DEVELOPMENT OF AN ONLINE TOOL BASED ON CFD AND OBJECT-ORIENTED PROGRAMMING TO SUPPORT TEACHING FLUID MECHANICS

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ABSTRACT

Fluid Mechanics is one of the most complex branches of science to learn. Traditionally, it has been taught from a positivism point of view. However, the latest technologies have led to the creation of new educational tools based on a constructivism approach as a complement to conventional teaching. This paper addresses the development of a course to spread knowledge related to Fluid Mechanics. It combines theoretical explanations with interactive applications to allow the student to assimilate the information easier. Computational Fluid Dynamic simulations have been performed to create the educational content shown in the applications. Users will be able to select from different boundary conditions, and the program will display the corresponding simulation results. Therefore, motivation is generated through gamification, retention is generated based on the Multimedia Learning Theory and transfer is generated by inductive teaching. A preliminary version of this course has been launched to a group of users with previous knowledge in Fluid Mechanics. The results indicate how users support the inclusion of multimedia and interactive tools in conventional teaching, because they help them to assimilate complex concepts. Furthermore, the created tool has been endorsed by the users in terms of organization and quality. The adaptation of current resources, such as CFD, to teaching Fluid Mechanics is an evident need that enriches both the student and the teacher. Thus, the educational goals of motivation and knowledge transfer are promoted under the auspices of a constructivism approach.

KEYWORDS

Fluid Mechanics, Educational Software, Distance Learning, Simulation

1. INTRODUCTION

It is a fact that education is one of the most important pillars on which modern society is based (Galor, 2011), and technology is one of the most powerful driving forces for change (McClure, 1991). Consequently, computers become more powerful, manufacturing machines become more advanced and metrology instruments become more accurate; therefore, the adaptation of the current education to the newest technologies is a clear necessity (Hernández, 2008). Future professionals and workers should be educated in accordance with new technological paradigms as well as social paradigms, such as globalization, and the digitalization of information should be considered (Cheng, 2005).

Fluid Mechanics is the branch of science that addresses the study of fluids, either in motion or at rest (White, 2008); it is a subject with a greater mathematical basis in any scientific degree. Furthermore, Fluid Mechanics is one of the most difficult subjects to understand. However, the primary objective of those teaching Fluid Mechanics is typically focused on students' understanding beyond extensive but necessary numerical developments. Nevertheless, this educational goal based on understanding, which was previously a considerable challenge for teachers, must take advantage of the synergies of these new social and technological paradigms to simplify and improve the educational experience of students studying Fluid Mechanics.

Furthermore, as a primary result of computing and the current trend towards globalization, digitalization and universal access to education, an early educational model known as MOOC was recently developed. This model, whose acronym corresponds to Massive Open Online Courses, is characterized by web development, i.e., making use of the facilities allowed by this type of approach, such as multimedia, encouraging user interaction or flexible timetables (Ruiz, 2015). Therefore, its onset presents a new framework in relation to the development of educational actions to improve the understanding and spread of Fluid Mechanics. Additionally, they are designed for massive distribution, thus providing free access to all their content in spite of the fact that semi-commercial platforms, such as edX or Coursera, have existed since 2011. These platforms provide additional services, such as verified certificates or online meetings, in exchange for a fee, thus leaving authors wondering if this funding model is legal (Daniel et al, 2015).

In 2012, an article titled "The year of MOOC" was published by The New York Times. The Massachusetts Institute of Technology (MIT) announced that the MOOC model was the most important educational innovation over the last 200 years (Regalado, 2012). Additionally, engineering students can benefit from these types of initiatives. Hence, the "Circuits and electronics (6002x)" course, which was developed by MIT in 2012 (for 155,000 students initially enrolled), has been one of the most important and analysed MOOCs in history (Breslow et al. 2013). This course has been a turning point when considering the volume of users. It was taken by students from 194 countries, who were encouraged by the knowledge they could obtain. However, this course was only completed by 5 percent of the users, and decreasing the dropout rates is one of the largest challenges that needed to be overcome by the MOOC model to ensure global and universal access (Brahimi & Sarirete, 2015). The current trend holds important demographic imbalances caused by the detriment of developing countries (Hone & El Said, 2016). However, there have been projects that have considered the education of people who are at risk of social exclusion.

