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COMBINED APPLICATION OF CFD AND FLIPPED CLASSROOM PRACTICES IN IMPROVING KNOWLEDGE ACQUSITION FOR AN UNDERGRADUATE WATER RESOURCES ENGINEERING RELATED COURSE

Abstract:

Water resources management plays an important role in achieving sustainable development and economic growth. The physical aspect of water management is associated to water resources engineering, which is mainly founded in fluid mechanics. We coupled computer fluid dynamics (CFD) and flipped classroom practices to improve the learning and teaching processes of an undergraduate course focused on the experimental aspect of fluid mechanics in Peru, an upper-middle-income economy. Under the light of our results, we believe that such combined application also results on a viable alternative for universities that may face limitations on implementing a physical fluid mechanics laboratory, and encourages the formation of cooperative clusters of academic institutions around high-performing ones, to create common-pool fluid mechanics sources of educational information.

Keywords:

Water resources and development, engineering teaching

JEL Classification: I00, O13, Y80

1 Introduction

Five domestic co-determinants define the level of economic development of countries, namely: entrepreneurship, government, ordinary labor, investment, and natural resources. The last one is usually qualitatively described by the availability of natural resources (i.e., water, soil), and the efficiency with which countries utilize them (Sng, 2010). Particularly, water resources development and management of water quantity and quality remain at the heart of the struggle for sustainable development, growth and poverty reduction. Hence, many developing countries, such as Peru, are successfully addressing catastrophic water risks, but have not yet achieved the infrastructure and institutional capacities that allow them to manage their water resources to optimize sustainable growth (Grey and Sadoff, 2005). Thus, consolidating a solid background in fluid mechanics in engineers from developing countries becomes particularly important for it provides a mechanical basis to water resources engineering (Horikawa and Guo, 2009). Water resources engineering is intimately related to the design of economic infrastructure (i.e., bridges, dams, channels, canals, levees, highway drainage, ports, sewerage networks, among others) as well as environmental engineering.

Past research suggests that computer-assisted instruction methods perform better in teaching and learning science and technology related courses (Mevarech, 1985), and are more cost effective (Hornback, 2001) than traditional instructional techniques that commonly use static inert media such as course material, books, class room boards, etc. However, it is still fair to state that no consensus on the former aspect exists (Merino and Abel, 2003; Endrizzi, 2012). Likewise, the use of graphical user interfaces for the aforementioned purpose suggests that digital natives find it more comfortable to interact with computer interfaces rather than books or printed course material (Merino and Abel, 2003). In this context, computer fluid dynamics (CFD)—which uses numerical modeling to analyze how gases or liquids flow— has been utilized as an instructional tool for teaching fluid mechanics mainly in developed countries (Guessous *et al.*, 2003; Stern *et al.*, 2006; Fraser *et al.*, 2007; Xanthopoulos *et al.*, 2011; Adair, Bakenov and Jaeger, 2014); however, to the best of our knowledge, in very few instances in developing countries.

In recent years flipped classroom (FC) practices are increasingly being used in teaching and learning of science-related courses by several higher education institutions (Herreid and Schiller, 2013). FC practices require students to engage in or complete some form of preliminary online learning in preparation for a structurally aligned learning activity on campus with their instructors and peers. Thus, students are encouraged to take responsibility for their own learning (Reidsema, Hadgraft and Kavanagh, 2017). FC represents a change from the traditional teaching system towards a system in which the lower cognitive load is assumed by the student outside the classroom; therefore, the instructor concentrates on the topics presenting the higher cognitive load during class. As a consequence, it demands intensive use of media such as videos and audio material (Saterbak *et al.*, 2014).

The Pontifical Catholic University of Peru (Pontificia Universidad Católica del Perú, PUCP)—which ranks among the top Peruvian universities—is committed to continually improve science, technology, engineering and math (STEM) courses; and thus, funds projects promoting innovative teaching and learning methodologies in STEM education. This contribution elaborates on the development of a project aimed to update both the content and improve the knowledge acquisition of the undergraduate fluid mechanics course from the School of Civil Engineering at PUCP, and discusses on the potential of such project to encourage the formation of cooperative academic clusters for the same aim.

