Simulation Apps for Teaching Engineering Delivered via COMSOL Server™

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Introduction

We use COMSOL Multiphysics® not only as a modeling tool for research and to teach applied math modeling to advanced students, but also as a convenient tool to help undergraduates learn engineering fundamentals [1]. In a laboratory class, for example, we use simulations to connect theory to experiment by solving and presenting the velocity, pressure, temperature, and concentration profiles within chemical process equipment. The simulations are used as pre-lab exercises to review fundamentals and prepare for subsequent encounters with the physical equipment.

Until now, we have delivered the simulations using the full COMSOL Multiphysics® software via a Class Kit license. For each simulation, the students, most of whom have never used COMSOL Multiphysics®, make changes in the model parameters and rerun a pre-built model at various prescribed conditions to gain insight into the process studied. This requires them to follow a detailed step-by-step written tutorial designed to walk them through changing the existing model, running the simulation, and examining the results. The step-by-step procedure also prompts them to write down answers to questions about what they are learning from the model. They subsequently submit the answers to the questions for grading via a separate online survey program.

Here we describe our experience in converting these simulations and tutorials into applications and delivering them via COMSOL Server™. Each application is a self-contained control panel for a virtual experiment that allows changing input parameters, running the experiment, and viewing the results without opening COMSOL Multiphysics® and manipulating the model tree. The applications also include built-in quiz questions that students answer and submit directly from the application via email to a grader. With this implementation, students should spend more time thinking about the underlying physics and results rather than following a tedious procedure to help them navigate an unfamiliar program.

To compare the two delivery methods, we used the tutorial method for review of fluid flow fundamentals and used the app method for review of heat transfer fundaments during the first week of a senior level laboratory class, before experimentation began. The two methods were compared with regard to instructor preparation time and convenience, as well as student satisfaction and learning.

COMSOL Server™ and Applications

For this study, two apps, one on Conduction in a Solid and the other on Convection During Pipe Flow, were developed to review heat transfer fundamentals. Figure 1 shows a screenshot of the Convection During Pipe Flow application. Students were instructed to start with the Model Documentation tab to review some theory and understand the goals of the app before running it at different conditions. Students were then prompted to vary input parameters and model assumptions and compare numerical and graphical results obtained at the various conditions. As shown in Figure 2, each app contained a multiple choice quiz that students could answer and submit directly from the app. Once the quiz was submitted to the instructor via email, the student could view his/her grade and the correct answer sequence.

Two instances of COMSOL Server™ were installed on the WPI computer network. One instance was a Windows version on a single Sun Microsystems server. The other instance was a three part Linux cluster. As shown in Figure 3, both instances had a customized login page and application library that delivered the apps to a student's browser. It was convenient to allow students to login as Guest00-Guest99 with a single password on either instance, but it is possible to give them each a unique ID and password.

Assessment of Student Learning and Satisfaction

The impact of the use of COMSOL® simulations on student learning was evaluated via two 8 question multiple choice diagnostic tests, one on fluid flow and the other on heat transfer. The diagnostic questions were different from the questions posed in the app quizzes and the tutorial questions but involved the same concepts. Some sample diagnostic quiz questions are shown in Table 1. Each diagnostic quiz was administered twice, once before (pre) and once after (post) studying the COMSOL® tutorials and apps.

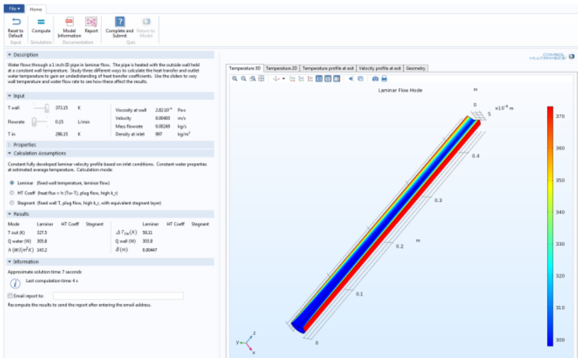


Figure 1. Convection during pipe flow application.

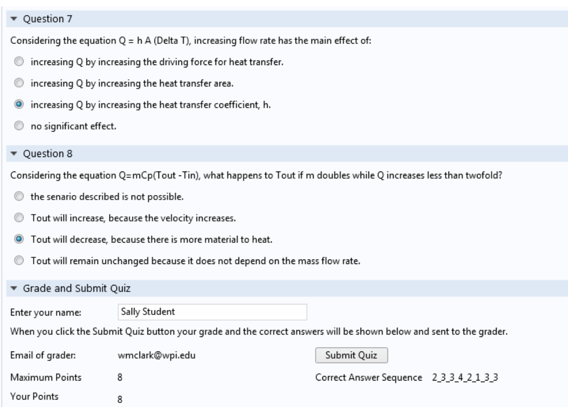


Figure 2. Students see their grade and the correct answers after they submit the quiz via email directly from the app.

