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To cite this version:
Anny Becerra-Romero, Miguel Díaz-Rodríguez, Octavio Andrés González Estrada. Development of a virtual learning environment for the subject Numerical Methods under Moodle. 1er Congreso Internacional de Educación Virtual. Retos y oportunidades, Oct 2018, Bucaramanga, Colombia. hal-01883091

HAL Id: hal-01883091
https://hal.archives-ouvertes.fr/hal-01883091
Submitted on 27 Sep 2018

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Development of a virtual learning environment for the subject Numerical Methods under Moodle

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Abstract. Numerical Methods is a core subject for most graduate and undergraduate engineering curricula. The course topics are transversal to most of the applied science courses. That is, any specific topic can include a problem requiring a numerical solution. Thus, developing an improved educational strategy for this subject is of paramount importance. Virtual learning environments (VLE) offer a tool for improving students learning outcomes. In this paper, we describe how we build a VLE for the subject numerical methods, based on Moodle. We use GeoGebra software and R programming language to develop virtual-learning-objects (VLO). To engage students, we propose a problem-solving activity based on movie action sequences. Each topic starts out with a movie clip that using physics principles, one can get to a equation requiring a numerical solution. For example, we explain the methods for solving ordinary differential equation by modeling a parachute sequence from a James Bond movie. The activity allows students to discuss whether the movie sequence is possible or not. Finally, we present preliminary feedback obtained on a graduate course. Also, we discuss the answers from a instructional design questionnaire applied to the course.

1. Introduction

Nowadays, it is almost taken for granted that any subject within curricula is taught along with virtual learning environments (VLEs). Even if the course follows traditional lesson type where teachers deliver the content through a master class, the VLE helps as supporting material or at least it helps for managing the course content and marks. Moreover, VLEs are useful when teaching Science and Technology, in general because they permit the implementation of many learning objects such as: youtube videos, podcast, presentation slides, programming codes, and links to other websites or animations showing in a dynamic way simulations and concepts very difficult to understand by the students [1]. A VLE or also known as learning management system (LMS) is the environment where students and professors participate, and the e-learning takes place [2]. The implementation of LMS has been proved to be a successful for Knowledge Management within organizations [3].

On the other hand, in most of the engineering degree curricula, Numerical Methods is traditionally taught following comprehensive textbooks such as [4]. The subject presents
fundamental knowledge for most engineering programs at undergraduate and graduate level; thus, any strategy to enhance its understanding is valuable. In this sense, Ref. [5] reported that teaching numerical methods using VLE compared to traditional approaches presents a significant improvement in learning outcomes. Ref. [6] developed a meeting point in Moodle, for students of Numerical Methods for Computer Science Engineering at the University of Malaga. Results have also shown that VLE enhances students outcomes.

At Universidad de los Andes, Venezuela (ULA), the Coordinación General de Estudios Interactivos a Distancia (CEIDIS) (http://moodle.ula.ve/) have developed a Moodle platform for online courses such that it can serve as an alternative or complementary way of teaching, covering levels of undergraduate and graduate. The motivation of this paper is to showcase the VLE developed for teaching Numerical Methods which has been put forward following instructional design concepts described by CEIDIS as well as the authors’ own contributions. One of the novel aspects of the course is to capture students attention by introducing a problem-solving activity based on movie action sequences. Each topic presents a movie clip that can be stated as an engineering problem requiring a numerical solution, e.g., the motorbike jump sequence from Point Break movie. The jump can be described using a nonlinear equation admitting a numerical solution. Also, for enhancing the teaching experience, several virtual learning objects (VLO) have been selected from online resources or developed by the authors.

The paper is organized as follows, Section 2 introduces Numerical Methods course content. Section 3 describes the basic features of the Numerical Methods VLE. Section 4 shows the VLOs selected or developed for each course topic. Section 5 discusses the preliminary assessment of the course. Finally, conclusions and further works are presented.