2 Data and methods

2.1 Project assessment phase

During the project assessment phase, the need for the project was explored and elaborated. The undergraduate fluid mechanics course is a two-block course which comprises an experimental fluid mechanics course and a theoretical fluid mechanics course that are taught during an academic semester. The former course comprises 12 laboratory experiments performed in five 2-hour laboratory sessions in which two 5-student groups are guided by a teaching assistant. In most of the laboratory experiments water—a newtonian fluid—, at ambient temperature are used, which limits the students' understanding of non-newtonain fluids (e.g., mining tailings, debris flows, etc.), to whom they will commonly be exposed during their professional practice. An analysis of the preconditions revealed that most of the laboratory instruments were old fashioned and did not allow for measuring the predominantly three-dimensional nature of most the flows, and that the laboratory infrastructure (i.e., instrumentation, equipment, devices, facilities, etc.) were being put under relative high pressure as the students in the Department of Civil Engineering are steadily growing in numbers. Therefore, the main objective of the project was to improve both the course content and rigor—to comply with the PUCP commitment to improve STEM education—while preserving the functionality of the existing laboratory infrastructure and updating it where needed. After analyzing the functional and operational requirements of the project, we identified the potential advantages of coupling CFD and FC and getting newest technology laboratory instrumentation to such end. Finally, the following specific objectives of the project were determined, namely: [1] performing a survey to set a baseline for the project, [2] developing virtual experiments for 6 out of 12 laboratory experiments by coupling CFD and FC, [3] updating the course syllabus and guidelines for students, [4] developing guidelines for teaching assistants and support technicians, and [5] building a graphical user interface (GUI) to present the virtual laboratory material (e.g., readings, media-based information, data, tools, among others.)

2.2 Project design and implementation phases

The main principles utilized in fluid mechanics are principles of mass conservation, momentum conservation, and energy conservation. CFD derives a mathematical solution of fluid dynamics by solving the Navier-Stokes equations under given boundary conditions (Horikawa and Guo, 2009).

During the design phase, each specific objective was associated to a corresponding task. For the case of Task 1, we performed an anonymous survey to obtain quantitative information related to the students' opinion on the course topics they find to be challenging and the potential of using media-based material to overcome the challenges these topics pose. The survey revealed that only 24% of the students thought that the laboratory experiments had to last longer than two hours. Likewise, 55% of the students agreed with the idea of including virtual tools to deal with the most challenging course topics. Only 40% agreed with such idea, but believed that virtual tools would have slight effect in dealing with such topics.

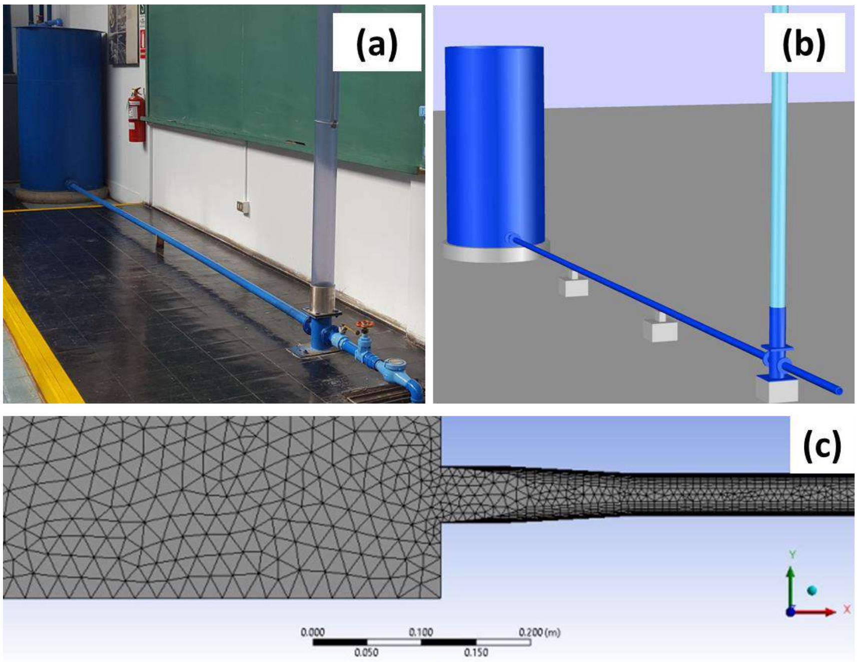
As per the Task 2, we built CFD models for 6 laboratory experiments aimed to study the following course topics: viscosity, flow under a gate, head loss from an oscillatory tank, head loss in piping systems, local head loss in a venturimeter, and local head loss in orifice plate flow rates. Typically building a CDF model comprises three stages, namely: data preprocessing (i.e., creation of geometry, mesh generation, selection of physics and fluid properties, specification of boundary conditions), model solution (initialization and solution control, and monitoring convergence), and model output post-processing which mainly involves plotting and analyzing the parameters that better describe the flow (Nakasone, Stolarski and Yoshimoto, 2006; Tu *et al.*, 2008). Most of the modeling process was performed in the academic version of ANSYS® CFX (a commercial CFD software,) which has self-contained analysis tools incorporating pre-processing, solver and post-processing modules in a unified graphical user interface (Nakasone, Stolarski and Yoshimoto, 2006). ANSYS uses unstructured grids and a hybrid finite-element/finite-volume approach to discretizing Navier-Stokes equations (ANSYS, 2015).

