Fluid Mechanics Phenomena Class Computational Apps for Engineering Students

Mohamed Edali[1], Zaed Sahem[2], Faraj Ben Rajeb[3], Walid Alaswad[4], Ali Bseibsu[5], Ali Elkamel[6]
[1,4,5]Department of Chemical and Petroleum Engineering, Elmergib University, Elkhoms, Libya
[2]Creativity Group for Technical Services, Ottawa, Canada
[3]Department of Oil and Gas Engineering, Memorial University, St. John's, Canada
[6]Department of Chemical Engineering, Waterloo University, Waterloo, Canada
dredalicreativitygroupts@gmail.com[1],sahemzaed@gmail.com[2], fabr67@mun.ca[3],walaswadzo@gmail.com[4], ali.bsebsu@gmail.com[5], aelkamel@uwaterloo.ca[6]

***Abstract*- This paper presents a case study of an undergraduate fluid Mechanics course teaching technique where students were challenged to work on a pre-designed intensive use of new App building features using the sophisticated COMSOL Multiphysics simulation software. The teaching experiments through lectures were assessed by quizzes to evaluate the simulation enhanced understanding of the fluid concepts. A student survey was conducted to evaluate how the simulation contributed to their learning experience. The goal is to immerse the students in all the main aspects of using COMSOL Apps so that they can feel comfortable with the software and confident that they are correctly solving their simulation problems comparing analytical solutions in their textbook with the new prepared COMSOL Apps. Students make COMSOL applications available to their colleagues as research working mates and professors who might not COMSOL users. Students will learn how to write methods to cover actions not possible by the standard commands available to go beyond what is possible to do with just a conventional model. The course was designed to be of interest to all with some knowledge of fluid Mechanics using COMSOL-APPS. Covering both theories and practical applications, this class emphasizes how to benefit from using its built apps for more efficient CFD simulations. The course apps cover each specific problem setup, the right choice of the boundary conditions, the post-processing options, and the result visualization tools. Users can investigate various APP data scenarios for each main topic problem in the fluid flow simulation.**

Keywords*- *Fluid Mechanics, COMSOL CFD Module, COMSOL Application builder.

I. INTRODUCTION

The Fluid Mechanics course at Elmergib University was delivered in the traditional format of using textbooks and some lab work activities.Our Fluid Mechanics curriculum does offer separate fluid lab experiments but not CFD simulation class. Consequently, students were by no means exposed to computer simulation trip on fluid mechanics at our common chemical and mechanical engineering curriculum. Although CFD has grown to be a critical phase of fluid mechanics exercise and industrial requirement nowadays, introducing COMSOL simulation works inside the everyday fluid mechanics path is an intensive project for many undergraduate institutes. For that reason, the authors endorse that using the COMSOL simulation on fluid mechanics on easy fluid problems as a section of every route chapter as a lecture App assignment could be a choice but advantageous way of offering CFD to students who have restrained get admission to CFD courses.

The technique of "learning with the aid of doing" has been regarded as one of the most effective methods to teach engineering students and this principle was once adopted as a pedagogy in this study. The computer simulation renders the perception of a concept, associated theory, and necessary modeling experience. The targets of this new teaching technique are as follows: (a) Promote the grasp of the Fluid Mechanics idea by doing theoretical evaluation through modeling with variable parameters optimization using the COMSOL solving techniques. Students can gain a greater understanding if they practice the notion in actual software modeling equations and simulating to achieve a problem answer and reconfirming it through simulation experiments. (b) Expose students to the current main technological know-how that the industry is presently adapting and heading to. Students examine to locate and grasp new technology as necessary. Pre-designed intensive use of new App constructing aspects using the state-of-the-art COMSOL Multiphysics simulation software. The teaching experiment through lectures that have been performed in the classroom is a method of gaining knowledge that lately won interest in many engineering training communities. This technique was once at first developed for ameliorate students getting to know by flipping the traditional lecture with a better simulation App working environment. This procedure approves students to get the right of entry to fundamental content material with the aid of educating technology, through computers, tablets, smartphones, and other devices. This way, the instructors can reserve extra class time for interactions with the students and answering questions about the materials covered by the lecture. The use of App educating classroom techniques in engineering fields stems from the need of mastering the way of solving real-world problems. "Engineering lends itself" to this new pedagogical approach, since traditionally it relies considerably on hands-on experiments and projects, as greater degrees of learning. Two separate research articles were accomplished via the authors of this work for two other Chemical Engineering courses, Heat Transfer [1], and Transport Phenomena [2], which showed elevated effectiveness of this App teaching publications compared with ordinary courses, in terms of route content, scholar performance, and students' grasp of their gaining knowledge of experience. In a Fluid Mechanics course, Instructor has roughly forty contact hours with students. Lecturing course material by handing out notes and letting the students find something more productive to do with all that time. The only way a skill is developed such as writing, critical thinking, or solving fluid mechanics problems, is practice: trying something, seeing how well or poorly it works, reflecting on how to do it differently, then trying it again and seeing if it works better. Why not help students develop some skills during those contact hours by giving them guided practice in the tasks they will later be asked to perform on assignments and tests. Which is to say, why not use active learning at several points during the class where students answer a question, sketch a flow chart or diagram or plot, outline a problem solution, solve all or part of a problem. Carry out all or part of a formula derivation, predict a system response, interpret an observation or an experimental result, critique a design, troubleshoot, brainstorm, and come up with a question. Students can be urged to work individually or in groups for an allotted time of minutes; be called for responses and additional volunteered responses, then Instructor provides the right response if necessary. This active learning teaching technique wakes students up and academically weak students get the benefit of being tutored by stronger classmates. Stronger students get a deep understanding that comes from teaching something to someone else.