2. Subject description

The subject Numerical Methods for Engineers provides a basic introduction to the methods available for the numerical solution of engineering problems. In order to implement the numerical solution, students have to develop programming skills. Software such as: Python, R, Matlab, C++, FORTRAN, can be used in laboratory sessions to learn how to program while implemented the specific numerical method being studied. The students take the course after the block of basic science knowledge: mathematics, calculus, physics, and before the block of subjects in which specific applied engineering knowledge are taught. Then, in subsequent courses students are able to implement numerical methods. For instance, in the Mechanical Engineering curricula at the Universidad de los Andes, Venezuela, the students can take the course in the fifth term (to obtain the degree the students have to course ten terms where each term last a semester). The topics included in the course are: solution of nonlinear equations and linear equations, data fitting through linear regression, interpolation, numerical integration, numerical differentiation, and solution of ordinary differential equations. The course is not intended to cover all numerical methods but rather to provide a basic skill set useful throughout their education.

As an example, one of the courses following numerical methods, we have the mechanism and machine theory course, specifically the position problem of a mechanism. When developing the equations related to the position problem, students often arrive at a set of nonlinear equations [7]. In a robotic course, the solution of the kinematic problem is related to solving a set of linear equations [8]. Further examples can be presented to highlight the importance of numerical methods which to our opinion is a transversal axis within engineering curricula.

At the end of the course, students are expected to understand and apply the methods for:

- Assessing the error or approximation of a numerical solution.
- Finding the numerical solution of a nonlinear equation.
- Finding the numerical solution of a linear equation.
- Finding the parameters of a linear model through linear regression.
- Computing the numerical integration of an equation.
- Computing the numerical derivative of an equation.
- Solving ordinary differential equations.

The course content is presented through six thematic blocks. The first block addresses the introduction putting emphasis on the importance of numerical methods, describing many examples where numerical methods can be applied. The second block describes methods for the solution of nonlinear equations, while the third block describes the solution of linear equations. The fourth block deals with the data fitting through linear regression, and how to model experimental data using linear models. The fifth block describes how to compute the numerical solution for differentiation or integration of equations. Finally, the last block refers to the solution of ordinary differential equations.

3. The virtual learning environment
We developed the structure of the VLE following the set of courses provided by CEIDIS, and the best practices on how to organize a Moodle course [9]. First, after studying the course’s content, we decided to take the Moodle Topic format. We split the course content in 10 topics. Each topic covering a specific numerical method, and they will be visible to the student after finishing the corresponding assignment of the previous topic. The topic starts out by setting the goals, answering what are the competencies students will expect to learn. Then, it follows the presentation of the learning material. After that, the topic includes an activity section where the learning objects are presented. The topic ends by assessing the learned skill through an evaluation activity. The structure of the topic is similar to the CEIDIS basic design course structure,

- Basic Competencies
- Content
- Activity
- Evaluation

Figure 1 shows an example of each topic structure, the figure specifically presents the content of topic two which is related to the errors and approximations underlying in a numerical solution. The topic follows the Introduction and precedes the topic on solving nonlinear equations.

The topics in the VLE are organized as follows:

- Introduction (Block 1)
- Errors and approximation (Block 1)
- Bisection and fixed-point iteration methods for solving nonlinear equations (Block 2)
- Newton-Raphson and Secant method for solving nonlinear equations (Block 2)
- Simple Gauss elimination method for solving linear equations (Block 3)
- Gauss-Jordan and Gauss-Seidel method for solving linear equations (Block 3)
- Data fitting (Block 4)
- Numerical Interpolation (Block 5)
- Numerical differentiation (Block 5)
- Numerical solution of Ordinary Differential Equations (Block 6)
First, each topic starts by describing the competencies. Then, the learning material is introduced after showing a movie clip related to a problem requiring a numerical solution. For instance, the teacher can start topic 3 by playing the video of the high-altitude low-opening (HALO) parachute jump sequence from the James Bond movies Tomorrow Never Dies. The HALO jump can be modeled through a differential equation that in the evaluation section will be solved by a numerical method. Due to the paper length limitation, we refer readers to see Ref. [10] to understand how mathematical equation for the movie sequence is developed. The topic include a forum section where students discuss whether the movie sequence is feasible or not, which engages his/her attention in understanding the problem and its solution. After presenting the motivation activity, each topic includes readings taken from the book Numerical Methods for Engineers [4]. As can be seen in Figure 1, the first topic includes three specific readings. Then, the topic presents activities so that the student can put in practices the knowledge presented in the content section. In the section of activity presents the learning objects to consolidate the learning outcomes. Then, the evaluation section include a forum where student can discuss the results found in the evaluation activity. The discussion section is open to any student so they can interact in a chat format.