Furthermore, engineering courses such as "Circuits and electronics (6002x)" typically add a few features to encourage learning support, e.g., virtual laboratories, where students will be able to assemble electronic and electrical circuits for testing, as well as other branches of science, such as medicine, which also includes numerical simulations of complex biological processes with an educational goal (Christ & Thews, 2016). Moreover, Computational Fluids Dynamics (CFD) is one of the most powerful tools used for the study of Fluid Mechanics (White, 2008), which consist of a set of numerical methods whose final objective is to obtain a numerical approach (Jiyuan et al, 2008). As well as circuit simulation programs are essential to electronic education innovation, CFD can be an important tool for learning Fluid Mechanics remotely.

In fact, the purpose of this paper is to provide a description of the development of an online course as a tool to support learning Fluid Mechanics using CFD and object-oriented programing to allow users to understand the main effects and principles of this branch of science easily.

2. DESCRIPTION

The solution to the proposed problem involves the integration of three different action lines, as depicted in Figure 1, because the development of a course structure is needed to add the educational content that will guide the user through the Fluid Mechanics topics. eXeLearning, which is an open software used for educational web content development, will be used for this purpose. Although this tool traces its origins to 2007 in New Zealand, the Spanish educative authorities took charge of project management in 2010 and has enabled HTML5 content format development since 2013 (Aznar, 2016). Furthermore, the course must be distributed online; thus, as a complement to eXeLearning, a file hosting service will be used as a cloud hosting server by sharing the public link of an "Index.html" file of the course, which will allow the home page to be viewed.

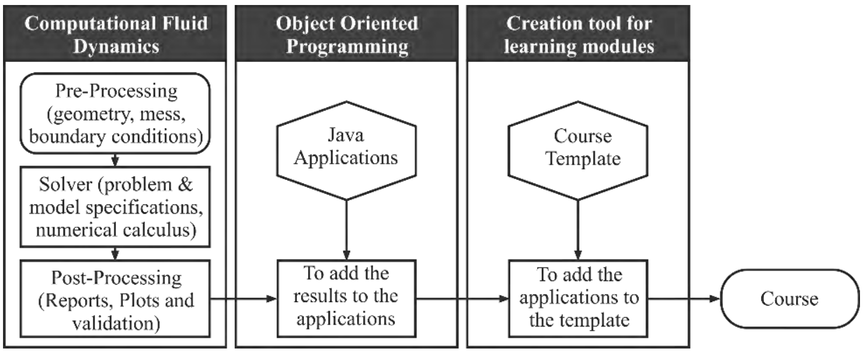

Figure 1. Action lines

Conversely, it is necessary to encourage autonomous learning and provide tools to ensure the interaction between the student and the system. Thereby, CFD will be used with a different goal in regards to the primary two objectives that have sustained its development. Instead of being used to solve industrial fluid flows or for research purposes, CFD will be used for an educational goal, thus allowing the development of realistic simulations to represent the primary effects and principles of Fluid Mechanics to students. It should be noted that unlike other initiatives, such as the CFD Educational Interface described by Stern et al. (2006), this tool does not inform the student regarding the preparation or launch of these type of simulations; it instead uses its results as a learning vehicle.

Additionally, CFD allows avoiding one of the largest problems in teaching Fluid Mechanics. It is necessary to teach a branch of science supported by such a powerful mathematical basis to the general public, without allowing a lack of advanced mathematical knowledge to keep students from completing the course. Non-engineer users interested in science and knowledge must be able to learn the primary topics right from the start whereas engineer users may use this course as complementary to their conventional teaching.

The user must be able to confidently handle a large volume of graphical results, such as contour maps and streamlines. At this stage, the object-oriented programing will be used as the third action line to create graphical interfaces allowing the selection between predefined boundary conditions; thus, the student can observe the influences of the primary variables on the desired effect or principle based on a comparison between the simulations shown.