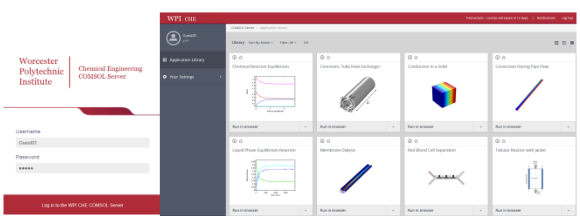


Figure 3. Customized login page and application library.

A survey on student satisfaction with the COMSOL® learning review and any preference for the tutorial or app delivery method was administered at the end of the study. The survey had 8 five-level Likert scale questions aimed at learning if students believed the review using simulations was useful and if they thought the tutorial or the app method was more informative, more enjoyable, and more convenient to use. Students were also invited to enter an open-ended comment on their experience with the learning tools.

Table 1. Sample diagnostic test questions.

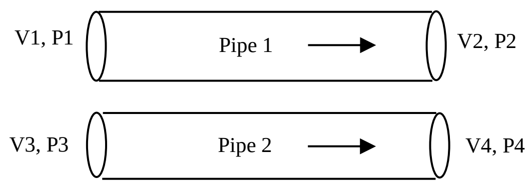
The two pipes shown in the figure below have the same cross sectional area and length, and both have water flowing through them in fully developed laminar flow, but at different flow rates. Both pipes are at room temperature and are open to the atmosphere at the exit. The second pipe has water flowing at twice the flow rate of that in the first pipe. Select the letter of the correct statement about the pressures (P) and average velocities (V) in the two pipes.

a. V4 equals V2 and P3 equals P1

b. V4 equals V2 and P3 is greater than P1

c. V4 is greater than V2 and P3 equals P1

d. V4 is greater than V2 and P3 is greater than P1



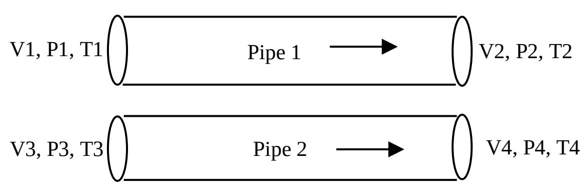
Two identical pipes with the pipe wall temperatures held constant at 100 °C are shown in the figure below. If water enters both pipes at T1 = T3 = 25 °C but the average velocity entering pipe 2 is twice that of pipe 1 (V3 = 2 V1), select the letter of the correct statement about the heat transfer rates, q1 in pipe 1 and q2 in pipe 2.

a. q1 is equal to q2

b. q1 is greater than q2

c. q1 is less than q2

d. the relative magnitudes of q1 and q2 cannot be determined from the information given



Results and Discussion

All 66 students in the course completed the pre and post diagnostic tests on both fluid flow and heat transfer, in addition to completing online quizzes on fluid flow while studying the tutorials and on heat transfer while studying the apps. The class averages on the diagnostic tests shown in Table 2 give a clear indication that both COMSOL® learning tool delivery methods were very effective in helping students review the introductory material for the course. It is of interest to note that the concept covered on one of the eight questions on the heat transfer diagnostic was not explicitly covered in the heat transfer apps. A few students missing that question was the main reason the heat transfer post average was not 100%.

Table 2. Class average on diagnostic tests.

Test	Pre	Post
Fluids (tutorials)	74	100
Heatx (apps)	66	98

The response rate for the student satisfaction and preference survey was 91%. Table 3 presents the percent of students responding at each of the Likert scale values for questions about whether the COMSOL® reviews (either/or both) were useful and whether each of the delivery methods was informative and enjoyable. Numerical values for agree plus strongly agree and disagree plus strongly disagree are indicated along with graphical results for the 5 different response levels. It can be seen that the majority of students thought both delivery methods were informative as well as useful. Only 25% of respondents reported enjoying using the tutorials while 45% enjoyed using the apps.

Table 3. Student satisfaction survey response (%).
■strongly agree, ■ agree, ■ neither, ■ disagree, ■strongly disagree

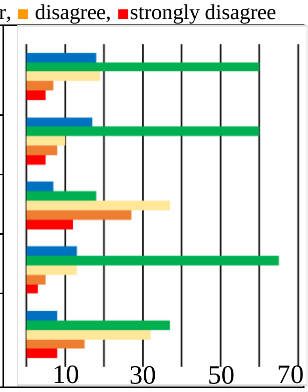
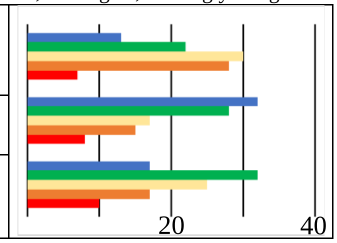
COMSOL® (both) useful A+SA=78, D+SD=12	
Tutorials informative A+SA=77, D+SD=13	
Tutorials enjoyable A+SA=25, D+SD=39	
Apps informative A+SA=78, D+SD=8	
Apps enjoyable SA+A=45, D+SD=23	

Table 4 shows student responses to direct questions about which delivery method they found more useful and more convenient and which they liked better. It appears that on average they found the two methods about equally useful, found the apps more convenient, and liked the apps slightly better.

