

An experience in learning in an open and online course on computational Physics at undergraduate level



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(Received 8 August 2011, accepted 15 October 2011)

Abstract

This work describes the experience of developing an undergraduate learner-centered course in the program in Physics at the University of Sonora (Mexico), in the context of an open social learning environment, supported by Web 2.0 tools, open educational resources and free and open source software. The course focuses in developing skills in the use of scientific software tools and programming environments used in real life scientific computing. Simultaneously, it promotes the development of transverse skills such as reading in a foreign language, writing scientific papers, collaborative work, time management and self directed learning. The course topics in Computational Physics are used to situate learning in subjects that students already know and are familiar from previous courses, but with a higher level of complexity, which can be studied using appropriate computational tools that enables a more in-depth knowledge, easing answers to new derived questions in a specific physical phenomenon. As a result of these experiences, students that have passed the course, not only acknowledge that they have achieved a higher level knowledge about certain Physics topics, but in addition, they began to develop a working methodology and have experienced a change in attitude towards meeting new challenges as those presented in the course.

Keywords: Computational physics, situated learning, blended learning, open learning environments, open educational resources.

Resumen

Se presenta la experiencia de un curso de la Licenciatura en Física de la Universidad de Sonora, en modalidad híbrida, centrado en el aprendizaje y ubicado en un entorno social de aprendizaje abierto, apoyado por herramientas de la web 2.0 gratuitas en línea, con recursos educativos abiertos y software libre. El curso se orienta al desarrollo de habilidades en el manejo de herramientas y ambientes de programación que se utilizan en entornos reales de investigación apoyada en cómputo científico. En paralelo, se generan habilidades transversales tales como lectura en un segundo idioma, redacción de documentos científicos, trabajo colaborativo, administración del tiempo y autogestión del aprendizaje. Los temas del curso de Física Computacional dan la pauta para situar el aprendizaje en temas asimilados por los estudiantes en asignaturas previas, pero con un nivel de complejidad mayor, y apoyarse en herramientas computacionales que, en conjunto, permiten profundizar y responder preguntas sobre un determinado aspecto de un fenómeno físico. Como resultado de esta experiencia, los estudiantes además de aprobar su curso y profundizar en sus conocimientos disciplinares, expresaron haber desarrollado una nueva metodología de trabajo y un cambio de actitud ante los retos presentados durante el curso.

Palabras clave: Física computacional, aprendizaje situado, aprendizaje mezclado, ambientes de aprendizaje abiertos, recursos educativos abiertos.

PACS: 01.40.-d, 01.40.Ha, 01.40.gb

ISSN 1870-9095

I. INTRODUCTION

The Computational Physics Course (CPC) was designed for intermediate university students. Taking into account their age and maturity level, we consider the 6 principles of andragogy or adult education theory developed by Malcom Knowles [1]:

- ▲ Adults need to know the reason for which they must to learn something (*Need to know*).
- ▲ Experience (including mistakes), provides the basis for all learning activities (*Foundation*).
- ▲ Adults need to be responsible for their education decisions; getting involved in planning and evaluating their learning (*Self concept*).

- ^ Adults are interested in learning topics that have immediate relevance in their work and/or personal lives (*Readiness*).
- ^ Learning in adults is more problem-centered than contents-oriented (*Orientation*).
- ^ Adults respond better to internal rather than external motivators (*Motivation*).

In parallel, associated with adult education, are the theories of situated learning of the cognitive anthropologists Jean Lave and Etienne Wenger [3], Hansman [4]. Situated learning, as a learning model in a community of practice, states that learning should not be viewed as a simple knowledge transmission in abstract and out of context from one person to another, but as a social process where knowledge is co-constructed in a specific context embedded in a particular social and physical environment. This type of learning allows a person (student/learner) to learn by socialization, visualization and imitation. A Community of Practice is a group of persons that share a common interest, activity or craft.

According to Hung [5], learning begins when people try to solve a problem. When learning is problem based (PBL), people explore real life situations to find answers or to solve a specific situation. The study carried out by Hung, focuses on the importance of being social in learning. Learners immersed in communities with common interests, tend to benefit from knowledge of those who know more than them. When students are in real situations, they take the initiative to learn more. PBL helps students in developing higher level thinking skills. On the other hand, to facilitate learning management in adults, there are two very useful tools:

- ^ Learning plan
- ^ e-Portfolio (*e-folio*)

A *learning plan*, consists of a description of a series of actions or activities to be done and learning goals to be accomplished within a finite time framework. To each action or activity, one or more resources (digital or human) are associated and one product is required, as an evidence of accomplishing the learning goal.

The *e-Portfolio*, *electronic portfolio* or *e-folio*, is an online collection of electronic evidences managed and updated by the own user/learner.

Taking into account all the elements above mentioned, the educational design of a nonconventional Computational Physics course was carried out.

