

A novel learning environment for undergraduate mathematics courses

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Abstract

This work presents a scaffolding design of learning objects as auxiliaries in the teaching-learning of mathematics at undergraduate level, through an electronic learning platform developed for using in formal mathematics courses. Its design is based on the results of surveying a group of mathematics teachers in the undergraduate fields of Science and Engineering in Mexico, about different aspects of their teaching practice. This survey is consistent with other national and international studies that highlight a series of problems found in the undergraduate fields of Science and Engineering. Guidelines for the development of this kind of learning objects were established, which leads to curricular changes that will result in an adequate process of integrating the use of technology in the classroom. An important feature of these objects is flexibility as they are helpful tools in the innovative design process. A grounded model for the creation of teaching materials is proposed, including elements that facilitate their use, and thus, it is concluded that the use of these tools is a factor that can help alleviate some of the learning problems currently present in undergraduate level mathematics courses.

Keywords: *Calculus, Evaluation, Learning environments, Learning objects, Undergraduate Education.*

Resumen

Este trabajo presenta las bases de diseño para objetos de aprendizaje como auxiliares en el proceso de enseñanza-aprendizaje de matemáticas en el nivel universitario, a través de una plataforma electrónica de aprendizaje desarrollada para su uso en cursos formales. Su diseño se fundamenta en los resultados de encuestas a un grupo de profesores de matemáticas en el área de Ingeniería y Ciencias en México, sobre diferentes aspectos de su práctica docente. Esta encuesta es consistente con otros estudios nacionales e internacionales que ponen de relieve una serie de problemas en esta área. Se establecen los lineamientos para la elaboración de este tipo de objetos de aprendizaje, que conducen a cambios curriculares y que se traducirá en un adecuado proceso de integración del uso de la tecnología en el aula. Una característica importante de estos objetos es la flexibilidad, ya que son herramientas útiles en el proceso de diseño innovador. Se propone el modelo para la creación de material didáctico, incluyendo los elementos de usabilidad, y por tanto, se concluye que el uso de estas herramientas es un factor que puede ayudar a aliviar algunos de los problemas de aprendizaje presentes en los cursos de matemáticas en la Universidad.

Palabras clave: *Ambientes de Aprendizaje, Cálculo, Educación Universitaria, Evaluación, Objetos de Aprendizaje.*

1. Introduction

For many years, the mathematics teaching followed a rote-based approach. Teachers presented and provided examples of routine concepts and techniques. Evaluations placed a greater value on algorithmic reasoning over the development of cognitive skills. In the rote-based scheme, students solved exercises and standard problems, following textbooks whose content was totally disconnected from the real world [3]. These practices have resulted in an overall rejection of mathematics and the mathematics learning by students. Also in this approach, professors play a very important part in the student learning. In the second half of the 20th century, a series of projects and changes in education resulted in innovative methods

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in the mathematics teaching which, nevertheless, have done little to alleviate these problems. In particular, these new methods have been unable to meet the learning demands of new generations, who are highly influenced by technology.

Although many changes have taken place in the mathematics teaching in Mexico over the last two decades, at all educational levels, each level has special needs and problems that must be addressed separately. This research focuses on the study of certain critical elements of the math educational process at higher education level, where students play now the most important part in their own learning. A strategy for the design of learning objects is presented, together with the development of a learning platform. This platform is based on novel teaching-learning models, and is supported by technological tools. In this proposal, the use of learning objects facilitates the innovative design to teachers, and the creative reasoning scaffolding to students.

The remainder of this paper is organized as follows: section 2 provides a brief overview on initiatives to strengthen the teaching-learning process by means of technology, learning environments, and learning objects. Section 3 fully describes the developed electronic environment. In section 4 we present the results about usability evaluation. Section 5 presents conclusions and future work.

2. Related work

Given that educational programs are not updated at the rate that social changes take place in the world, it is considered that traditional systems for the mathematics teaching do not meet the learning demands of the new generations. The works of Fernández [9] and Silva [29] point out the need of using new educational models, viewing learning as the central axis, and sharing knowledge at all levels in society, as well as having more appropriate technology-based methods for the improvement of teaching processes.

An innovative strategy that promises substantial change in the teaching-learning process is the use of new technological resources represented by information and communication technologies (ICT) with the aim of expanding the scope of learning at the different educational levels, from K-12 through university level [24]. These new strategies suggest the use of interactive and motivating approaches, while exploiting the medium of instruction inherent to ICT, computers and software designed for this purpose [14, 31].