Table 4. Student preference survey response (%).
■strongly agree, ■ agree, ■ neither, ■ disagree, ■strongly disagree

Tutorials more useful A+SA=35, D+SD=35	
Apps more convenient A+SA=60, D+SD=23	
Liked apps better A+SA=49, D+SD=27	

Other results of interest include how the course instructor felt about the apps. Making the first app was a bit of a challenge due to lack of familiarity with the process. There are online video tutorials as well as a built-in code recorder and editor tools that make the process easy, however. After learning the process, building an app with a built-in quiz takes only slightly longer than making a model with an associated detailed tutorial. Installing and using COMSOL Server™ was straightforward and organizing and delivering self-contained learning modules as apps to any browser was very convenient. Discussions with colleagues about this project met with great enthusiasm as most were unfamiliar with COMSOL apps, but thought they would be of value in their own courses once they learned about them.

Student Comments

Seventy seven percent of the students in the course provided comments when prompted at the end of the satisfaction and preference survey. Representative samples of these comments are present below to elucidate differences in student preferences.

Liked Both Methods

"Very good reintroduction to the material, especially considering some of us have not taken fluids and heat transfer since sophomore year."

"COMSOL can be useful to review material and good for visualizing the materials."

"I think a mix of using the software and using the apps is necessary. The apps are very convenient to use, but I think that our education as engineers would be incomplete without using the actual software, learning how to pull values or even set up simulations ourselves."

“[Tutorial] was better for understanding how to use COMSOL as a tool, and [app] was better for understanding the material.”

Liked Apps Better

“The app was more convenient since it can access on the web.”

“I did prefer the apps over the simulation. Overall, these visuals were extremely helpful, and I hope more are used in the future.”

“Having the module and quiz integrated in the app was more efficient.”

“The apps are easier to access and slightly more user-friendly.”

“[Apps were] much better because I could focus on understanding the concepts whereas [with tutorials] I spent more time trying to get the program to work than understanding the actual review material.”

“I prefer the ease of access of the apps, and think while COMSOL [tutorials have] more options, that the narrower focus of the apps allowed me to more easily understand what exactly I was supposed to be reviewing/learning.”

“I feel as if even though I read the [tutorial] word document, I did not feel comfortable using the software and did not utilize it as much as the apps.”

Liked Tutorials Better

“I felt as though the [tutorials] I was actually learning things compared to just clicking around in [the apps].”

“[Apps were] a lot easier to do. However, I felt like [tutorials] helped me learn a lot more than [apps].”

“The [tutorials] provide valuable computer experience and more flexibility for identifying different trends within flow or transfer problems.”

“The online apps while good, in theory, were confusing to use and less intuitive than using the actual COMSOL software.”

“I thought that using the apps was more enjoyable; however, I believe it is good background to get experience using the actual COMSOL program, as we will most likely need it in the future.”

“The detailed guide leading us through [the tutorials] was incredibly helpful. [Using] a prepared model like the ones in the homework was beneficial to my own learning.”

“I didn't think that the app was that much more helpful than using the actual software to do the simulations. The instructions in [the tutorials] were very clear so it was easy enough to manipulate the COMSOL software without the use of the app.”

Liked Neither Method

“We should focus on reviewing problems instead of introducing a new software that we have never seen before.”

Conclusions

COMSOL Server™ is a convenient way to deliver interactive online learning materials. Apps are time consuming to build, but only slightly more so than models plus detailed tutorials. As measured by pre and post diagnostics, both the tutorial and app delivery methods were very effective with regard to student learning. Although a large majority of students believed that both learning methods were useful, there were differing opinions with regard to which method was preferred. Most students preferred apps, but others preferred working directly with .mph files while following tutorials. Very few students preferred neither. Based on this initial experience with COMSOL® apps, we look forward to complementing our existing COMSOL Multiphysics® licenses with a COMSOL Server™ license and delivering learning apps for other engineering courses in the future.

References

1. Clark, W. M., Work in Progress - Computer Simulations to Correct Misconceptions in Fluid Flow and Heat Transfer Fundamentals, Proceedings of the Frontiers in Education Conference, Washington, DC, October (2010).

Acknowledgements

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