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Contributions to the Teaching and Learning of Fluid Mechanics

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Editorial

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1. Introduction

This issue showcases a compilation of papers on fluid mechanics (FM) education, covering different sub topics of the subject. The success of the first volume [1] prompted us to consider another follow-up special issue on the topic, which has also been very successful in garnering an impressive variety of submissions.

As a classical branch of science, the beauty and complexity of fluid dynamics cannot be overemphasized. This is an extremely well-studied subject which has now become a significant component of several major scientific disciplines ranging from aerospace engineering, astrophysics, atmospheric science (including climate modeling), biological and biomedical science and engineering, energy harvesting, oceanography, geophysical and environmental science and engineering, etc. While each of these disciplines has its own nuances and specific constraints, the fundamental physics behind the kinds of 'flow' phenomena discussed remains the same. In this volume, we bring together articles from authors with diverse expertise ranging from mathematics, physics, mechanical engineering, aerospace engineering, environmental engineering, and chemical engineering to discuss topics in fluid mechanics, many of which are of multidisciplinary interest.

The focus of all articles in this issue remains on the presentation of fundamental and advanced ideas on fluid mechanics which are suitable for presentation in an undergraduate or graduate course in fluid mechanics. Overall, I would divide the collection into the following four categories: (a) Pedagogy of fluid mechanics; (b) experimental or lab-based perspectives; (c) computational approaches; and (d) mathematical fluid mechanics. The following pages provide a brief summary of each of the contributions.

2. Pedagogical Issues

Student-centered practices such as problem-based and project-based learning (PBL) are more commonly practiced in the arts. PBL related instructional methods promote a more inductive approach to learning whereby generalizations and abstractions follow from first understanding specific cases. This approach is in contrast to the deductive strategy taken in the sciences which is a more top-down approach and a possible cause of alienation towards math and science in several students. The concept of problem-based learning began more than 30 years ago in the context of medical education and has been defined as the "posing of a complex problem to students to initiate the learning process" [2,3] and as "experiential learning organized around the investigation and resolution of messy, real-world problems." [4]. PBL can be implemented at various scales in a course with a focus from a "teacher to student-centered education with process-oriented methods of learning." [5]. The recent popularity of the project-based learning approach in physics and engineering education is based on research indicating the effectives of PBL in enhancing student engagement [5–7]. This volume presents a selection of papers that speak to the efficacy of PBL-based experiences in fluid mechanics courses.

The first article in the collection [8] by authors Garrard, Bangert, and Beck discusses an innovative pedagogical approach by planning and delivering large scale, multi-disciplinary labs with as many as 80 students in a single cohort and nearly 1000 students over a year.

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Topics discussed in the lab are those which would be common to students from various branches of engineering at their institution including basic flow measurements, pressure driven flow in pipes, dimensional analysis, and other open ended projects. Besides the obvious financial and logistic advantages that come from sharing of resources, the authors point to its pedagogical value and efficiency.

The second article by Pérez-Sánchez and López-Jiménez [9] in this collection highlights the use of PBL in a fluid mechanics course taught at a Hydraulic Engineering Department in Spain that caters to over 2000 students. Just as in an earlier paper [8], the project described in this article proposes the coordination of fluid-based labs in different subjects at both the bachelor's and master's degree levels. The paper discusses the improvement in student performance, as well as the new teaching approaches which the authors note to have "increased the student's satisfaction index".

The final article in this section by Zoupidis, Spyrtou, Pnevmatikos, and Kariotoglou [10] is aimed towards teaching the concept of 'floating and sinking' (FS) to elementary school children. The authors explain the value of a "density-based explanatory model ... rather than the buoyancy-based" arguments typically used to explain FS phenomena, which is a conceptually challenging concept for children who instinctively associate floating and sinking with visceral experiences of 'lightness' and 'heaviness', respectively. The paper presents and evaluates the success of a novel instructional design paradigm founded on inquiry-based learning.

3. Experimental in Fluid Mechanics

The first article on experiments in FM by Wulandana discusses an impressive student driven project focused on building a recirculating flow tank [11]. Such tanks are an essential part of the collection of any fluid mechanics-based program and are very valuable due to their versatility and the ease with which many topics can be easily introduced. The only drawback of a prefabricated tunnel is its prohibitive cost. In this article, the author describes the design and fabrication of an open flow tank, built by students as part of their senior design project in a mechanical engineering program. The construction of this tank additionally provides opportunity for training in computer aided design (CAD) and computational fluid dynamics (CFD) as students perform comparative tests to validate flow structures in ideal and experimental conditions and also improve experimental designs so they meet expected flow conditions. The ideas introduced in this article can be replicated in any engineering program and also lead to interdisciplinary learning opportunities for students in physics and mathematics.