In this study, students were challenged with the COMSOL simulation use and its effect on the enhancement of learning was assessed by their test scores and end of class surveys. The key question answered in this paper is that the COMSOL simulation adopted as a tool to strengthen the active learning technique adopted. In the classroom, the effectiveness of the teaching technique to be assessed in enhancing the learning and introducing CFD to students without having to dedicate a whole semester course of separate computer simulation class.

II. CONCEPTS AND PROPERTIES OF FLUIDS

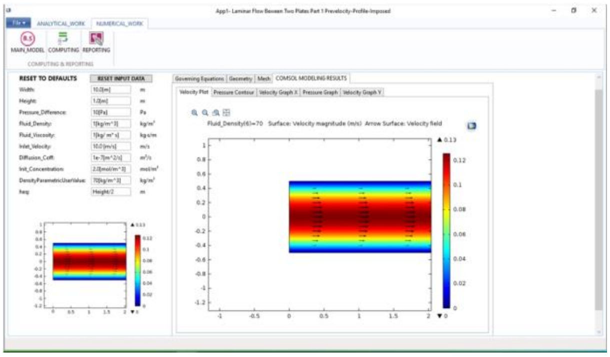
The influence of forces on moving and stationary boundaries is the physical science called Mechanics. The science that deals with the behaviour of fluids at rest are Fluid Mechanics and it is Fluid Dynamics when it deals with behaviour in motion. In fluids, stress is proportional to the strain rate. Any characteristic of a system is called property. The most common properties of the fluid are Pressure, Density, Temperature, Viscosity, and Thermal Conductivity.Using COMSOL in fluid mechanics course

Fluid Mechanics has several functions in many engineering fields and with useful resources, computerized applications have been used to investigate, analyze, and optimize engineering designs. One of these useful numerical software packages is COMSOL Multiphysics. This package described as finite factor analysis, solver, and simulation software designed for many Multiphysics fields of science and engineering such as electrical, mechanical, civil, and chemical applications.

The COMSOL in a fluid mechanics direction has the capability of building numerical simulation Apps. These Apps are designed as an effective instructing tool, which will be maximizing the effectiveness of the getting to know technique and enlarge the studying horizons for college students. Also, COMSOL simulation apps will assist college students to strike such stability with the aid of introducing them to complex principles in a simplified visualized format.

IV. SAMPLE OF APPS "CASE STUDIES"

To see the influence of viscosity on fluid behaviour, we consider a layer of fluid confined between two infinite parallel flat plates separated by a distance as shown in Fig.1.The liquid can be thought of as comprising of numerous lean layers parallel to the plates such that the liquid in contact with the plates and adheres to them. This is known as the "no-slip" boundary condition. Fig.1, displays a snapshot for a COMSOL App that was created to study a pre-velocity imposed laminar flow between two plates design problem where the App is designed in a simple way to allow students to navigate the two sections of the problem. The theoretical background is shown in the first section and multiple numerical analysis tabs (Geometry, Meshing, Temperature profile, and more) in the second section. The App understudy flow configuration is known as a fully developed flow since the effect of the fluid viscosity is felt throughout the flow field and the resulting parabolic velocity distribution has the same shape at every value of x. However, to reveal how the flow became



fully developed is by the solution to the Navier-Stokes equation for this configuration. Since the equation terms are non-linear, the solution of the Navier-Stokes equation in the entry region is very complicated mathematically so it is worth discussing the physics of the situation. The uniform velocity distribution of the flow enters the space between plates within which the value is the same at the entrance.

Figure 1. APP1_ Laminar Flow Between Two Plates Design Problem Part 1 – Pre-velocity Profile Imposed.