3. METHODOLOGY

As previously stated, eXeLearning enables the creation of the web pages that will constitute the course. These pages will be related to each other in the order mark by an index whereas the program will independently create the hyperlinks between these items, thus allowing the user to move from one page to another by a simple click of the mouse. Each of these pages represents the HTML file that would be shown using a web browser. Furthermore, if the created contents are saved as a self-container folder, which is one of the exportation actions allowed by the software, it is possible to guarantee online access to the course by hosting those files on a cloud file service and sharing the URL of the "Index.html" file. Thus, it is possible to launch a preliminary version by minimizing the cost required in comparison to acquire a proprietary domain.

3.1 Course Topics

The first topic is based on previous Fluid Mechanics ideas: viscosity and density properties, surface tension and types of flow. Using aeronautic principles, the flow over simple geometric shapes has been considered. Different object sizes and flow velocities have been analysed to visualize the trail type relative to the Reynolds number. Values ranging between (48-180) require special attention because that is where the Von Karman effect occurs (Rajani et al, 2009). These phenomena are an expression of the drag force; however, this force is not the only one. Lift force, which is responsible for the flight of an airplane or the deflection of a rotating sphere from its main flight path, is also taught in this topic. Jet propulsion will be considered in an additional module, which is the high speed ejection of a gas from a combustion chamber at high pressure.

Furthermore, there are two modules that address Bernoulli's principle. The first one is Torricelli's law, which describes the flow of a fluid in a tank discharge. The second one is the Venturi effect, in which a fluid through a lower section in a pipe increases its dynamic pressure while simultaneously decreasing its static pressure. Both of these phenomena are a consequence of the same equation, the Bernoulli's principle. This principle emphasizes that the energy per unit volume must remain constant along a streamline.

3.2 CFD Simulations

CFD simulations were performed using the ANSYS Fluent solver (ANSYS, 2013). The first few cases, based on the supersonic propulsion phenomena though a Laval nozzle, are steady simulations, where a density-based algorithm has been used to solve the fluid flow. A tank discharging process has been simulated with a multiphase model named the "Volume of Fluid" (VOF). This model solves a set of momentum equations and tracks the volume fraction of each of the fluid phases over the entire domain (ANSYS, 2013). Additionally, this model has been used for an open and ideal tank, for Mariotte's flask simulation.

The Magnus effect, which is the phenomenon in which lift is generated by a rotational body, has been simulated by the creation of a sliding mesh, thus enabling the mesh motion option for the region containing the domain. Furthermore, drag over a cylinder (Mallick & Kumar, 2014, and Gautier et al, 2013) and airflow over 0012, 2424 and 2408 NACA profiles cases have been introduced. The primary characteristic of the second of those groups of simulations has been the use of the same 3 domains for all of the simulations, thus attributing the velocity due to its components whereas the pressure contours and domain are rotated in the post-process stage to visually transform these velocity components using an attack angle.

Additionally, the Venturi effect has been simulated. This effect describes how a fluid through a lower section in a pipe increases its dynamic pressure while its static pressure decreases (White, 2008, and Çengel et al, 2006). It should be noted that Fluent provides two different wall conditions: a specific shear condition or a no-slip option (ANSYS, 2013). The no-slip option has been selected because it is the most realistic alternative, and the null velocity at the contact surface between the solid and the fluid based on the Boundary Layer Theory must be considered.

Lastly, other isolated simulations have been introduced to complete the educational content, such as a rotating naval and aircraft propeller as a supplement to the propulsion explanation, animation of a wave propagation using the "BC Open Channel" condition at the velocity inlet and the "Open Channel Flow" at the pressure outlet of a square domain. Numerical beach treatment has been considered to smooth the influence of the wave diffraction (Black & Rosenberg, 1992).

Lastly, internal flow through a pipe, and external flow through a torpedo completes the simulations launched.

3.3 Object-oriented Programming

Object-oriented programming is the link between the structure of the course and the CFD results. Instead of handling a large amount of images and videos in a gallery, mechanisms are needed for organizing data. Thereby, users have access to a computer tool for each main topic so that they can set boundary conditions, among several options, to display the corresponding simulation.