II. METHODOLOGY

Computational Physics, like Mathematics, allow the study of physical phenomena described by mathematical models for which a solution is sought, being this by means of either an analytic algebraic manipulation of equations or a numerical simulation. Both disciplines are very broad, like Physics.

The design of a semester course in computational physics, must hence focus on skills development in students

for working in scientific computing, taking into account his/her academic background in order to be in a better position to manage the required computational work for solving a given physical problem.

The vast majority of real physical problems, are first described by simple mathematical models. As further additional characteristics are incorporated to these models, then nonlinear terms may appear, equation coupling terms need to be considered, or maybe a more complex model has to be introduced, among multiple possible scenarios. In such cases, solution options need to be explored, being by linearizing the mathematical model, start with particular solutions to construct more general solutions, use perturbation theory, asymptotic analysis or many other appropriate mathematical techniques used as opportunities to extend our knowledge of any given physical phenomenon.

The working tools and methods used in computational physics in general, extend our basic cognitive capabilities, and in a real situation having developed the required skills, we are able to select the appropriate ones or look for those that can help us solve a given problem.

A. Context of the Computational Physics Course (CPC)

The course is planned for the fourth semester of the Bachelor in Physics program; it has as prerequisite having approved and passed three courses: Ordinary Differential Equations, Programming and FORTRAN Language. It is part of the mandatory professional courses of the program, which has the goal *to train the student in the use of experimental techniques, giving him/her the analytic methods, numerical and computational techniques needed for his/her professional development* (Bachelor in Physics program, 2009) [2]. The CPC course, focuses on developing students' capability to solve physical problems that involve algebraic or matrix problems, as well as those which involve the use of ordinary differential equations.

Specific Skills:

1. Install and configure software applications and tools.
2. Work in diverse operating systems and configure program development environments.
3. Use of an ASCII text editor, for working in programming environments.
4. Construct function and collected data graphics for their analysis.
5. Scientific document preparation that include mathematical equations, tables and graphics.
6. Use of scientific programming languages and specialized software libraries.
7. Select appropriate algorithms for the numeric solution of ordinary differential equations.
8. Use of general computational algebra systems for symbolic manipulation, numerical solutions and visualization.

Transversal skills:

1. Scientific and technical document composition.
2. Reading in a second language different to their native language.
3. Use of Information and Communication Technologies (ICT).
4. Time management.
5. Complex thinking.
6. Self learning.
7. Problem solving in holistic form.
8. Collaborative work.

In the course offered during Spring 2011, there were 10 students registered. In total, 8 approved and passed the course, and 2 abandoned it from the beginning.

B. Suggested and implemented didactic strategies

- a) Main strategies appearing in the CPC official program:
- ⤴ Learner centered, promoting active participation as well as skills development in the involved computational tools and methods.
 - ⤴ The course is carried out in a workshop format, under project and problem based learning models.
- b) Educational technology involved in the CPC.
- ⤴ A Linux based computer lab, with free and open source software composed of symbolic, numerical and visualization systems.
 - ⤴ Online content management system hosting contents, digital resources and activities descriptions for the students.
 - ⤴ Access to computer systems with the appropriate computational tools like high-level programming languages, computer algebra systems, electronic typographic systems and visualization tools.

C. Course development

The course is carried out as a workshop that includes individual as well as collaborative work. Face to face group sessions are organized at the beginning of each project, where the problem to be solved is presented. Each following problem has greater complexity level, and the student is required to connect to his previous knowledge in order to start analyzing possible solution scenarios. Also group sessions are carried out occasionally when all the students (individually or in group) cannot overcome a specific difficulty, and then a discussion is guided by the instructor in order to explore different solution strategies in order to advance in the problem solution. There are also periodic face to face individual sessions or thru a social network group, in order to do a follow up on students, to clarify doubts about the complexity of the problem or answer specific questions. This will depend on each student's individual learning curve, previous academic background and computational skills. The rest of the time, the student works autonomously and at some points in collaboration with fellow classmates.

The activities are done using a variety of platforms and free and open source software, which are mentioned in Table I.

The essential characteristic of these tools is, that they can be freely downloaded from the Internet and there are available versions for almost all operating systems (*Windows, MacOS, Linux* and others), or they are online tools that can be used thru any Internet web browser (*Firefox, Safari, Google Chrome, Opera, Internet Explorer* or other). These features allow versatility and portability for the user in any working environment. On the other hand, it helps the students develop the necessary skills to download, install and configure software tools on their personal computers or in the ones in the computer lab. In any case, the student has the choice of working in an environment that makes him feel comfortable or try a new one that more experienced classmates use.

TABLE I. List of software tools used during the CPC.

Purpose	Tool
Text Editor	Emacs [6]
Programming Languages	Fortran [7], Python [8]
Plotting tools	Gnuplot [9], Matplotlib [10]
Document preparation	LaTeX [11]
Computer Algebra System and Numerical Analysis	Maxima [12]
Operating system virtualization	VirtualBox [13]
Analysis and reflection about the learning process of each activity (metacognition)	Blogger [14]
Online publishing of products (milestone evidence)	Google Docs [15]

Regarding educational technology, online open educational resources are used like the ones available in Wikipedia, diverse online tutorials related to the use of specific software tools, open forums, and other relevant resources needed for specific activities.

