COMSOL Multiphysics® Models Combined with Experiments to Teach PID Controller Tuning

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Introduction: Process control is important in the chemical industry and every chemical engineering student needs some understanding of it. We report a laboratory experiment that combines a physical process with a COMSOL model to teach the practical aspects of PID controller tuning. COMSOL allows students to run virtual experiments to discover the effect of changing each control parameter and to test various controller tuning methods. The virtual experiments are tied to reality and learning is strengthened by applying the knowledge gained to control the physical experiment.

The objective of the experiment, shown schematically in Figure 1, is to control the process temperature, T_p, inside a jacketed, well-stirred reactor vessel. The temperature of the circulating fluid is adjusted with a temperature bath containing a heater and a refrigeration unit.

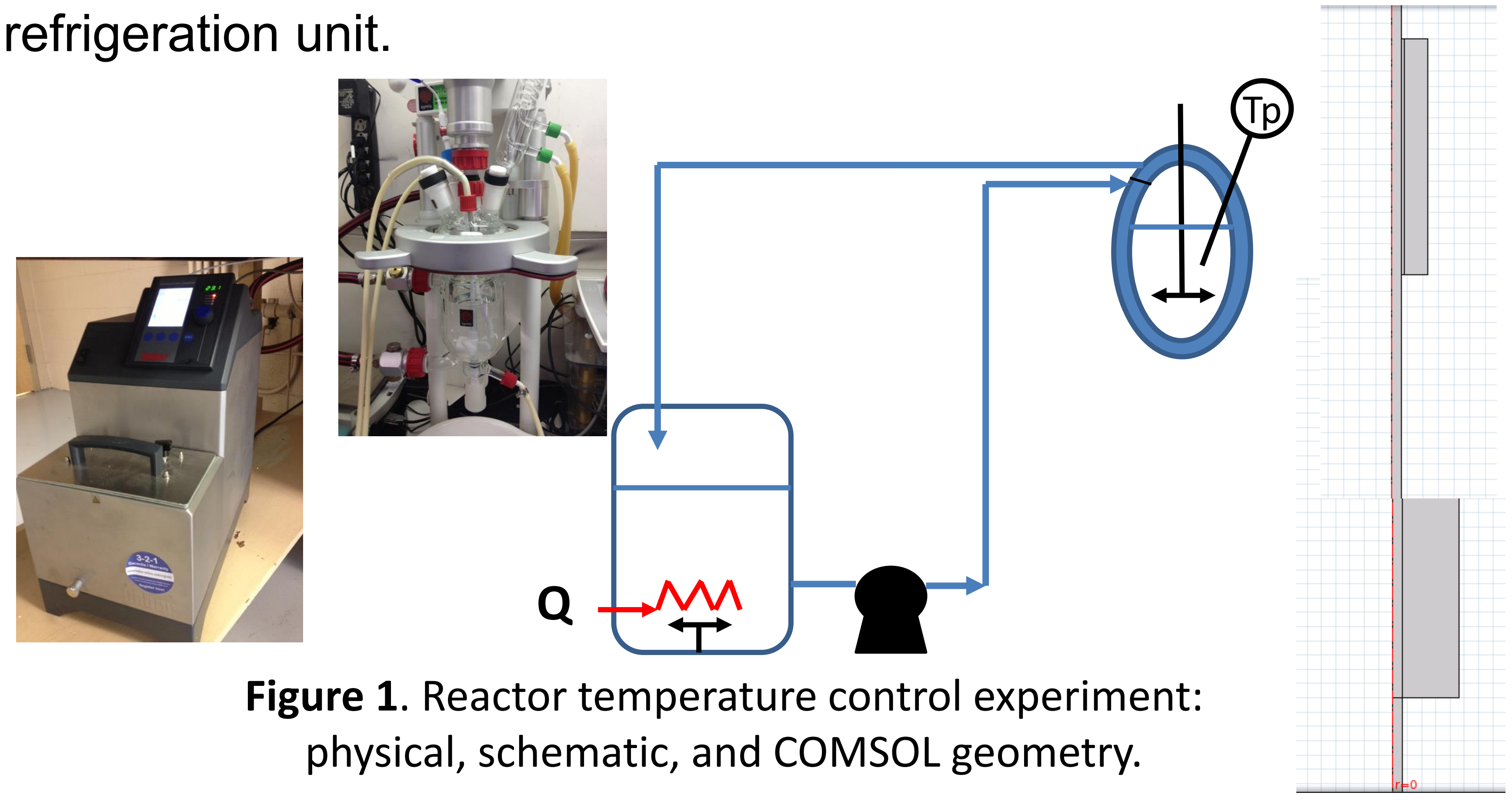

Figure 1. Reactor temperature control experiment: physical, schematic, and COMSOL geometry.

