A new Master Course in Applied Computational Fluid Dynamics

D3.1 APPLY COURSES – LEARNING MATERIAL (REPORT)

WP 3 APPLY development and academic staff training

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Executive Summary

This deliverable describes the actions taken for "WP 3.1 Development of APPLY courses". It illustrates the innovative approach of the APPLY project in establishing Computational Fluid Dynamics (CFD) as the central focus of a Master's program, departing from traditional supplementary offerings.

The document describes the collaborative effort through which, the consortium developed a comprehensive training material, including a compendium for the MSc APPLY program and modules for practical training, ensuring a holistic educational framework. It details the innovative teaching methodologies such as problem-based learning, inquiry-based learning, and experiential learning to deepen student understanding and foster critical thinking.

Additionally, the report explains the effort to create material that promotes effective class management and that emphasizes clear learning goals and adaptability to student needs. Moreover, the expandable and updatable teaching material ensures relevance and flexibility. By embracing collaborative engagement and student-centered approaches, the APPLY course material aims to empower students to excel in CFD studies and navigate the evolving landscape of fluid dynamics education effectively.

Finally, the report gives a brief overview of the course material that has been created by the members of the consortium. The deep analysis of the CFD subjects, the diversity of the paradigms and the extent of the offered knowledge reflect the quality work that has been carried out by all the partners of the APPLY team.

1. Introduction

The innovative character of the project rests on the fact that it aims to set CFD area to the core of a Master program. The vast majority of CFD related courses in postgraduate programmes are currently offered as add-ons or complementary to existing Masters programs (e.g. MSc in Mechanical Engineering, MSc in Environmental engineering, etc). APPLY aspires to be place CFD first and expand to the different engineering disciplines that use it as a tool.

The design of the CFD centred master programme is conceptually innovative compared to traditional MSc courses, even for EU standards. It follows a practical and application-orientated approach to CFD, by initially focusing on targeted core subjects, which are necessary for the understanding of the fundamental principles of CFD, and then expanding outwards to meet the needs of different engineering disciplines. This structure allows for the maximum exploitation of CFD as an engineering tool, without reducing the academic nature of the programme.

To this end, the APPLY consortium developed training material collectively during the project lifetime. We build a compendium of materials to be used for the MSc APPLY programme, as well as supporting further development of modules for the APPLY professional training.

2. Approaches to Delivering of the courses

The MSc programme was designed according to the recommendations and the targets delivered by the end of the preparatory activities of WP1, WP2. Based on the survey of relevant courses in EU Academia and on the needs analysis of Asian partner countries (WP1), but also on the extensive discussions and exchange of opinions that took place in the course of WP2, the structure of the courses was finalised. It is a blend of core and elective engineering courses, structured in a flexible, modular manner, according to the Bologna convention.

The educational goal of the core courses is to expose participants in the complementary areas of Mathematics, Physics, Programming, Engineering simulations and experiment methodologies that constitute the innovative field of Computational Fluid Dynamics. This requires innovative teaching and learning strategies, appropriate for a transdisciplinary master's program that encompasses various methodologies. These include problem-based learning, projects focusing around real-life applications, inquiry-based learning and experiential learning.

2.1 Problem based CFD teaching

The method of problem based CFD teaching is embedded in almost all the core courses and especially the two “Hands on CFD” courses, i.e. C4 and C6, which include topics such as

- Bifurcating artery
- Li-Ion battery

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- Wind turbine
- Jet dynamics, etc.

They represent a dynamic approach to learning that immerses students in the practical application of CFD. In this method, students are confronted with authentic, real-world problems representative of those encountered in engineering and scientific contexts. Through these challenges, students develop critical thinking skills and problem-solving abilities as they analyze fluid dynamics phenomena and devise solutions using CFD techniques. By engaging in problem-based CFD teaching, students gain a deeper understanding of theoretical concepts while simultaneously honing their computational skills and engineering intuition. Ultimately, problem-based CFD teaching empowers students to tackle complex engineering challenges with confidence and creativity, preparing them for success in their academic and professional endeavors.

