will be developed in different software, and are intended to provide dynamic, graphic and visual problems to enable students to understand the concepts more easily.

The first step to develop this project is to determine which physical and mathematical concepts the students have greatest difficulty in understanding. This data is obtained from the university web (www.upm.es). This web has a platform called "Starting Point" (www.upm.es/alumnos/punto_inicio.html) where the incoming students are able to test their own knowledge of mathematics and physics. From the results of the test we have drawn up a list of questions in each subject which the students appeared to have difficulty in grasping. With these questions, we will conduct a survey among the teachers of these pre-university courses in order to develop two modules: one for mathematics and one for physics. Each one consists of a minimum of 10 theoretical-practical units.

This material can be accessed by both teachers and students, and will offer teachers a useful tool for making these difficulties easier to understand. Students will also benefit from the project, as they will now have available a visual aid to help them grasp these problematical concepts.

Keywords: interactive didactic materials, incoming students, physics, mathematics.

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1. INTRODUCTION

In recent years, certain gaps have been detected in the knowledge of incoming university students. This weakness can primarily be observed in mathematics and physics, and in these subjects, the students' level is lower than might be expected from their marks. The Polytechnic University of Madrid (UPM) has developed some tools to correct this situation. The material used in these tools could be improved by the inclusion of some additional didactic interactive material. In secondary schools, there are already didactic multimedia units available with interactive materials (the Descartes and Newton research projects) that

can be used by teachers and students. One of the collaborators in our research project is currently responsible for the Descartes programme. We hope that the material we develop will create a common space between secondary school and university.

2. RESEARCH PROJECT DEVELOPMENT

To develop this project, we have divided it into three stages. The first consists of the investigation of the concepts that are the hardest for incoming students. The second involves compiling all the multimedia resources currently being used by the UPM and secondary schools, and developing the new materials. In the third stage we will upload our work onto the most suitable platforms in order to disseminate our work.

2.1 Diagnosis stage

2.1.1 Data gathering in 'Starting Point'

The search for the content of the multimedia material required for mathematics and physics.

In order to determine the main deficiencies in the students' knowledge, we follow several steps:

We first examine all the multimedia resources made available to students by the UPM. The UPM has a special link on its web page which contains these resources. This is called "Punto de Inicio" ("Starting Point", in English). (http://www.upm.es/alumnos/punto_inicio.html)

The UPM, aware of the difficulty and the importance of the beginning of university studies, has developed this aid for new students. "Starting Point" is a platform where incoming UPM students can improve their pre-university knowledge in several areas (mathematics, physics, chemistry, technical drawing, English and study techniques) in order to provide a solid base for building their future education. This structure offers the flexibility of the web and makes it easier for the students to review their own knowledge.

In "Starting Point" each subject has a space where the students can find the concepts that they will need to use in their future university courses, and there is also a test to evaluate their experience of these concepts. These concepts and the test are structured in several units. The units correspond to one area of the subject (in physics the units are: mechanics, thermodynamics, optics, electromagnetism and modern physics). Each unit is divided into two levels, intermediate and advanced. In each level there is an explanation of the concepts included in the unit. After understanding the unit, the student can evaluate him or herself with the test included at the end of the unit. The tests each have 20 questions and are corrected by a teacher, who can offer personal observations that can be seen by the student. From these tests we have compiled a selection of the main difficulties for students in mathematics and physics.

2.1.2 Statistical analysis of the data.

In order to determine the most difficult concepts for the students, we selected the test questions the students most frequently answered wrongly. A statistical test hypothesis was done to select these questions, specifically, a mean comparison. First, we calculated the average mark for the 20 questions of each test (M_{tot}). Then we determined the average mark of the students in each question of the test (m_i) and we did a test hypothesis of equal means for normal populations, between the mean for each question and the total average mark. The hypothesis test had the following characteristics:

$$\text{Null hypothesis: } m_i - M_{tot} = 0$$

$$\text{Alternative hypothesis: } m_i - M_{tot} < 0$$

$$\text{Significance level: } \alpha = 0.05$$

From this statistical test we obtained the 15 most difficult questions for the students. The questions are shown in tables 2 and 3.

We compared these difficult concepts with the secondary school syllabus. In this contrast we observed that most of the difficult concepts are previously covered in secondary education courses, although a few are new to the students. In mathematics, all 15 questions are included in the syllabus, but in physics the three questions on thermodynamics and one on electromagnetism did not appear on the syllabus. These questions are the following:

THERMODYNAMICS:
- Pressure-volume graphics.
- Thermal expansion problems (linear, superficial and cubic expansion).
- Definitions and expressions of: isothermal, isochoric, isobaric, adiabatic.
ELECTROMAGNETISM:
- Electric flux concept

TABLE 1

We obtained 15 questions with the results of the test, but we also wished to know the opinion of the teachers, as they can tell us whether these questions are really the most difficult, and whether they agree with the need for creating interactive material. A survey was therefore drawn up with the 15 questions, as shown in tables 2 and 3.