Computational Methods: A model that captures all the necessary physics was developed using 2-D axial symmetry with a circulation hose connecting a cylindrical reaction vessel to a cylindrical temperature bath. The circulation hose is made continuous by connecting the outlet to the inlet through a periodic boundary condition. The fluid flow is modeled with turbulent flow, k-ε physics. The circulating fluid transfers heat to the reactor through a glass wall using heat transfer in fluids physics. The heat input to the process is simulated as a volume heat source inside the temperature bath and is evaluated using the standard proportional, integral, derivative control equation

$$Q(t) = Q_o\left[K_P\,E(t) + K_I\int_0^t E(t)dt + K_D\,\frac{dE(t)}{dt}\right] \qquad (1)$$

where E is the difference between the set point temperature and the process temperature and K_P, K_I, and K_D are the controller tuning parameters. The fluid flow equations are first solved in a stationary study using an average temperature. The resulting velocity field is then assumed to be constant in a time dependent study of the heat transfer.

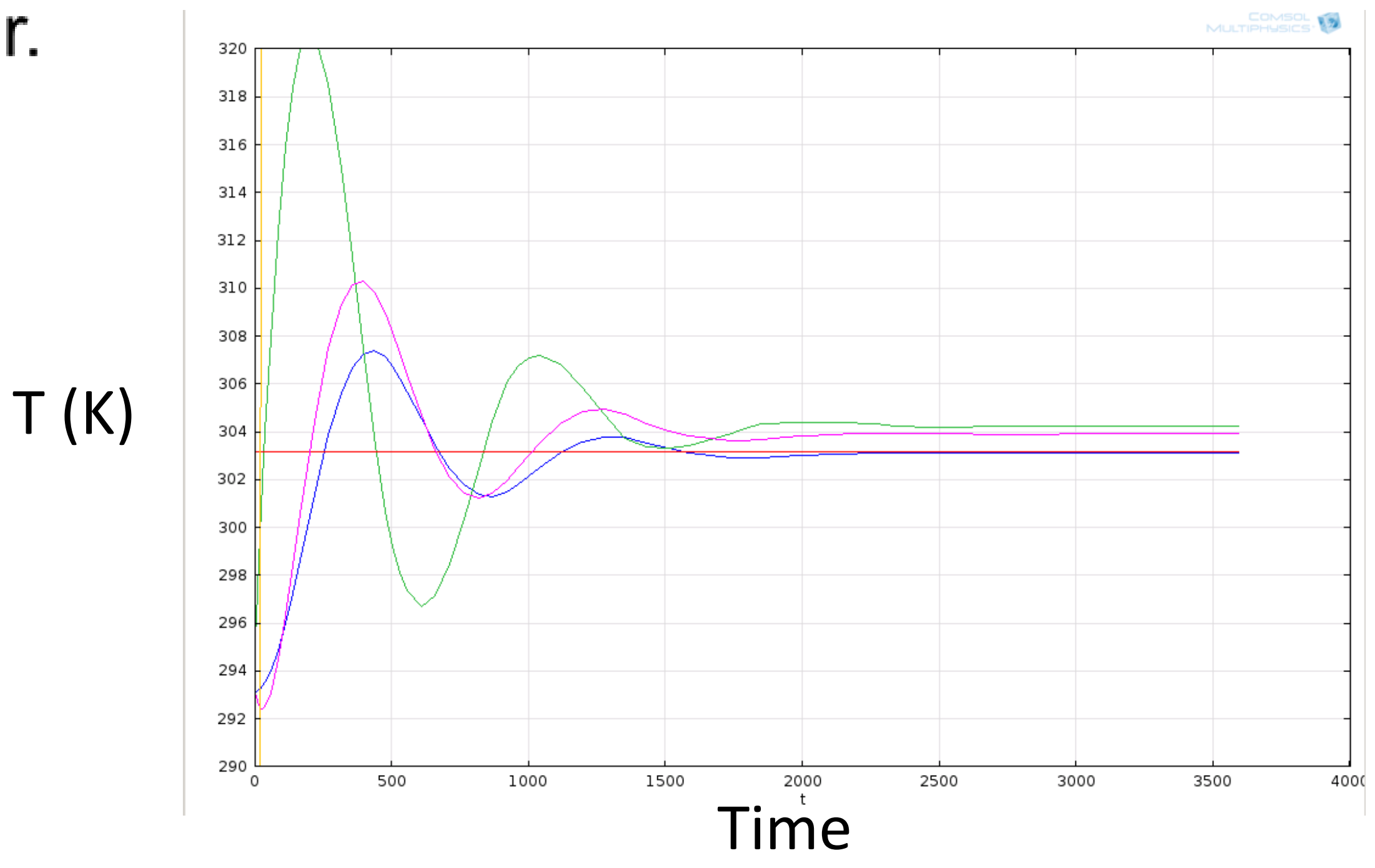

Figure 2. Temperature (K) in the reactor (blue), bath (green), and hose (magenta) as a function of time in seconds. Set point temperature is in red.