2.2 Projects about real-life applications

Another approach that is followed in several courses, is teaching though projects that focus around real-life applications. In courses such as “E.6 Environmental CFD” and “E7. Multiphase flows”, projects serve as an invaluable tool for fostering practical application and deepening comprehension of computational fluid dynamics principles. These projects typically involve students working on simulated engineering problems that are linked to the subject of the course, where they apply CFD techniques to analyze and solve complex fluid flow phenomena. Through this approach, students gain hands-on experience with CFD software, learn to interpret results critically, and develop proficiency in problem-solving within fluid dynamics contexts. Projects often span various disciplines, including aerospace, mechanical engineering, environmental science, and more, reflecting the interdisciplinary nature of CFD applications. For example, the projects of the course “E6. Environmental CFD” include projects that study

- Buildings and the urban environment
- Atmospheric pollutant dispersion
- Pollutant transport in a river
- Erosion in bare soil area,

By engaging in these projects, students not only enhance their technical skills but also cultivate teamwork, communication, and project management abilities essential for success in the field. Moreover, the outcomes of CFD projects contribute to advancements in research and innovation in fields that are of great important to the Asian partner countries, making them a cornerstone of effective CFD education.

2.3 Inquiry-based learning

Although the elective courses of the curriculum are ideal for teaching approaches such as the ones outlined in the previous paragraphs, the core courses that provide basic knowledge to the students require a different method. Inquiry-based learning is a dynamic pedagogical approach that empowers students to explore and construct knowledge through inquiry and discovery. By encouraging students to ask questions, analyze problems, and seek solutions independently, inquiry-based learning cultivates a deeper understanding of fluid dynamics principles, mathematics, and computational methods. An illustrative example of this approach is course “C1. Numerical Methods for PDEs”, where the students are encouraged to discover the links between the Partial Differential Equations and the physical systems that they model. In this approach, students actively engage with concepts, theories, and simulations, fostering their intuition of the physical phenomena and critical thinking skills. In other courses, such as “E4. Linking experiment with CFD”, students develop a profound appreciation for the complexities of fluid flow phenomena and gain practical experience in problem-solving within CFD applications, through hands-on experimentation and investigation. Inquiry-based learning not only enhances students' technical proficiency but also encourages creativity and innovation, preparing them to address complex engineering challenges with confidence and ingenuity in both academic and professional contexts.

2.4 Experiential learning

Another teaching approach that flows through almost all the courses is the experiential learning. It embodies a hands-on approach that immerses students in practical applications of fluid dynamics principles. Through experiential learning, students engage directly with CFD software, simulations, and real-world scenarios, gaining firsthand experience in analyzing and interpreting fluid flow phenomena. These is achieved through the use of commercial and open-source CFD software, which are the main simulation tool in the academia and the industry. The main CFD packages that are presented in the teaching material are

- OpenFOAM, which is the leading open source CFD library, ideal for solving Multiphysics problems modelled by PDEs
- ANSYS Fluent, which is the leading commercial CFD package, widely used in the industry for R&D activities

Through the simulations of carefully designed case studies, students develop a deeper understanding of CFD concepts and their real-world implications. Experiential learning fosters critical thinking, problem-solving skills, and the ability to apply theoretical knowledge to practical situations. Moreover, it cultivates a sense of curiosity and exploration, encouraging students to investigate complex fluid dynamics phenomena and innovate solutions.

3. Effective Class Management

Effective class management for the transdisciplinary CFD teaching is the ability to create and maintain a positive learning environment where students from different disciplines are engaged and productive. To this end, the material prepared follows specific guidelines that clarify the learning goals of each course. Students from different disciplines and different backgrounds have different knowledge and different expectations for what they will learn in the program. It is important to be clear about the learning goals so that everyone can arrange the study time, the effort that needs to be put into every assignment and be assisted in the specific needs that arise.

3.1 Variety of teaching methods.

There is no one-size-fits-all approach to teaching a CFD Master’s program. Instructors need to be flexible and use a variety of teaching methods to meet the needs of students from different disciplines. As detailed in the

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teaching approaches section, the methods that are employed in the teaching material encourage collaboration and teamwork through projects and multi-person assignments. Students from different disciplines can learn from each other by collaborating on projects and assignments. Instructors should encourage collaboration and teamwork in the classroom.

3.2 Adaptable teaching style and student-centered approach

Given the multidisciplinary nature of CFD and the varied backgrounds of students, the teaching material must employ flexible and inclusive teaching methods. This entails assessing the prior knowledge, and skill levels of students and tailoring instructional approaches accordingly. For instance, students from a theoretical background (mathematics, physics, etc.) may benefit from simulations of real-world applications and visualization of the solutions, while students from more a practical background (technical schools) may benefit from theoretical knowledge and fundamental learning sessions. Additionally, incorporating active learning strategies such as group discussions, problem-solving exercises, and collaborative projects can foster engagement and deepen understanding. Furthermore, providing ample opportunities for feedback and personalized support enables students to address individual learning gaps and challenges. By embracing a student-centered approach, instructors can create an inclusive learning environment that empowers students to excel and thrive in their CFD studies.