The first step involves identifying which programs will be created. eXeLearning allows the integration of Applets to create the educational content. These type of Java programs are characterized because they do not have a main class, instead an HTML tag calls the full content (Schildt, 2000). They are designed for a network transmission, which would be a suitable choice to address the proposed problem, and they have already been used to manage similar projects (Graham & Trick, 1998). However, once the first prototypes were created and tested on a local Tomcat server, Google Chrome compatibility problems were detected. Based on the aid support, the technology required for displaying Applets is no longer supported after the 4.1.1 version. Therefore, to ensure access to the material regardless of the browser used to open the course, common applications have been used instead of Applets, and the final programs are thus attached instead of embedded. These applications are similar to those that can be developed using other languages, such as C or C++; however, the operating principles of Java are completely different (Deitel, 2004). In fact, its creation responds to an interpreted language instead of one that is purely complied.

Java applications have been designed as Graphical User Interfaces (GUI) using Swing and Abstract Window Toolkit (AWT) packages from the Java Foundation Classes (JFC). In all cases, a JFrame has been used as the primary container, and JTabbedPanes have been created to host theoretical explanations and simulations tabs. Contour maps and streamlines have been added to the "src" folder of the project as "png" files, and they are displayed as icons of a JLabel object inside those simulations tabs. The initialization of these labels was performed with a constructor method using the School of Industrial Engineering logo.

When considering videos and animations, instructions to call a user's web browser have been used to display these types of multimedia data. Additionally, it should be noted that a video player has been created using the classes provided by the external package to the Java Development Kit, known as the Java Media Framework (Xiong & Jia, 2012); however, the supported codecs are extremely limited. The videos played in this method must be converted to unusual formats, thus losing quality, and it is necessary to take appropriate measures to protect the intellectual property according to the current Spanish law. Therefore, private videos can be uploaded to a cloud storage service using a "Creative Commons-BY" labeling (Aliprandi, 2011), which is a better idea with respect to the intellectual property, quality and number of code lines.

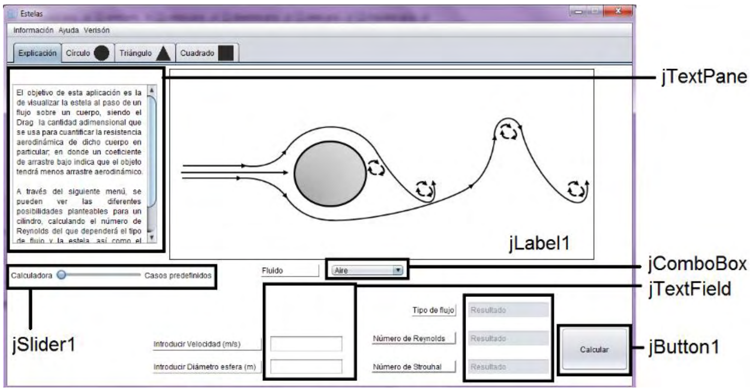

Figure 2. Sample simulation tabs for air flow around a cylinder.

In any case, as indicated in Figure 2, the interfaces also contain JComboBox and JSlider objects to enable the boundary condition selection. Based on the selected condition, internal program variables take a particular value so that the selected picture is displayed while the chosen URI is loaded in the web browser through "if" and "switch" loops.

3.4 e-Learning Criterions

According to Cabero (2006), it should not be forgotten that the network is used as a way to distribute information, which provides an e-learning aspect to the tool. Furthermore, although a significant fraction of users are Fluid Mechanics students at Vigo University, it should be noted that the tool does not fit into the b-learning profile of combining on-line and face-to-face instruction. As previously stated, this is a tool created to improve the educational experience for both the student and teacher. Additionally, it has been promoted to combine conventional teaching with more innovative methodologies that make use of current technologies but with different curricula and a clear boundary. One of the primary causes of error in these types of e-learning initiatives, which rarely occurs in conventional teaching, is the technocentrism (Vasquez, 2007). This concept refers to the fallacy of referring all knowledge acquisition to the technology used, without considering organization and clarity (Papert, 1990). Therefore, in spite of the fact that there is a powerful technological exercise behind the CFD and object-oriented programming, one of the goals set when developing requirements has been that the average user does not spend more than five minutes to understand the operating principle of the applications and the creation of a friendly interface without lengthy technological demonstrations. Any user can go from any menu to another with a single click and enter the web page right from the start without cumbersome registration steps, which typically result in a noticeable decrease in the number of participants. Auto-evaluation tasks consist of mark, relate or select from various items without ever losing sight of the content. Users are given the appropriate hyperlink to quickly and directly install or update their Java version to the correct one. Thus, the user does not have to evaluate incompatibility problems on his own. Furthermore, applications have been converted from jar files, which may not be familiar to users without programming knowledge, to Windows-, Mac- and GNU/Linux-based (tested in the latest versions of Debian and Ubuntu) operating systems' native executables. Users must only click on the hyperlink corresponding to their operating system. According to Pfeffer & Sutton, (2000), there is a gap between knowledge and know-how, thus the entire course has a clear connection with the real world, i.e., how Fluid Mechanics phenomena are manifested in everyday life, such as sports or transportation (Heather et al, 2016), hence attempting to avoid technocentrism and infocentrism, which are two of the greatest causes of failure for e-learning initiatives.