Due to the fact that each block presents not only similarities but also differences, we develop for each block different learning objects which are presented in the following section.

4. Virtual learning objects
The similarity in all blocks is given by the fact the student must implement the corresponding method learned in the topic. Thus, a learning objective transversal to all the topic should be an activity based on developing programming skills. In our case, we take advantages of the R programming language; however, any high-level programming language can be selected for such activities.

4.1. Learning objects based on R programming language
We developed the programming objects in R based on the fact that is a free software available under the GNU General Public License, also it has high statistical and graphics tools that we want to implement in the Mechanical Engineering curriculum. When working at home, the students can combine R package with the graphical front-end RStudio which is one of the most
notably available free and open-source Integrated Development Environment (IDE). How to download and install R and RStudio is presented in topic one. Before sending the evaluation assignments, we demand the student to first test the code on SageMathCell [11] which is a web interface software system where you can run code in python, sage, R, and many other programming languages. In this way, we are able to evaluate the students by asking them to modify or implement a set of code in R-language. Then, they can copy and paste the code on the Moodle activity task tool. Thus, we avoid the issue of uploading or sending any file.

To exemplify the use of R as a learning object, the code for the topic 3 is presented below.

```r
# paramentros
a=0.2;#[m]
b=1.2;#[m]
c=0.75;#[mm]
d=1;#[m]
K1=d/a;
K2=d/c;
K3=(a^2-b^2+c^2+d^2)/(2*a*c);
theta_2=45*pi/180
f=function(x)K1*cos(x)-K2*cos(theta_2)
+K3-cos(theta_2-x);
curve(f,0,2*pi,n=2001)
abline(h=0,v=0,col="gray60")
a=1;b=2
tol=1e-5
iter=0
while(abs(b-a)*0.5>tol){
c=(a+b)/2
if(f(a)*f(c)<0){
b=c
}else{
a=c
}
iter=iter+1
}
print('Resultados')
print('theta_4_Iter_Error')
c((a+b)/2*180/pi,iter,(b-a))
```

The above example presents the code for solving a nonlinear equations through the Bisection method. The nonlinear equation is taken from the engineering problem presented in Ref. [12]. In the activity, students can copy and paste the code in his/her one IDE. Then, they can run it to interact with the results by modifying parameters of the numerical method, for instance changing the tolerance threshold parameters (tol). Finally, students can reuse the code when performing the evaluation task. For topic three, the task is based on solving the equation for projectile motion applied to the bike jump sequence presented in the movie Point Break [13].

4.2. Learning object based on GeoGebra

We use GeoGebra software for developing some of the learning objects. Objects created using GeoGebra have the potential that students can interact with the parameters of the numerical method being taught in a free and dynamic way, which helps to visualize the different behaviors through graphs. Students can estimate by their own guesses, ideas and conclusions, achieving a more lasting and significant learning through manipulation, exploration and experimentation [14]. The core of the method for blocks two and five of the course can be better explained using a graphical solution. Those blocks are suitable to develop a solution in GeoGebra making visual the interpretation of the method. As an example, Figure 2 shows the solution of a nonlinear equation through the fixed-point iteration method.