The second APP-2 is presented in Fig.2, where a Laminar Flow between two plates design problem with a flat velocity profile imposed is investigated. In this case, as the fluid comes into contact with the upper and lower plates, the Newtonian fluid model boundary condition of the "no-slip" the fluid at the surface of the plates is slowed to zero velocity. Initially, the influence of the solid boundary is confined to a very small region near the surface of the plates, but as the fluid moves downstream, this region of influence, known as the boundary layer, begins to diffuse further out into the flow in a direction normal to the solid boundary (wall). As the flow progresses in the x-direction, the boundary layer grows in thickness.

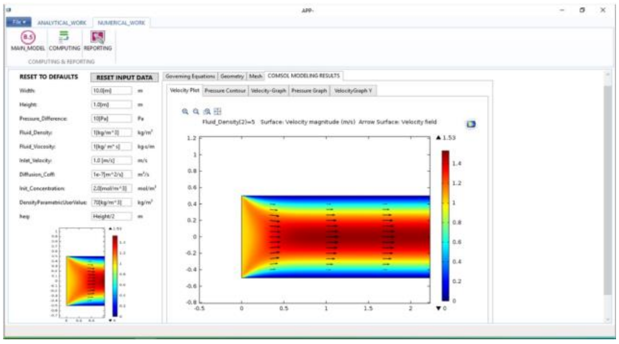


Figure 2. APP2_ Laminar Flow Between Two Plates Design Problem, Part 2 - Flat Velocity Profile Imposed

The third sample of using COMSOL Apps in a Laminar Flow due to the top Moving Plate study is presented and displayed in Fig.3. In this App geometry, the flow is generated by the viscous drag of the fluid on the moving top plate. The Newtonian fluid model no-slip boundary condition causes the fluid to be stuck to the top plate and move with it. The action of the viscosity of the fluid produces a velocity gradient in the fluid. The flexibility of inputting data section enables students to try different scenarios to investigate different profiles at different fluid densities and velocities.

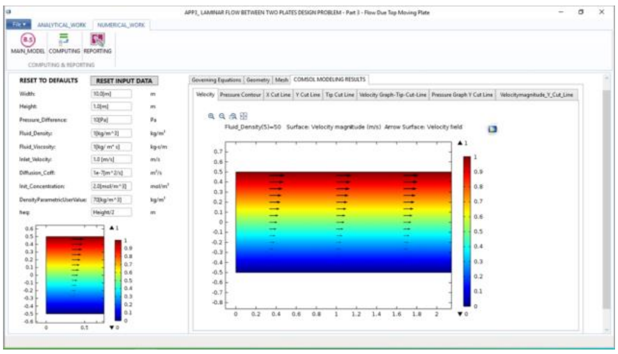


Figure 3. APP3_ Laminar Flow Between Two Plates Design Problem, Part 3 - Flow Due Top Moving Plate

The fourth App-4 is to simulate the flow around a sphere in several different flow regimes; steady-state laminar flow at a different Reynolds number (Re). These simulations provide a test of the ability of the code to accurately reproduce typical flow structures observed in the generic bluff body flows, such as those experienced by submarines. The simulations are compared both with experimental results and computations from other computer codes and it is found that COMSOL can accurately simulate the fluid behavior in each of the above flow regimes.

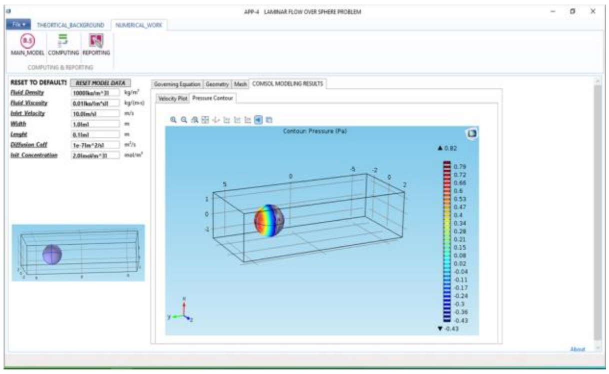


Figure 4. APP4_ Laminar Flow Over 3d Sphere Design Problem

Another example of using COMSOL Apps in teaching is shown in Fig.5, where the fluid flow of a class of materials is characterized by the existence of a threshold stress level known as yield stress below which the fluid does not shear and deforms like an elastic solid. Once the applied stress exceeds the yield stress, such a fluid may exhibit a constant shear viscosity; Bingham plastic fluid or a shear-thinning viscosity.

Figure 5. APP5_ Bingham Flow Design Problem

One of the main sections in the fluid mechanics' course is studying App6 that represents the two layers laminar flow between two plates as in figure (6), where the flow is due to moving top plate which has a wide range of applications.