In the last twenty years, major efforts have been made to introduce teaching-based technology in mathematics classrooms at different levels in formal education. The standards of the National Council of Teachers of Mathematics (NCTM) in the US consider information technologies and computers as means of supporting the mathematics learning from primary school through high school [22].

In Mexico, the federal government has been making great efforts to include technology-supported teaching methods within classrooms. An example of this is the “Encyclomedia” project [27], which featured interactive textbooks as part of the curricula in grades 5 and 6. This program created great expectations in both society and educational authorities; however, during the four years that it has been operating, there is no solid evidence of improvement in the quality of students’ mathematics learning. Rather, the academic and scientific

communities have criticized the program given its high costs, lack of teacher training, debatable education model, and poor management [28].

Another initiative carried out by groups of Mexican researchers, this is the case of the Center for Research in Mathematics (CIMAT). They created educational software for the teaching of geometry at higher education level. In the Center of Research and Advanced Studies of the National Polytechnic Institute (CINVESTAV), educational software for algebra and calculus at higher education level has been developed [19]. The efforts of the National Pedagogical University (UPN) to employ programmable calculators in mathematics courses at primary and secondary school level also stand out [6].

In the international context, research has been made into taking educational material available onto websites and using it in engineering programs, as seen in Humar et al. [11]. Thus, mathematics teachers are realizing the value of using computers in the teaching processes, for which they use educational software developed with generic software or a particular aim in mind.

There are other novel strategies for the math learning, such as the use of recreational mathematics to give students non-trivial mathematics problems with a recreational edge. The work of Schaffer and Douglas [26] and Averbach and Chein [2] also stand out, given that they used recreational mathematics in higher educational mathematics courses.

A strategy that is an alternative to the traditional approach is found in the work of López-Morteo and López [18] who present an approach based on recreational mathematics and the use of learning objects in an electronic learning environment. Learning objects are designed to utilize learning methodologies orientated to problem resolution while using interactive elements computers.

It is evident, from our diagnosis, that it is necessary to consider new learning schemes that feature information technologies and computers.

2.1 Learning environments

Learning environments are seen as the result of the interaction of both objective factors (e.g. physical, organizational, and social) as well as subjective factors (e.g. perceptual, cognitive, and cultural). Namely, we are always a part of, and immersed in, different environments. We create them, generate them, and live them. In this sense, learning environment integrates both pedagogical and a didactic proposal one that makes it possible to create an environment conducive to learning [8, 25].

The following learning environments are worth of mentioning: Intelligent Tutors, Learning Management Systems and Interactive Instructors of Recreational Mathematics Environments.

- *Intelligent Tutors* not only transmit knowledge, but they also evaluate students' results. Some of them engage in tutoring according to students' learning styles, in which tutoring is centered on modeling students' preferences, which implies various adjustments in the design of tutorials [5] according to the specific needs they were created for. In other cases, these systems allow for improvements in the learning process by adjusting contents and pedagogical strategies to students' capacities [4].
- *Learning Management Systems (LMS)* are installed in a server and allow us to manage, distribute and control teaching-learning activities, both in a classroom setting and also in e-learning format [33]. Their main functions include: managing users, resources and

learning activities, restricting access, controlling and doing follow-up of learning processes, evaluating tasks, creating reports, and promoting communication services such as discussion boards and video conferencing, among others [34]. Besides, an LMS generally does not allow users to create their own contents, but is centered on managing contents created by different sources. The creation of contents for courses is done through a Learning Content Management System.

- *The Interactive Instructors of Recreational Mathematics Environment* is defined as a collaborative platform for conveying mathematical knowledge. The conceptual model is designed for the exchange of information between its elements, and is based on a model made up by functional units organized in layers. Components are independent of each other, which makes possible to expand the system's functionality and management. This environment is an educational and holistic option, and it has a great potential for being implemented and helping promote the mathematics learning [16].

Some elements of the three models above were taken into account for the learning environment developed in our research, including learning objects design, to develop a learning management system that provides support to mathematics courses regarding the most important needs expressed by mathematics teachers [1].

2.2 Learning objects

Learning objects (LO) are an educational tool that can be used for curricular proposals and in various teaching-learning methodologies. A learning object is, first of all and generally, any digital resource that can be utilized to favor learning [13]. Chiappe et al. [7] regard LO as “self-contained, re-usable digital entity with a clear educational purpose, made up by at least three editable internal components: contents, learning activities and elements of contextualization. As a complement, LO must have an (external) information structure for an easier identification, storage and retrieval (metadata)”. According to the several authors, a LO must have the following elements [7, 10, 20]:

- Size: it must be a fine-grained unit such as a part of a lesson or unit.
- Re-usability: the capacity to be used in different units or learning activities.
- Accessibility: easy to locate and use.
- Impact: used not only as part of a LO, but also as a complement to other LOs.
- Durability: low maintenance.
- Interoperability: the capacity to be used in various technological platforms or in different course management systems.
- Flexibility: this allows integrate both students and teachers in a creative process. In the former, it stimulates reasoning, and in the latter, it facilitates design.