3.3 Expandable and updatable teaching material

In preparing the teaching material for the courses, we have adopted a dynamic approach that facilitates easy updates and revisions. Content is structured with modularity in mind, allowing for seamless integration of new findings, methodologies, and technological advancements in numerical methods, fluid dynamics, and also up to date applications. The material utilizes digital platforms, online sources, and multimedia tools thus enhancing the flexibility of teaching materials, enabling swift modifications and updates as the field evolves. Incorporating open-access tools, such as the open-source digital library of OpenFOAM, enriches the learning experience while ensuring access to the latest developments in CFD. Moreover, fostering a collaborative environment where students and instructors contribute to content creation and refinement can promote continuous improvement and adaptability in course materials. By prioritizing flexibility, accessibility, and collaborative engagement, educators can effectively prepare teaching material that remains relevant and up-to-date in the ever-evolving landscape of Computational Fluid Dynamics.

4. Teaching material for the APPLY courses

The APPLY consortium has prepared material for a total of 17 courses (6 core and 11 elective). The following table summarizes the material that has been prepared.

4.1 Core courses

Course Title	Course Coordinator	Countries	Material provided
C1. Numerical Methods for Partial Differential Equations (PDEs)	UPatras & MUJ	Greece & India	• Collection of presentations for the 8 modules of the course • Exercises for the students • Class coding projects • Solutions of the coding projects in Python programming language and in MATLAB
C2. Fundamentals Fluid Dynamics and Heat Transfer	UM & MUJ	Malaysia & India	• Collection of presentations for the modules of the course • Exercises for the students • Class coding projects • Solutions of the coding projects
C3. Hands-on Computational Fluid Dynamics (part 1)	MAHE	India	9 CFD projects based on real-life problems, including • Bifurcating artery • Li-Ion battery • Wind turbine • Jet dynamics • 2D cylinder • Airfoil dymanics, etc.
C4. Introduction to the Numerical Solution of the Navier-Stokes equations	UPC	Spain	• Collection of 16 presentations for the modules of the course • Exercises for the students • Class coding projects

C5. Turbulence modelling and simulation	UPC	Spain	•Collection of 15 presentations for the modules of the course
			• Exercises for the students
			• Class coding projects including
			  • Flow around a cylinder
			  • Application of RANS model

			• Application of LES model, etc
C6. Hands-on Computational Fluid Dynamics (part 2)	VIT	India	6 CFD projects based on real-life problems, including • Jet dynamics • Fluid-structure interaction • Microchannel heat sink •Shock generation, etc.

4.2 Elective courses

Course Title	Course Coordinator	Countries	Material provided
E1. Computational Aerodynamics	CMU	Thailand	• Collection of 12 presentations for the modules of the course • Exercises for the students
E2. Chemically Reacting Flows - Combustion	CU	UK	• Lecture notes
E3. Fluid Structure Interaction	MAHE	India	•Collection of presentations for the 7 modules of the course • Projects using ANSYS Fluent commercial software •.Notes for practical problem solving
E4. Linking experiments with CFD	CU	UK	• Collection of presentations for the modules of the course • Individual assignment • Test cases and tutorials
E5. Environmental Flows	UPatras	Greece	• Lecture notes for the modules of the course • 5 CFD projects based on real-life problems, including • Buildings and the urban environment

			• Atmospheric pollutant dispersion • Pollutant transport in a river • Erosion in bare soil area.
E6. Multiphase Flows	UPatras	Greece	• Lecture notes for the modules of the course • CFD projects based on real-life problems
E7. Modeling and Simulation of Energy Systems	NU	Thailand	• Lecture notes for the modules of the course • Projects based on real-life problems, including • Solar collector • Gas turbine • Boiler • Wind turbine, etc.
E8. Introduction to the Numerical Simulation of Environmental and Atmospheric Flows	UPC	Spain	• Lecture notes for the modules of the course • Practical guide for modelling
E9. Introduction to Finite Element Analysis of Solids and Fluids	CMU	Thailand	• Collection of presentations for the modules of the course
E10. Transport Phenomena	NU	Thailand	• Collection of presentations for the modules of the course • Projects based on real-life problems
E11. Internship/Master Thesis	UiTM	Malaysia	• Program structure, • Main rules • Accreditation report