4. RESULTS

Once the course has been completed by the addition of CFD results to the applications and those applications have been uploaded to the eXeLearning structure as attached files to be downloaded by the user, a zero-beta version is launched via email to a group of more than 200 users with prior knowledge of Fluid Mechanics

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(members were students or ex-students from the Industrial Engineering School), and an anonymous satisfaction survey has been distributed for feedback, (Evans, 2004).

Out of the users who participated in the survey, 71.42 percent were males while 28.58 percent were females. Moreover, it should also be emphasized that 14.28 percent of the users could be current Fluid Mechanics students with an engineering degree, and it should be noted that users can distort information despite the fact that they have been warned of the absence of subject qualification retaliation and confidential data treatment according to Spanish law. Furthermore, the selected group for the zero-beta release were mostly students. Thus, the study reveals that most of the users worried about teaching innovation were student repeaters, industry professionals or students about to finish their engineering degree whereas Fluid Mechanics students appeared less motivated.

Additionally, most survey participants acknowledge that they have interacted with other online courses in similar proportions between both genders (75 percent and 70 percent for women and men, respectively). It should be noted that the average mark given by the users to the course as feedback remains unchanged by the user experience. Students with experience in distance learning marked the course at an 8.75/10 whereas novice students marked it at an 8.80/10. In fact, the same marks resulted when distinguished by gender. The average mark for males was an 8.7/10, and females set a 9/10 as a general quantitative mark.

The statistically average mark was an 8.71/10 with a mode of 9 points. Moreover, the lowest mark was a 6, indicating that the course was approved by all of the survey participants.

It must be emphasized that all participants consider that the use of interactive tools facilitate learning, and 93.8 percent of them would incorporate a similar tool into conventional classroom teaching. Furthermore, 100 percent of the participants consider the use of videos and animations beneficial to assimilating concepts.

Additionally, Figure 3 presents the responses recorded on the structural and functional issues of the course, where it can be seen that, except for isolated cases, users gave high marks to the clarity of the explanations, quality and organization. Moreover, it should be emphasized that the lowest marks refer to organization whereas the worst score over among all of the categories results from the same fraction of users. It should be noted that the beta-testers have not been advised of a massive distribution of the course. Therefore, as it can be seen by the general comments given by the survey, the remarks suggest to follow the teaching guide of the subject. However, this type of approach is impossible to achieve due to the consideration that any user is a final "customer". Because the goal of the course is to provide an online course that allows users with no advanced mathematical knowledge to understand the main effects and phenomena of Fluid Mechanics while an engineer profile can use this tool to strengthen their knowledge of this branch of science, a specified educational content management is required.