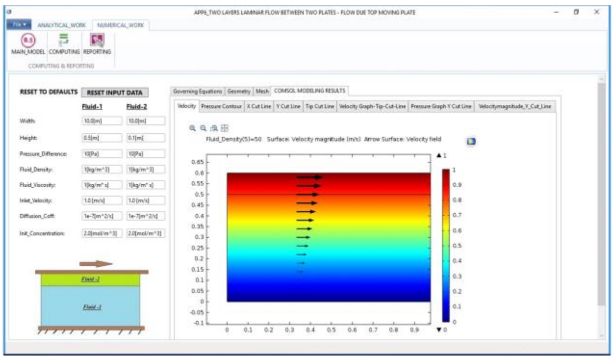


Figure 6. APP6_ Two Layers Laminar Flow Between Two Plates - Flow Due Top Moving Plate

V. COMSOL APP NAVIGATION EXAMPLE

To cover all the sides of the simple fluid mechanics problems, The COMSOL Apps were organized basically into two main dropdown ribbons as presented in the following Fig. 7 to 19:

- Analytical background works ribbon
- Numerical steps and outcomes ribbon

The analytical work tabs as shown in Fig.7, are illustrating the necessary steps that students should perform before starting the numerical work. These steps are sorted as shown in Fig.7, 8 and 9.es (7), (8) and (9).

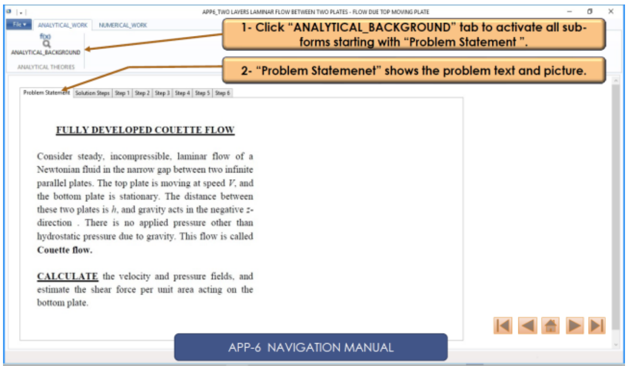


Figure 7. APP-6 navigation snapshot – Analytical background dropdown ribbon components – detailed problem statement tab

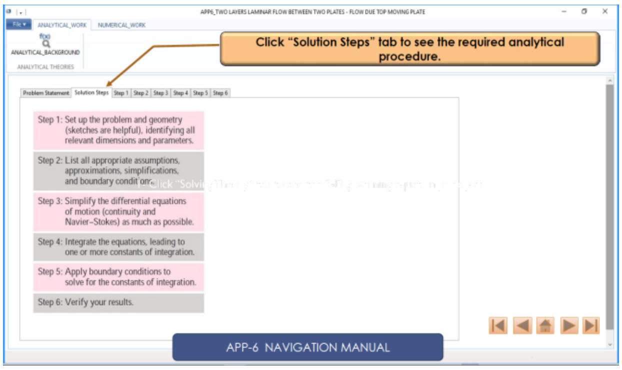


Figure 8. APP-6 navigation snapshot – Analytical background dropdown ribbon components- Solving theory principles

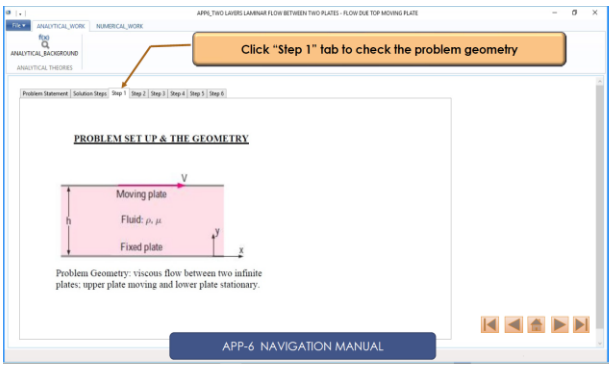


Figure 9a. APP-6 navigation snapshot step 1 -Analytical background dropdown ribbon components - Formal analytical calculation

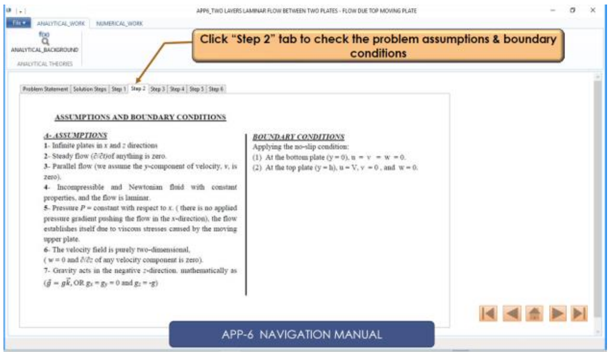


Figure 9b. APP-6 navigation snapshot step 2-Analytical background dropdown ribbon components - Formal analytical calculation