SURVEY OF POSSIBLE DIFFICULTIES FOR INCOMING STUDENTS IN PHYSICS

Mark from 0 to 10 the importance in your subject of the following fields of physics, and indicate what kind of application would help to clarify better the concepts: animation or interactive graphic program.

1. MECHANICS:	**MARK**	**ANIMATION**	**INTERACTIVE P**
- Curved and circular motion (angular velocity and acceleration)			
- Centrifugal and centripetal forces.			
- Angular momentum problems.			
2. THERMODYNAMICS:			
- Pressure-volume graphics.			
- Thermal expansion problems (linear, superficial and cubic expansion)			
- Definitions and expressions of: isothermal, isochoric, isobaric, adiabatic.			
3. ELECTROMAGNETISM:			
- Problems of magnetic fields generated by inductors			
- Electric flux concept			
- Circuit resolution (Ohm's law)			
4. OPTICS:			
- Thin lens problems			
- Light dispersion concept			
- Refractive index			
5. MODERN PHYSICS:			
- De Broglie wavelength.			
- Energies in the theory of relativity (kinetic energy and rest energy			
- The Heisenberg uncertainty principle			
6. SUGGESTIONS. Indicate any new concepts you consider appropriate for inclusion in addition to the above.			
1)			
2)			
3)			
4)			

TABLE 2

SURVEY OF POSSIBLE DIFFICULTIES FOR INCOMING STUDENTS IN MATHEMATICS

Mark from 0 to 10 the importance in your subject of the following fields of mathematics, and indicate what kind of application would help to clarify better the concepts: animation or interactive graphic program.

1. ARITHMETIC	**MARK**	**ANIMATION**	**INTERACTIVE P**
Calculations with powers and roots			
Concepts of geometric progression and arithmetic progression			
Calculations with complex numbers			
2. ALGEBRA			
Solving simultaneous equations			
Definition of homogeneous equations			
Solving algebraic equations of degree n>2			
Complex number algebra			
3. CALCULUS			
Calculations with logarithms			
Solve limits of a sequence			
4. GEOMETRY			
Analytic geometry (straight line, plane, ellipse, hyperbola, parabola)			
Trigonometry (triangles: secant, cosecant…)			
5. PROBABILITY			
Concept of conditional probability			
Statistical independence			
Variations, permutations and combinations			
Concept of success			
6. SUGGESTIONS. Indicate any new concepts you consider appropriate for inclusion in addition to the above.			
1)			
2)			
3)			
4)			

TABLE 3

In the survey we also ask the level of difficulty of every question, and whether the respondent considers it better to use an interactive program or an animation. We also provide a space for any new difficult concepts that the respondent, as a teacher, might have found in the students. The survey will be sent by e-mail to all first-year mathematics and physics teachers in every technical university in the UPM, particularly to those teaching pre-university courses. These one-month courses are offered in the Technical School of Engineering in order to complement the knowledge of the incoming students in certain subjects. We specifically ask these teachers, as they are best placed to provide an assessment of the difficulties experienced by new students. For this reason we pay particular attention to their suggestions.

In order to conduct the survey and obtain the results, a seminar, entitled "Researching by means of Surveys", is to be held in March. This is an open seminar for 30 teachers and students interested in this method of investigation. It has a duration of 20 hours (8 theory and 12 practical) divided over four days, namely March 25, 26, 27, 28. The programme will be:

I- Researching by means of surveys. The population and the sample. How to design a questionnaire.
II- Conducting the surveys. Resources and methods.
III- Statistical analysis of the results.
IV- Develop of conclusions and verifying the survey.

2.1.3 Comparing the data.

The results of the survey will provide us with the questions on the most difficult concepts for the students. These concepts will assist us in creating a course in each subject. The course will be structured into a minimum of 10 independent didactic units, one on each question, which will include the theoretical development of the question and its application to the interactive didactic materials, as well as some practical examples for the better understanding of the student.

2.2 Selection of interactive didactic materials.

This is the phase in which we are currently working; it involves finding the most useful software to apply for each question. We will conduct a seminar on the Descartes software, and then create the multimedia material.

2.2.1 Search for software

We require a software that is simple to work with, and which allows us to formulate graphic questions and problems to solve these difficult concepts. In graphic questions and problems we include animations, videos and interactive problems, where the student can change the initial conditions in order to observe different reactions.

Applet Descartes is a software that has been developed by the Education and Science Department. The creation of this software is included in the Descartes research project (for mathematics) and the Newton research project (for physics). These two projects were established in order to provide secondary school teachers with a new multimedia tool which could be used to improve their explanations. Descartes [1] and Newton [2] also have a web page where there are applets and some theoretical concepts from the various secondary school courses. This page is continually expanding as teachers upload applets. The web pages are also designed for use by the students, and allow them to develop the concepts learned in secondary school, and to practise them in the applets.