For the organization of digital resources and online activities description, we have chronologically used different content management systems, like *Moodle.org*, *Grou.ps* [16], *Wikispaces.com* [17], and lately *Pbworks.com* [18] platforms, deciding accordingly to a criteria of accessibility, ease of online content and resources management, student coparticipation, and to provide open access to resources and activities.

During the CPC, it is expected that the students develop the required skills thru the following activities:

The construction of an e-folio that contains evidences of the student own skills development.

The student is required to open a Blog for the course, where he/she will describe his/her own learning experiences and also include the links to the online activities products.

This Blog is the basis for the e-folio construction that will host the CPC learning evidences and products.

Scientific document preparation with equations and graphics.

The first activities are planned to use the basic document preparation tools like the *Emacs* Editor and the electronic typographer *LaTeX*. The student is required to prepare a report of a project based on resources appearing in *Wikipedia* [19], where the research topic is described around a physical phenomenon, the history of the mathematical model involved or system of equations to be solved and if there is a known family of solutions. For example, the small amplitude pendulum has been used because it is a familiar subject to the students. The product document is prepared and compiled in *LaTeX* to produce a *PDF* format file, which is then uploaded and published in *Google Docs*. The student is required to create a new entry in his/her Blog, where he/she writes his/her thoughts about the learning process and possible personal difficulties that were needed to overcome.

Identify the elements and parts of a Python program code and modify it to solve a new problem.

In a second stage, a problem with a higher level of complexity is selected. The equation of motion or system of equations cannot be solved analytically, so a numerical approach can be used with a specific method or an appropriate algorithm. Several strategies apply here, one is to start from an available program code in a defined development environment that solves a close physical problem and modify it to solve the new problem. The students experience at first hand, establishing and modifying a working environment to solve the problem and answer the initial posed questions.


The product for this activity is a technical report, that describes the problem to solve, the involved mathematical model, the solution method used, the main results obtained in graphical form and the program code used to solve the problem in an appendix. The final report must be in *PDF* format and uploaded and published in *Google Docs*. In a new Blog entry, the student will comment his/her learning experiences and link to the product for this activity.


Problem solving using holistic thinking, aided by the computer algebra system *Maxima*.


The computer algebra system *Maxima*, offers not only algebraic manipulation capabilities, but also offers predetermined numerical methods and data visualization tools. A real life scenario in computational physics involves a set of tools for which skills are required to combine the strengths of each tool and being able to advance in the solution of any given problem.


III. RESULTS AND DISCUSSION


At the end of the course, students were asked to respond a poll of questions related with the CPC and are synthesized as follows:


 *Working format compared with other courses:* The students found the freedom to manage their time; they were free to ask and experience by themselves; they believe that PBL is more realistic.


 *Changes that were needed to do in order to work in this course:* Everyone was allowed to work at his/her own pace when other courses advance at the instructor's pace; they were allowed to experience without pressure, by establishing their own computational working environment and to solve problems in a heuristic form.

 *Course development activities that were considered as appropriate:* The course does not impose a learning ceiling; autonomy is granted to explore new problems and try to find possible solutions and ask for instructor assistance when needed.

 *Advantages of the course format:* Work is done at students' own pace, allowing each student the possibility of better organizing the general academic work load, not only the CPC one.

 *Disadvantages of the course format:* When students do not receive pressure from the instructor, there is a risk of relaxation of the overall activities, with a tendency to accumulate work for the end of the semester.

 *What was learned in the CPC:* The skills to learn new computational tools that are significative, because not only they were used for the course activities but were also used in other courses activities as well.

 *Suggestions for improving the course:* To have more frequent group sessions to share each student experience and *know how*.

In general, the satisfaction index is high, each person responding differently to the course workload. Some students require more help than others, specially in overcoming the resistance and fear to use of new computational tools or to experience different tools and computer environments. Without a daily pressure, where trial and error is allowed without penalization, students change their attitude towards working in a new field a bit unfamiliar at the beginning.

IV. CONCLUSIONS

The workshop format of the course, with complementary student's autonomous work, guided within a community of practice, fosters the development of skills, attitudes and knowledge described in the CPC program.

Furthermore, the fact that students have experienced by first hand a realistic working environment in computational physics, has shown them that the problems presented in the course can be addressed and solved in many ways as well as a variety of computational tools that can be used. In the same line of thought, it is very helpful to the student, that he/she can advance at his/her own pace in the activities and knowledge assimilation which can be community consensed among his/her peers.

Finally, it is highly significative and gives proof of accomplishment, that the student writes a technical report that is integrated in his/her e-folio, where the work, results, and answers are complemented by a reflexion about his/her own learning.

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