To preprocess the models, the physical properties of the fluids and the geometric characteristics of the devices involved in the virtualized experiments were surveyed. This information was subsequently used to generate three-dimensional meshes; determine the physics and fluid properties of both newtonian fluids (e.g., water, oil, petroleum, glycerin) and non-newtonian fluids (e.g., silver and copper mine tailings, water-laden masses of soil); and define the temporal and spatial boundary conditions of the models. During the processing stage, the convergence of the iterative process and grid independence were checked by using the graphical interfaces provided in the ANSYS platform. During the post-processing stage, we focused on obtaining velocity, pressure, vector, contours and streamlines plots which were used to develop video animations, and data from the virtual experiments. Finally, to complete Task 2, explanatory videosfor all 12 laboratory experiments were built by following FC practices. Subsequently, tasks 3 and 4 were completed.

For instance, the CFD model input data for laboratory experiment # 7, which concentrates on the visual and quantitative analysis of head loss in a pipe section induced by an oscillatory tank draining into a 1 1/2” galvanized steel pipe (Fig. 1-a), consisted on surveyed three-dimensional geometric model (Fig. 1-b) from which an unstructured mesh was built (Fig. 1-c). One of the models replicated the flow of water at 20°C (average ambient temperature) and 4 other ones virtually replicated the transit of water at 5°C, water at 80°C, soybean oil, gasoline, and silver mine tailings. The virtual experiments allowed for visualizing the markedly three-dimensional behavior of the flow at the beginning of the galvanized steel pipe, and the development of the velocity distribution along such stretch.

During the execution of Task 5, we decided to allocate the virtual experiments’ resources GUI at the online platform named PAIDEIA, which has various tools aimed to performing academic tasks and it is not device sensitive (Araujo, 2014). Figure 2 shows the academic services that PAIDEIA provides to the students. The course material for each experiment is distributed in 4 blocks (Fig. 2-a), namely: the student guideline containing information related to both the physical and virtual experiments, course reading material that the students are encouraged to read, data and tools to perform quantitative analysis of the data; and complementary material (i.e., news, online information, papers, etc.) Such scheme of distribution is intuitive and allows the students for finding the information quickly. PAIDEIA is accessible from any electronic device (Fig. 2-b) such as PCs, laptops, tablets, and cellphones, and is compatible with any web browser and operative systems. Likewise, it is linked to PUCP's students and personnel data base, and thus the credentials to access to the platform are provided easily.

Figure 1: Experiment # 7, head loss in a pipe section. (a) Experiment device for the physical experiment, (b) 3D geometric model of the device, and (c) inset of the unstructured mesh near to the tank outlet.