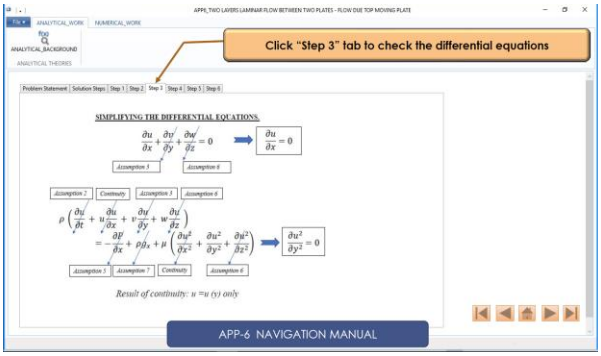
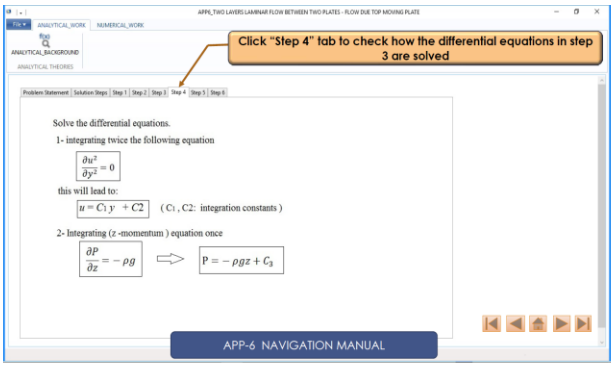


Figure 9c. APP-6 navigation snapshot step 3 -Analytical background dropdown ribbon components - Formal analytical calculation

Figure 9d. APP-6 navigation snapshot step 4 -Analytical background dropdown ribbon components - Formal analytical calculation

Fig. 10 to 19, describe the numerical work tabs arrangement. Students should activate all the tabs "forms" associated with the numerical work to start the numerical work steps by clicking the "Main Model" tab. The first tab on the list for the left side is showing the repeated problem statement as shown in Fig.10, where students can refer to it easily while staying in the numerical interface. The input values section which is designed to be visible all the time while navigating the numerical work tabs as displayed in the figure as well.



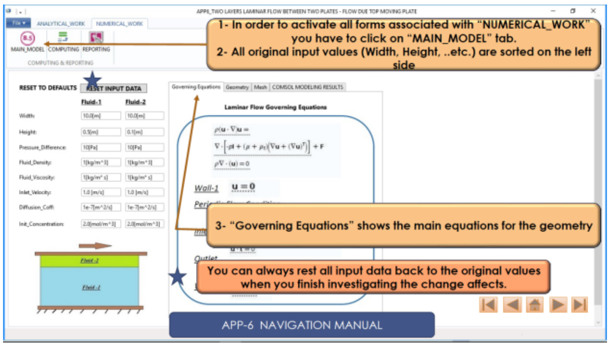


Figure 10. APP-6navigation snapshot -Numerical work dropdown ribbon components - Activating and inserting problem values

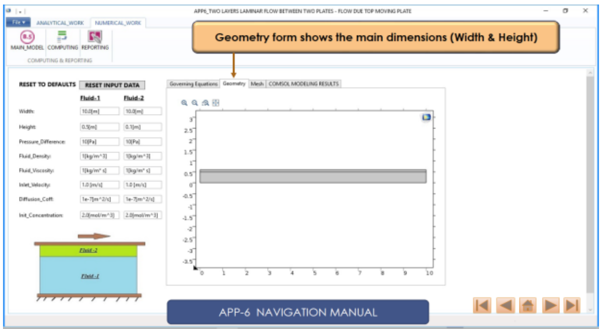


Figure 11. APP-6 navigation snapshot - Numerical work dropdown ribbon components - Geometry configuration and dimensions

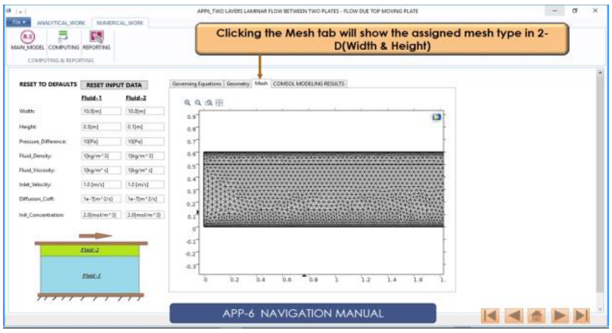


Figure 12. APP-6 navigation snapshot – Numerical work dropdown ribbon components - Meshing visualization tab