To fully use and maximize a specific LO, its design and use must have an appropriate framework, which can be an electronic environment. However, despite of the fact that conceptualization and usage of LO have proven essential in the creation of teaching and/or educational material that is digitally distributed in different educational projects [7, 17, 31], their appropriate and efficient use depends, to a great extend, on the context of the creative reasoning model and innovative design, and on the activities they are associated with. The formal scheme for learning objects that is presented in this paper is the Learning Unit (LU), whose key elements are learning objectives, activities, and actors. LUs are contained in a learning environment called ILPC developed by us. The learning environment has the resources and services necessary to realize the proposed activities, as it is considered that students learn while undertaking tasks in a given context, and LUs are the resources that

facilitate the tasks, and make meaningful learning possible, providing students with a framework that can be used in a asynchronous and synchronous way.

3. ILPC: the developed electronic environment

In this study, a LMS was developed. It has been conceived as an educational platform, and it was named Interactive Learning Platform for Calculus (ILPC). Its development is based on JetSpeed². JetSpeed is an open source platform with a component-based architecture under the license of Apache.

For the learning of Calculus the following functions for the system were established from the must-have list of the management system:

- Content creation: The platform must deal with content regardless of its presentation to end users. Thus, teachers will center their attention on content without worrying about the structure and approach in which it is presented to students.
- Content management: Allows uploading or erasing content, as well as searching and retrieval of all contents that have been created and added to the portal.
- Content publication: Regardless of the format, it allows for the control and display of content through the use of previously created templates, without changes in the display.
- Content presentation: The portal must offer the possibility of transforming all contents into HTML-format documents if they have a different format, which guarantees compatibility with all web browsers and platforms that are used. The use of technologies such as Java and JavaScript allow interactive content to be included, thus enhancing user experience, as this type of technology allows for the management of traditional HTML pages by incorporating elements that define a through the inclusion of dynamic behavior in web pages.

3.1 Design of the ILPC platform

For the design of the platform the following issues were taken into consideration:

- 1) Scalability of architecture, for which a component-based, layer-organized architectonic model was chosen.
- 2) System maintenance, so that corrections to flaws, updates and corrections to programming errors can be done agile and effective.
- 3) Platform structure, with the aim of selecting the units that make up the system.
- 4) Unit-based architecture, to maintain a degree of separation between elements in the platform and achieve a greater flexibility for system maintenance.
- 5) Pedagogical support based on learning objects and models for online contents design, cognitive models for the math learning, and strategies for competence-based learning [32].
- 6) Instructional design, which guides the development of all components and makes it possible to follow the structure of the contained elements.
- 7) Structure of the contained element, in which each of the aspects that must be tackled for all contents are specified.

3.2 Unit contents

² <http://jakarta.apache.org/jetspeed>

The following is specified the structure for each topic in terms of unit contents (fig.1):

- Competence: There are complex processes that people implement in terms of action-performance-creation with the intention of solving issues and carrying out certain activities, which in turn add to the construction and transformation of reality.
- Historical presentation: A component with historical elements that are related to particular concepts. The value of this component has been described in different works [21, 30, 35].
- Background: This refers to previous concepts or notions students will require to better understand each topic.
- Instructional content: Topics are divided into subtopics: Subtopic 1, Subtopic 2, ..., Subtopic n .

Supón que $f(x)$ es continua y no negativa para $a \leq x < \infty$ como se muestra en la figura siguiente:

Area de a a $r = \int_a^r f(x) dx$

Sabemos que la integral $\int_a^r f(x) dx$ es el área de la región entre la curva y el eje x , en el intervalo $[a,r]$. Cuando r tiende a infinito, el área es la región no limitada que se muestra enseguida:

Fig. 1. Unit contents of the Interactive Learning Platform for Calculus.

- Feedback exercises: Each topic has a series of exercises. Some are multiple-choice items, others are short answer items. The system validates their answers, grades them, and provides feedback.
- Evaluation: This section features exams per subtopic and per topic, and a final exam for the course. Evaluation is immediate and students are graded. Evaluations are also sent to the system's database for academic follow-up of students, and also to teachers' grades folder.