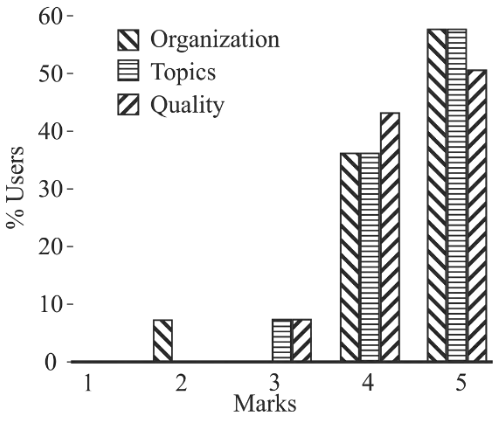

Figure 3. Organization, topics and quality validations

Furthermore, the goal is not to create a tool that replaces conventional teaching, and although these types of remarks are reasonable, they are inconsistent regarding the primary objective. Based on the user's remarks beyond the discussion on whether a deductive model is better than a inductive model or other pedagogical discussions, in terms of encouraging user motivation, analysing the users' observations can be seen as a simple fact of proposing a change or an adaptation in the educational model to the new technological paradigms, which is perceived as a motivating factor for the users, and the student, when perceiving a clear and true interest on the part of the teachers in their training instead of believing their education is a simple task to complete, corresponds that interest with a greater motivation to learn.

Based on Java applications, one of the objectives set as a non-functional requirement of the software engineering process was its simplicity, thus using the estimated learning time needed by users to understand the operation principle of applications as an indirect measure for quantifying this property.

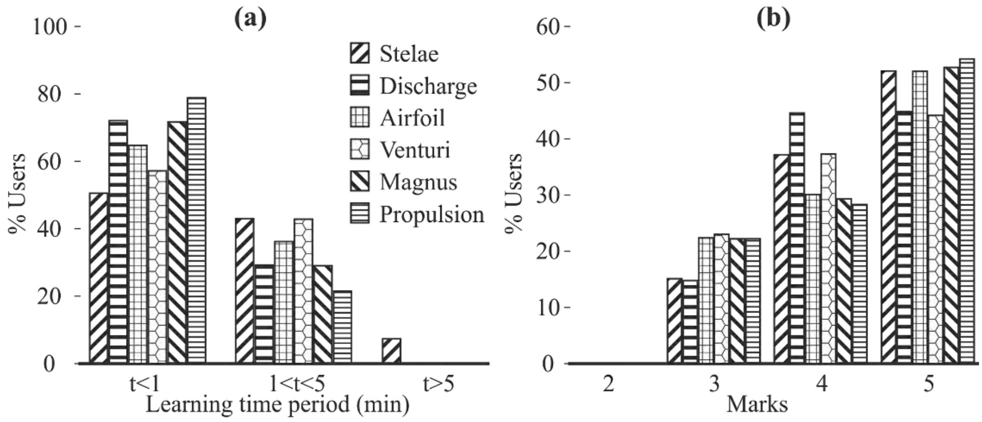

Figure 4. Learning time period and marks given by users.

Figure 4-a illustrates the responses recorded regarding this criterion, where it can be seen that there is only one application where 8 percent of the users estimated that they needed more than 5 minutes to understand how the program worked. This software requirement is verified through Figure 4-a. For example, applications on "deposits discharging" and "stelae", which are complex because they have more code lines than the rest are perceived by students as the most difficult to understand whereas applications referring to the "Venturi effect" and "propulsion", which are chronologically accessed last by the user, are perceived as easier applications to understand.

As indicated in Figure 4-b, users had a positive view on all of the applications, and all of them gave the highest mark as the mode score in each case. It should be noted that significant differences between genders were not detected by the survey.

5. CONCLUSION

In this paper, the solution adopted for the course development has been explained, and a free access online learning application for Fluid Mechanics has been developed. To achieve this goal, eXeLearning has been successfully used as an educational tool while Java has been used to optimize the organization of the information in the course. Furthermore, applications to improve user experience through videos and images have been created. Conversely, the integration of CFD tools for educational use has been achieved, and the main principles of Fluid Mechanics have been typified computationally. In fact, CFD is one of the most important features of the course, and its use has allowed the development of a more user-friendly course simplifying the understanding of Fluid Mechanics for the student. Additionally, the integration of technologies in learning Fluid Mechanics is based on a powerful pedagogical and psychological basis, which is justified from constructivist and inductive perspective contributions to motivation, retention and transfer of knowledge.

In short, this project fulfils the primary objective of sharing knowledge on Fluid Mechanics. However, it is a fact that the final assessment cannot been given by the course developers; the responsibility for assessing the course depends on its users. Against this background, a zero-beta was launched to a group of people with previous knowledge of Fluid Mechanics as a beta-tester. All of them claimed to repeat a similar course, and more than 95 percent of them would add it as a supplement to conventional teaching.

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