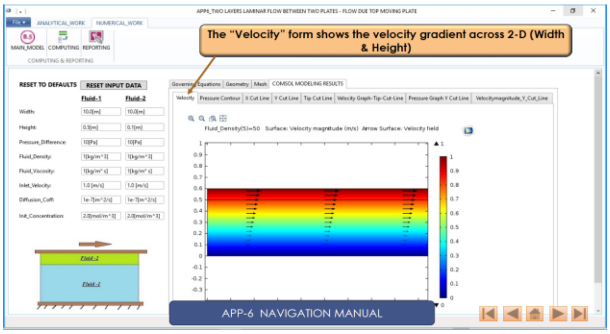


Figure 13a. APP-6 navigation snapshot velocity gradient- Numerical work dropdown ribbon results components distribution.

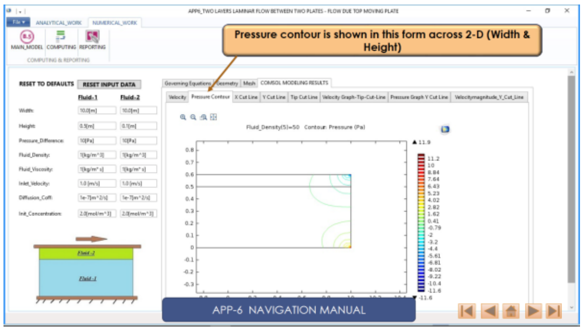


Figure 13b. APP-6 navigation snapshot pressure contour - Numerical work dropdown ribbon results components distribution

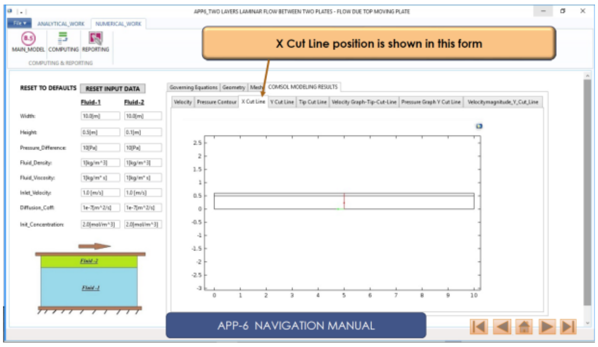


Figure 13c. APP-6 navigation snapshot X cut line - Numerical work dropdown ribbon results components distribution across the geometry.

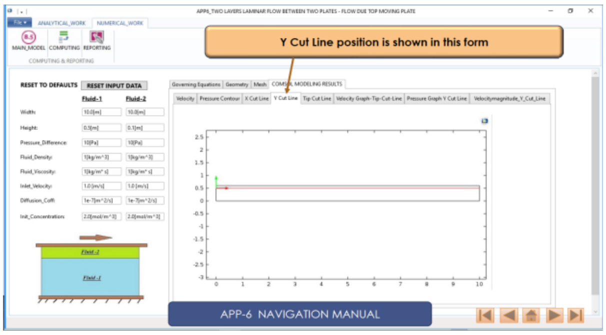


Figure 13d. APP-6 navigation snapshot Y cut line- Numerical work dropdown ribbon results components distribution across the geometry.

Once students apply any changes to the input values, they should perform the computing process by clicking the "COMPUTING" tab as described in F.ig.14 All the numerical models will be run by this step and the 'sound tone' finish signal should be heard.

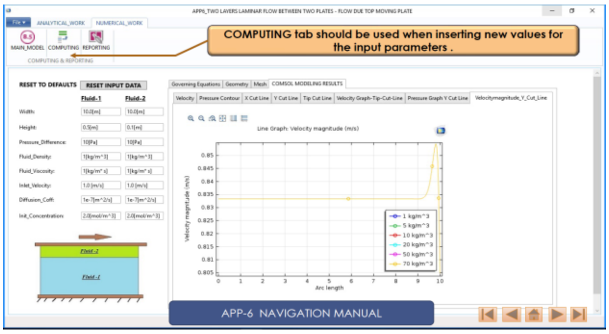


Figure 14. APP-6 navigation snapshot computing – Numerical work dropdown ribbon components – Numerical computing step.

The APP is equipped with a very useful reporting feature as shown in Fig.15. By this step, students can extract an editable Microsoft Word file which has a pre-arranged report section as displayed in Fig .16.The file can be saved later in the desired directory. The produced technical report will have the main sections such as cover page, table of contents, input list, charts, and coloured plots.