In the classic book, *A Splash of a Drop*, published by A.M. Worthington in 1895 [12], the world was introduced to the stunning visual world of droplet splashes. Worthington was certainly a strong influence on the movement in fluid dynamics scholarship to incorporate a visual element in order to understand the complex and beautiful structures that lie hidden behind the veil of transparency. Advancements and affordability of optical technologies makes is easier to introduce students to the fascinating world of flow visualization. The paper by Moghtadernejad, Lee, and Jadidi [13] introduces us to a course on multiphase flow where the instructors lead students on an experimental and theoretical investigation of splashes. Students also investigate the impact of temperature, wettability, impact velocity, droplet volume, shape, and relative humidity upon the splash dynamics. As the instructors note, this is an apt topic to introduce in a fluid mechanics course since it brings advanced knowledge into the classroom and also provides opportunities to discuss fundamental science and applications.

4. Computational Approaches

In this section we feature computation-based articles which cover both, articles of methodological nature and those that use computations to illustrate interesting physics of flows which can be introduced in any course on fluid mechanics.

The article [14] by Oz and Kara discuss computational methods relevant to 'Boundary Layer theory', a subject appropriate for introduction in an upper level undergraduate or graduate course. Relevant problems such as Blasius, Hiemenz, Homann, and Falkner–Skan flow equations are derived and numerically solved using the language, Julia. The codes have also been made freely available to the readers.

The article [15] by Ahmed, Pawar, and San provides a fundamental introduction to the mathematics and computational aspects of data assimilation methods which are fundamental to the study of climate science. Readers are exposed to the various methodologies through a series of Python modules which can be easily incorporated and adapted in an advanced course which treats such methods.

Mou, Wang, Wells, Xie, and Iliescu provide a survey of reduced order models which are computational models "whose dimension is significantly lower than those obtained through classical numerical discretizations" [16]. ROMs, in their various forms, have been found to be valuable in several complex computations involving uncertainty quantification, control, and shape optimization and in the numerical simulation of fluid flows. In this article, the authors summarize recent developments in ROM for barotropic vorticity equations, which are used to model geophysical flows.

In the article by Mongelli and Battista [17], the authors undertake a systematic study of pendulum dynamics by properly and fully accounting for the flow around a moving body which is not captured through the classical mechanical pendulum equations (see, also, another recent study that examines this issue through the lens of the least action principle [18]). The authors develop a computational fluid dynamics (CFD) model of a pendulum using the open-source fluid-structure interaction (FSI) software, IB2d. Comparisons with the results of the classical ODE model reveal very interesting and noteworthy results which ought to be discussed in any class which discusses pendulum dynamics.

Karlson, Nita, and Vaidya [19] discuss the interesting physics behind the vortex shedding phenomena. Computations using the program COMSOL are used to analyze the length of the primary vortex behind an elliptical body with varying eccentricities. The vortex length is used as a metric to understand and identify flow transitions from steady symmetric to asymmetric regimes which could potentially also be used as a noninvasive experimental strategy to distinguish flow regimes. The impact of the eccentricity of the body is seen to be particularly significant. While the physics itself is interesting and easy to follow and can even be discussed in an elementary FM course, such an example can be easily implemented in an advanced course in fluid mechanics or CFD course where students are exposed to a software for flow modeling.

5. Mathematical Fluid Mechanics

The final paper by Berselli and Spirito [20] is an extremely well written and much needed review of one of the most challenging mathematical problems of the last two centuries [21] and listed as one of the 'Millennium problems' in mathematics, namely the existence of solutions to the Navier–Stokes equation (NSE). While the history of this problem and various approaches is long and complex, the authors have done an excellent job in explaining and leading the readers through one aspect of this problem, namely the global existence of Leray–Hopf weak solutions to the NSE. I would strongly recommend that this article be made part of any course in an upper level undergraduate or even in an early graduate course in theoretical fluid mechanics or PDEs.

The papers in this volume, while selective and covering various different topics, showcase significant and cutting-edge knowledge of fluid mechanics in a manner that is easily adaptable for presentation in a course to undergrads, graduate students, and even in K12 settings. While the foundational materials traditionally taught in FM courses are important, our texts and curricula have not changed very much since the middle of the last century. The articles here provide templates for 'lesson plans' which can easily be implemented in our courses to make them more current and up-to-date. Many of the computation focused articles provide plug-and-play codes that can be implemented without much training and time and comprising the larger objectives of the courses. We hope that educators will take note and find these papers helpful in their own teaching efforts and also in encouraging their own efforts towards incorporating other newer results into their classroom discussions.

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