Source: own preparation

2.3 Project evaluation phase

During the project evaluation phase two anonymous 10-question surveys were carried out to assess the students' perceptions regarding to the difficulty of the material and its usefulness in clarifying the course topics presenting the highest cognitive load. The first one took place at the end of the very first semester the project was in operation (March-July 2016), and a second one at the end of the second semester (August-December 2016).

The first survey revealed that 62% of the students found the material to be difficult and had a relative negative perception regarding to the potential of the project, which contradicted their initial expectations. The second survey indicated that 48% of the students had such impression. Therefore, we decided to carry out an informational campaign addressed to the students, from August 2016 on, aimed to disseminating the potential and benefits of the project. A third survey will be carried out at the end of the current semester. Judging from the comments of the students, we expect their overall perception about the project to improve.

Figure 2: Academic services of the PIDEIA platform. (a) GUI for Experiment # 7 showing the four-block in which the course material is allocated, and (b) a student working on the tasks related to the virtual portion of Experiment # 7.

Source: own preparation

3 Results and discussion

Peru is an upper-middle-income economy that ranks 67 among 138 world's economies and also ranks 133 in quality of math and science education (Schwab, 2016). Therefore, over the long term, if Peru wants to become a developed country with an innovation-driven economy, it must provide high-quality science education and continuous investments in research and development (WB, 2015). Peru has an estimated infrastructure gap of USD 159,549 million for the period from 2016 to 2025 (AFIN, 2015), which is mainly related to economic infrastructure that will demand in a relative higher proportion the contribution of civil engineers having both solid theoretical and practical background in water resources engineering. In this line, PUCP is committed to enhance the quality of the fluid mechanics course, which has a central importance for such specialty.

The best practices for educational project development require a commitment to a systematic, iterative process of assessment, design, implementation, and evaluation (NOAA, 2009). Such approach was used during the project development. Under the light of our results, the coupled application of CDF and flipped classroom facilitates knowledge acquisition on the behavior of both newtonian and non-newtonian fluids, three dimensionality of flows, and flow development. Thus, during the laboratory sessions, teaching resources were effectively spend on the topics having higher cognitive load. This combined application has also allowed for diminishing the execution time of the physical laboratory experiments and markedly increased the availability of learning resources for the students.

Implementing this learning-teaching practice requires certain adaptation time for the students. They are apparently reticent to it at the early stages as also reported by Herreid and Schiller (2013), possibly because of the fact that it involves an increase in homework load, which in time may increase anxiety. Although some body of research suggests that an increase in homework in high-performing institutions hinders learning, full engagement, and well-being (Galloway, Conner and Pope, 2013). Further analysis of any possible side effect of the project on this regard will be performed in the short term.

Project evaluation tasks are being conducted; for instance, informational presentations were carried out, firstly from professors to the students and later from the water resources oriented students group to the students. Our results suggest that the latter performs better. An informative video was also built, which can be accessed from the following link: www.pucp.edu.pe/HbuNxl. We expect to improve the general perception the students have towards the project. Over all, past research indicates that virtual material have a positive input in knowledge acquisition of fluid mechanics but it may not very visible in the short term (Mokhtar, 2011). To the best of our knowledge, the combined application discussed in this contribution has not been performed in any other regional academic institution.

Science has entered a "fourth paradigm" that is more collaborative, more computational, and more data intensive (Tenopir *et al.*, 2014). In this line, we believe that this project allows for sharing the academic resources we built with other institutions if they are appropriately allowed to access to our platform. This collaborative approach would potentially result on the formation of national, or even regional, common-pool resource data sources of virtual experiments. The authors are currently working on it by involving medium and small sized universities from Peru, Colombia and Chile.

4 Conclusions

The efficient management of water resources plays an important role in achieving sustainable development, growth and poverty reduction. PUCP is committed to improve the quality of water resources engineering-related courses, and hence consolidating the fluid mechanics background among students is particularly important. Under the light of our results, we believe that the combined application of CFD and flipped classroom practices has the potential to provide insightful fluid mechanics teaching and learning resources. We also believe that such application is a viable alternative to improve the course quality of academic institutions that may have resource limitations to build fluid mechanics laboratory settings. It also encourages the formation of cooperative clusters of academic institutions around high-performing ones to efficiently spend the resources that are commonly restricted in developing countries.

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