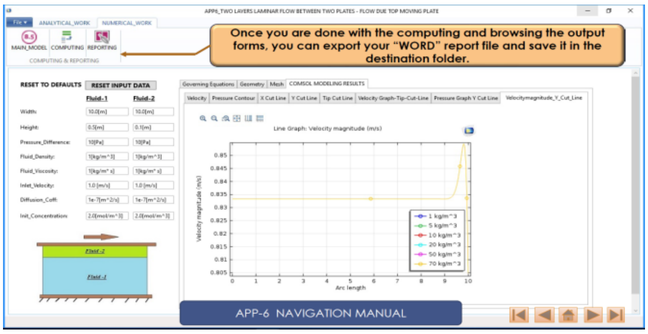


Figure 15. APP-6 navigation snapshot – Numerical work dropdown ribbon components – Extracting the final study report.

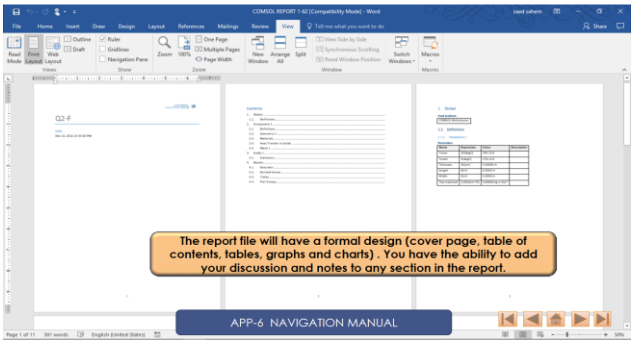


Figure 16. APP-6 editable produced report.

VI. RESULTS OVERVIEW

The APP-3 describes scenarios comparison of velocity profiles at first scenario S1 of 1m/s and second scenario S2 of 5m/s. Students should investigate the comparison of case study two possible scenarios looking at the effect of implementing any change to the input values, students will be able to see the results of that change. In this section, App-3 is dealing with a case study of finding the effects of upper plate velocity increment from 1m/s to 5 m/s to the velocity profiles changes as in figures (17) to (20). Figure 17 is presenting two scenarios, the velocity magnitude at "Tip Cut-line" Zoomed in at Domain tip line Profiles at two velocities 1m/s & 5m/s. The pressure graphs comparison is shown in Figure 18. Where the two pressure graphs are drawn at Y Cut-line Profiles for two velocities 1m/s and 5m/s. The Figure 19. Is illustrating velocity graphs comparison at Y Cut-line profiles for the two initial velocities 1m/s and 5m/s. Mid-Domain velocity profiles are presented in Fig. 20, where the comparison is taking place at Y Cut-line Zoomed in at Mid-Domain location for the two initial velocities 1m/s and 5m/s.

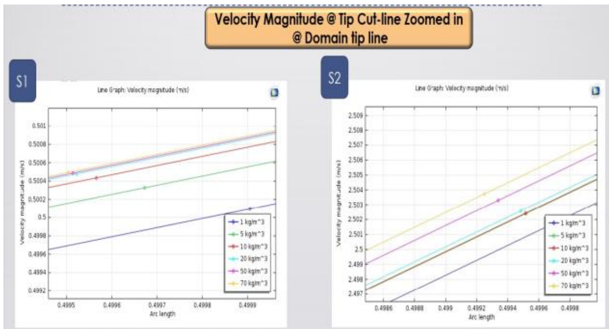


Figure 17. APP-3 Scenarios Comparison, Velocity Magnitude @ Tip Cut-line Zoomed in @ Domain tip line Profiles @ 1m/s & 5m/s.

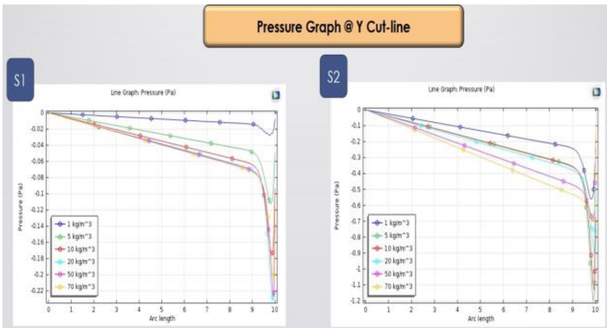


Figure 18. APP-3 Scenarios Comparison, Pressure Graph @ Y Cut-line Profiles @ 1m/s & 5m/s.

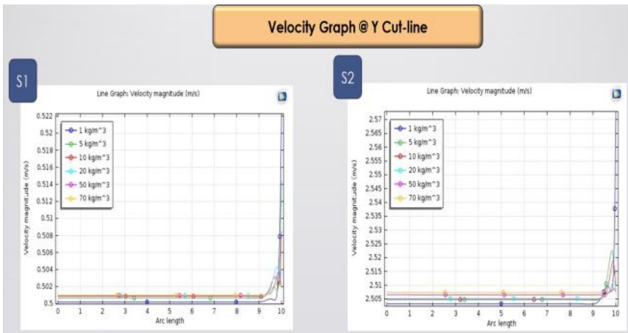


Figure 19. APP-3 Scenarios Comparison, Velocity Graph @ Y Cut-line Profiles @ 1m/s & 5m/s.