Each subtopic is conceived as a LO, and is made up by the following parts:

- Presentation: A detailed presentation of the subtopic is done, which includes the description of concepts, theorems, deductions, demonstrations, developments, exercises and generalizations. At time animations are also included to illustrate certain concepts.

- Activities: Problem cases or situations are presented for students to solve them during class.
- Auxiliary objects: They are materials designed in various formats: text, audio, web page, video, applet or any resource that can be accessed through an URL that supports the mathematical concept under study. An example of an auxiliary object is shown in figure 2.
- Solution: Cases or problem situations that were issued in the activities section are solved in detail.

Figure 2 shows a screenshot of an applet that corresponds to the topic ‘derivative concept’. The purpose of this LO is asking students to prove how the selected function and their derivative work, how it is expressed, and what its graphic behavior is. For this, students are requested to manipulate the object, varying each of the functions and changing the intervals, among others. This activity closes by asking students to present a function that is different to the one that was initially presented.

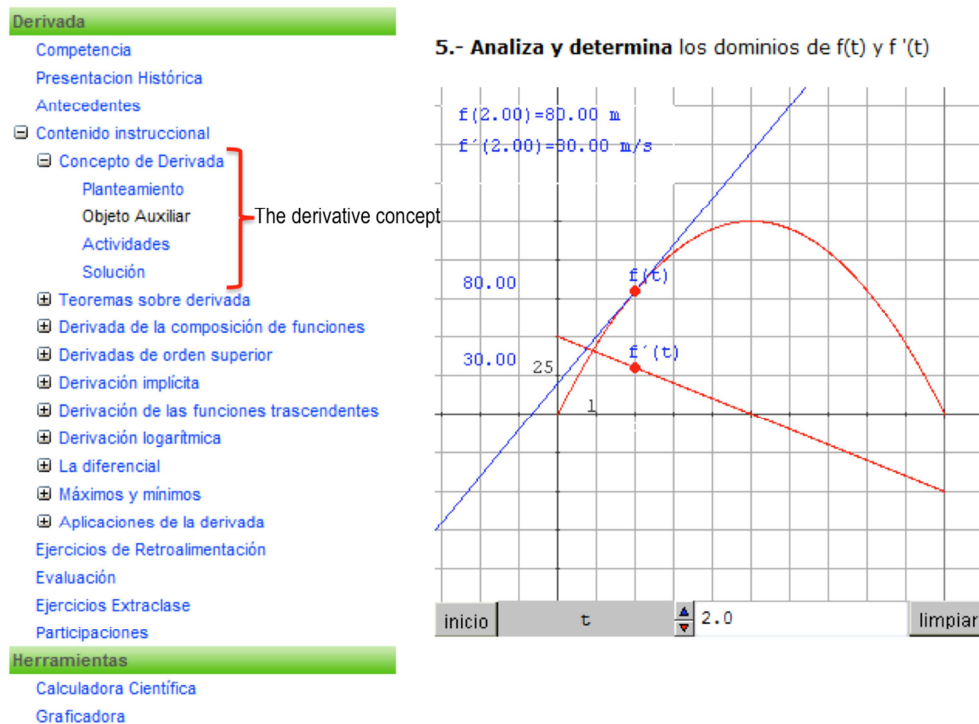


Fig. 2 Example of a learning object “Derivative concept” (‘Concepto de derivada’ in Spanish).

For the innovative design of each of the learning objects (cf. results section), it was necessary to:

- 1) Identify their purposes.
- 2) Select the technology to be used.
- 3) Generate its content.
- 4) Develop the LO using standards.
- 5) Evaluate the learning object.
- 6) Register the object metadata.

4. Results

In this section the results of the usability evaluation of the ILPC learning environment are described.

The learning environment ILPC, meets the requirements of standard learning objects [12, 15]. This platform contains the resources and services needed to perform the educational activities defined by the instructional design based on the TUM, so that students can use the learning environment to interact with the different LU that are part of a given course.

We assessed the following technological aspects of this platform from three approaches, according with Nielsen and Loranger [23], technical analysis, heuristic evaluation, and user test.

a) *Technical analysis*. This test was performed before the release of the learning environment, and was used to verify whether the system presented functional problems that needed to be corrected during the development phase. It was verified that the platform accomplished a series of technical requirements commonly associated with a web software application, namely testing the operation in different web browsers, checking that the hyperlinks work correctly, and reviewing the format of the content. At the end of this test, the 100% of these requirements were fulfilled satisfactorily [23].

b) *Heuristic evaluation*. This is a form of a usability evaluation, where usability specialists reviewed each element of the user interface following a list of established usability heuristics. The heuristics activities consisted of a free exploration within the learning environment. Then, evaluators were asked to write, using free-text style, their observations of any problems, inconsistencies, and weaknesses within the system.