The software has already been used previously by the education innovation research group entitled "Técnicas cuantitativas para la ingeniería medioambiental" ("Quantitative techniques for environmental engineering"). Descartes has been used to explain some concepts to the students [3], and to encourage the students to do some work in Descartes [4]. Descartes is very useful to our research project and we intend to use it for process of assembling the multimedia material. The basic structure of our courses will be similar to that of the Descartes and Newton research projects. For this reason, and as we intend to use the

Descartes software, we are holding a seminar on Descartes. This seminar will be open to both teachers and students.

Descartes is only one of the software programs we will use. We are searching for software to help us in developing the multimedia material. As our aim is for all the students to have access to our material from their homes or technical universities, the software that we use must be freely accessible.

Another software program we intend to use is Interactive Physics 2005®, developed by physics teachers from the United States as a tool for explaining concepts in physics. This provides a very useful tool for solving problems in physics. Interactive Physics includes some predetermined physical laws, and this makes it easier to provide complex programs. Interactive Physics is not free-access software, but the outputs of this software can be transformed into digital videos, which will be included in our course.

We will also use a software program that allows us to explain concepts in physics using real videos of physical examples, recorded by us. This software is called Measure Dynamics®.

We continue to search for additional software that could be of interest for use in our research project.

2.2.2 Development of interactive didactic materials

Once we have selected the appropriate software, we will begin to develop the courses.

First we will review all the material on the Descartes and Newton web pages and compare the material on both web pages with our questions. We will then compile all the applets that could be useful in the process of development of the multimedia material for courses. We will also develop animations and interactive programs with the selected software.

A group of teachers will be involved in the development of the programmes in order to create this multimedia material. Once this step is complete, the material will be structured and included in a context. As stated earlier, a ten-unit course will be created for each discipline. The units will include the theoretical development of the question and its application to the interactive didactic materials, as well as some practical examples for the better understanding of the student. Our intention is that every unit should be enough to enable the student to fully understand the concept.

Two courses will be created: one for mathematics and one for physics. Each course will contain the questions obtained from the survey.

2.3 Incorporation of the interactive didactic materials.

When the two courses have been completed, they will be incorporated onto the platforms in order to make them accessible by the students. There are three principal platforms that are suitable for disseminating the results of our research project.

The first is the UPM's 'Starting Point". This web page will enable us to reach to the maximum number of students. Our courses will serve to improve the content of this UPM web page. We have compared the level of knowledge that the students have when they finish secondary school with the level required of them by the university, and we have filled in the gaps. This is how we can improve 'Starting Point'.

The other two platforms are both from the Education and Science Department: the Descartes and Newton research projects. As stated, we obtained some information from these projects, and our results will in turn increase the level of the Descartes and Newton projects, thereby providing the chance for students in their last year of secondary education to start on their way into university. Our programme can be used by secondary school teachers in order to highlight any weak points in the knowledge the students will need in university.

We also consider that it would be useful to include our work in pre-university courses (one-month courses for incoming students). This would provide a support to the structure of the pre-university course.

A statistical study should be conducted in order to verify the effects of including our courses into the training projects for incoming students. This study should compare results of the test done by the students this year (in September 2007, without using the multimedia support that we in the process of developing), with the results of next year's test. This study cannot be included in this research project due to its duration; it therefore needs to be covered in future research projects.

3. CONCLUSIONS.

As the project is in progress, there are still no overall conclusions available. However, the fact is that incoming students have a range of problems on entry into university. Our work has demonstrated that the origin of the problems lies in certain gaps in the students' knowledge. This lack of knowledge is in some cases due to the secondary school syllabus, and in other cases the origin is not defined. In order to solve these problems we will create some interactive didactic materials to help students on their entry in the university.

References

[1] http://descartes.cnice.mecd.es/
[2] http://newton.cnice.mecd.es/
[3] Tévar Sanz, G. y Grande Ortiz, M.A. "Un sistema de Applets para la enseñanza de la Cinemática Plana". Congress: 4º Simposio Iberoamericano de Educación, Cibernética e Informática (SIECI 2007). Made in Orlando, Florida (USA) 12-15 July 200. Published in Mendez-Vilas et al (eds.), Current developments in technology assisted education (2006) Vol. 2 pp:1319-1321.
[4] Tévar Sanz, G.; Grande Ortiz, M.A. & Ayuga Téllez, E. "The creation of applets by the students of Mechanics in the E.T.S.I. Montes (U.P.M.)" Congress: IV Conferencia Internacional sobre multimedia y tecnologías de la información y comunicación en educación. Made in Sevilla (Spain) 22-25 September 2006. Published in the reports of the congress, second volume, pp 63-67.