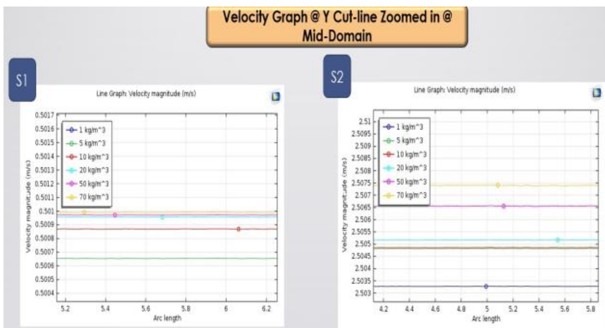


Figure 20. APP-3 Scenarios Comparison, Velocity Graph @ Y Cut-line Zoomed in @ Mid-Domain Profiles @ 1m/s & 5m/s.

VII. CONCLUSIONS

A. Concluding remarks

- The Fluid Mechanics APPS were created to allow students to explore, conduct, analyze and apply as many case studies in Fluid Mechanics as they want.
- Therefore, this methodology will advance their critical thinking and understanding of the physics beyond the visualized graphs.
- Visualized outputs in the APPS are clearly flexible with view and export features. These results are changeable once the student controls the input parameters.
- The software has very useful connection features with other software packages such as MS. Excel, MS. Word for the final reporting.

B. Future work recommendation

- From the APP 3 scenarios, an advanced way of expanding the investigation can be implemented.
- Operating the APPS with POP-UP windows can be added to guide students while navigating the APP.
- Ability to export the graphs as an image to other image editing software without a need of producing the full problem report.
- Using the APPS for complicated cases in the graduate-level courses.

C. Conclusions

Teaching the fluid dynamics concept and introducing a modern engineering tool was implemented and assessed for its effectiveness using the COMSOL simulation on fluid dynamics. COMSOL simulation APPS were created to cover the fluid mechanics' course. The APPS were developed to allow students to review, investigate, analyze, and apply as many case studies as they want. Their vision and understanding of the topics will be advanced following this technique. Visualized results in the APPS are changeable once the student controls the input data. Other packages such as MS Excel can be used to collect all results from data exported where they can process for further analysis. Employing COMSOL within traditional lecture classes as a part of a project has a significant impact in enhancing the learning and exposure to cutting edge engineering tools and proves this study effectiveness. It should be also noted that the experience with COMSOL could render students a universal Multiphysics simulation tool to simulate various other problems such as heat/mass transfer or fluid-structure analysis for undergraduate research projects.

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BIOGRAPHY

Mohamed Edali is Assistant Professor of Chemical and Petroleum Engineering at Elmergib University. He holds a BSc in Petroleum Engineering, MS in Mechanical/Chemical Engineering from Concordia University, and PhD in Process Engineering from Regina University. His research is in computer-aided modeling, simulation, and engineering teaching using smart engineering Apps using COMSOL.

Zaed Sahem is the founder of Creativity group Engineering Simulation R&D Smart teaching APPS in Engineering and Science fields using COMSOL & CAD SolidWorks. Host Institutions: University of Waterloo & Elmergib University. He holds a BSc in Mechanical Engineering from Nasser University, and MEng in Mechanical Engineering from University of Ottawa.

Faraj Ben Rajeb is PhD candidate in process Engineering at Memorial University of Newfound. He holds a BSc in Chemical Engineering from Bright Star University of Technology, and MSc in Chemical Engineering from University of Tripoli. His research interests are fluid

mechanics, Newtonian, and non-Newtonian multiphase flow.

Walid Alaswad is the Head of Department of Chemical and Petroleum Engineering at Elmergib University. He holds a BSc and MSc in Chemical Engineering from Elmergib University. His research interests include fundamental studies of heat and mass transfer, fluid mechanics teaching strategies.

Ali Bseibsu is the head of academic affairs and examination office of faculty of Engineering at Elmergib University. He holds a BSc in Chemical Engineering from Elmergib University, and MS in Chemical Engineering from the University of Waterloo. His research interests include fundamental studies of Chemical Reaction Engineering teaching strategies, air pollution control and wastewater treatment. His main research interest is computer simulation techniques to solve chemical engineering problems.

Ali Elkamel is Professor of Chemical Engineering at the University of Waterloo. He holds a BSc in Chemical Engineering and BSc in Mathematics from Colorado School of Mines, MS in Chemical Engineering from the University of Colorado-Boulder, and PhD in Chemical Engineering from Purdue University (West Lafayette), Indiana.