The observations were arranged in descent order in agreement with its importance; indicating its frequency, impact and persistency. For this test, the participation of 5 experts: 2 designers, 1 teacher, 1 expert in educational technology and 1 professor of mathematics to evaluate the design and the usability of the platform were requested.

After the test, the evaluators assessed both the pedagogical and technological design, as well as the content. Each evaluator assigned a score in the scale of 0 to 10. On average, it scored 91% of acceptability.

c) *User test*. This test consisted of academic assignments for students that they have to complete within the platform. Students also had to answer questionnaires for evaluating three aspects of the interface: pedagogical design, functionality, and usability. The validation of these aspects was made by 65 students.

Regarding pedagogical design, all users successfully completed all the assignments, namely: create an account, log in the website, review a particular Calculus issue, and find tools to understand the issue, solve a problem on a specific topic, navigate from one topic to another, and manipulate a learning object.

For the functionality and usability evaluation of the platform, students answered a questionnaire based on a Likert scale with these three options: disagreement, regular agreement, and agreement. The questionnaire and the results are presented in table 1. The instrument designed was adapted from Nielsen and Loranger [23].

The items 1, 3, 4, 8, 18, and 20 correspond to the functionality evaluation. In this evaluation 88% of the students agree that the design of the interface and the functionality of the platform

are very good. Finally, the items 2, 5, 6, 7, 9-17, and 19 are used to evaluate the usability of ILPC. According with data in table 1, 84% of students agree that the usability of the platform is good.

	Dissagreement	Regular agreement	Agreement
1.- I can quickly find what I'm looking for at this site	1.5%	12.3%	86.2%
2.- This site is logical to me	3.1%	7.7%	89.2%
3.- The pages on this site are nice	1.5%	10.8%	87.7%
4.- I get what I want when I click on the links	0.0%	6.2%	93.8%
5.- I consider inappropriate font sizes, images and graphics	84.6%	9.2%	6.2%
6.- I think the site difficult to use	80.0%	12.3%	7.7%
7.- This site helps me find what I am looking for	1.5%	13.8%	84.6%
8.- Learning to find the pathway on this site is a problem	86.2%	10.8%	3.1%
9.- Everything on this site is easy to understand	3.1%	7.7%	89.2%
10.- The site activities are easy to perform	1.5%	6.2%	92.3%
11.- This site is very interesting to me	7.7%	15.4%	76.9%
12.- It is hard to tell if this website has what I want	6.2%	12.3%	81.5%
13.- The use of the environment motivated me to learn mathematics	6.2%	13.8%	80.0%
14.- The use of the site led me to explore concerns a different mathematics topic	4.6%	10.8%	84.6%
15.- I consider this site activities interesting	6.2%	13.8%	80.0%
16.- I need to learn many things before using the site	69.2%	21.5%	9.2%
17.- I would like to visit this site often	3.1%	7.7%	89.2%
18.- The instructions and warnings are helpful	7.7%	13.8%	78.5%
19.- The way the system information is presented is clear and understandable	1.5%	7.7%	90.8%
20.- The site responds too slowly to requests	95.4%	4.6%	0.0%

Table 1. Results of the evaluation of interface usability of the ILPC using scale Likert.

Considering these aspects, we averaged the data to obtain a global user test score as a measure of the overall experience of the users with the system in terms of usability. Thus we found that 86% of the students agree that the overall usability of the ILPC is also very good.

5. Conclusions

Information technologies must be used along with a psycho-pedagogical strategy, which look to offer students different learning resources. Student-centered learning requires that teachers understand, to a great extend, course contents, psycopedagogy techniques, and information technologies.

The platform presented here was developed as a supporting tool for the learning of Calculus at higher education level, and it features the use of LO within an innovative design approach.

Its contents are part of the mathematics curricula currently used in our school, and the creation of LO was based on standards.

In the development of learning management systems, such as the Interactive Learning Platform for Calculus (ILPC), incorporating and using information technologies helps students in their learning process and provides a balance point among knowledge, teacher, and student. The creation of this type of environment involves developing a scaffolding to support students and professors in the learning/teaching process, as the one we have described, based on an adequate selection and planning of learning strategies that make it possible to increase the achievement of learning targets.

To achieve the purpose of helping students in their learning process, in particular of mathematics, it is necessary to implement and evaluate this kind of platform with undergraduate groups for whom this Calculus course is a part of their curricula. Thus, the experiment phase and the analysis phase of the results of the implementation are future work.

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