The use of GeoGebra presents the advantage that we can reuse lots of resources and objects already on the web. Thus, we did not have to develop new objects, remember that reuse of object is one of the advantages when developing web-based courses. Instead, we search in the Classroom Resources page of GeoGebra [17], which also provide the capability of sharing the object such that we can embed the object within the specific topic in the Moodle VLE.

The list of objects, topic and link to interact with the object is listed below,

- Topic 3, Bisection method [15]
- Topic 4, Fixed-point iteration method [17]
- Topic 4, Newton-Raphson method [18]
- Topic 8, Numerical integration [19]
4.3. Additional learning objects

The web offers lots of material we can reuse for different purposes, e.g., block one deals with the fact of how the significant figures are relevant to the numerical solution and the error. After conducting a web search, we found out an application to play and learn about significant figures [20]. The app randomly presents a number and the user has to answer how many significant figures have the displayed number. In this way, the students self-evaluate his/her ability to identify significant figures. The activity section of topic one includes a link to the app, see Fig. 1, the app can serve as a learning object.

5. Preliminary assessment of the course

The course was taught to graduate students following an hybrid approach. That is, both online and face-to-face components were implemented. The course normally is based on 4 hours face-to-face week lectures. In the hybrid approach, students interact only 2 hours. Seven students, which scored above 80 scale from 0 to 100 points, participated. Each assignment was performed in due time. The activities showed positive feedback, and lots of discussions were presented in the forum section. Participants gave a mean score of 4.4, scale from 1 to 5, when asked for the activity regarding the movie sequence. In some movie clips, the students agreed clips were feasible, based on their own numbers, while others found out the clip was unfeasible. However, one of the students claimed that at the end it is a movie, so action sequences even if they are not feasible as long as they are good enough to entertain they are worth.

In addition, the VLE was evaluated by an expert under the subject on analysis of an instructional design of the Master Degree in Educación Informática y Diseño Instructional, at the Universidad de los Andes. Overall, the expert provided positive feedback. With respect to the cognitive aspects, the VLE was developed following a constructivist approach. The comprehension of the learning material is based on cognitive operations such as logic operation and reasoning. The VLE promotes active participation through forums using written language, the resolution of the assigned activities, review of the material in a visual way or through podcasts, reading skills, the searching of information for choice concepts, similar applications, observation and discussion of results, and also the VLE presents results graphically in an on-line simulator.

With respect to the behavioral aspects, the VLE presents a sequential order to each assigned activity and questions so that the students achieve the competencies that will enable them to provide solutions to the problems presented. Students have to repeat the step shown through tutorials, e.g., to install the R program used during the programming assignments. The VLE promotes the interaction with their peers through the chat platform. To enhance the student mental processes, the VLE presents the instructions through readings in which the teacher...
developed the particular activity. Thus, students can take notes, view and listen to the tutorial videos on their computer and install the program to use, participate in written in forums either by giving their perception or asking questions, clicking on the documents to download. Students have to complete written activities, practical exercises in the R-program and write the conclusions based on the results.

With respect to the constructive aspect, student are expected to ask questions on the forum section, comment on what they have learned relying on previous knowledge, provide solutions to practical exercises, build numerical calculation using RStudio, develop numerical solutions to engineering problems, interpret the results obtained from a numerical solution, and recognize that numerical methods represent approximate solutions.

Finally, the expert recommended that the VLE has to extend the constructive approach from individual learning as it is right now for an approach based on collaborative learning. For instance, the VLE can include a project where each student can write a part of code that combined together they can solve the task at hand. In addition, the actual design of the VLE only allow the construction of knowledge within the VLE, they recommend building knowledge outside the VLE.

6. Conclusions

In this paper, we have showcased a VLE developed in Moodle for teaching Numerical Methods. The course structure, and the learning objects designed for the course have been also presented. In addition, we have discussed the preliminary assessment of the course based on its implementation in a graduate course, and also from a questionnaire applied for an expert on instructional design. The developed VLE represents a tool for e-learning, blended learning or flipping classroom strategies. Currently, the course is being evaluated on undergraduate courses, future works will provide the assessment from students feedback.

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