Results: Figure 2 shows a typical result plot of the temperature at various probe points including T_p, in blue, and the set point in red. Students studied the effect of changing control parameters on plots like Figure 2 and tried to minimize the integral absolute error in the simulation and the physical process.

$$IAE = \int_0^\infty \left| T_{set} - T_p \right| dt \qquad (2)$$

Student satisfaction and learning was evaluated using a multiple choice test before and after the lab exercise and collecting a survey at the end of the course. There was marked improvement in the number of correct answers to the test after the lab, as shown in Figure 3, and the survey indicated that the students were pleased with a balanced use of simulation and physical experiments as indicated in Table 1. Some students particularly liked the friendly competition of trying to find the lowest integral absolute error and the use of the COMSOL model.

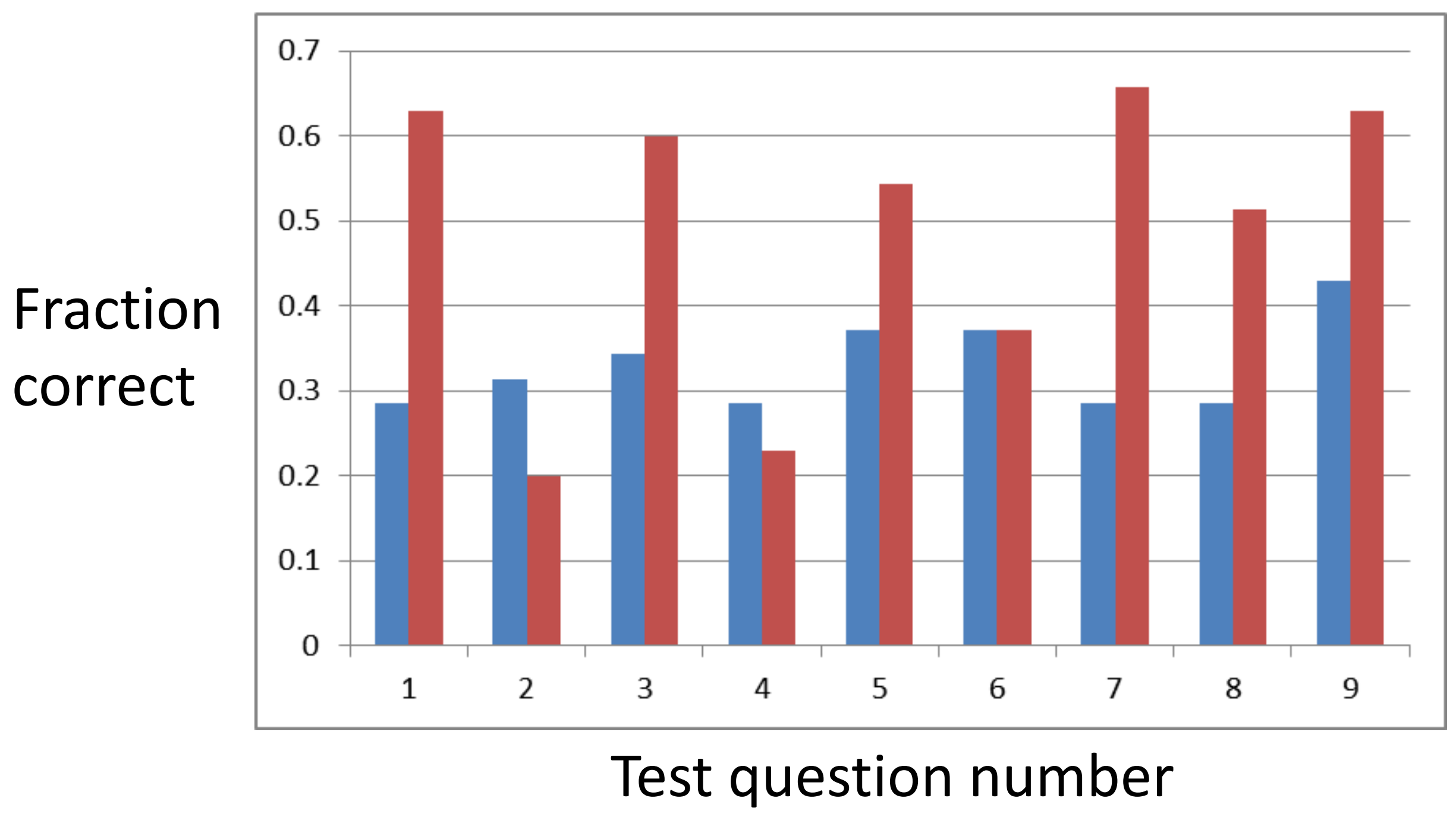

Figure 3. Fraction of correct answers on individual questions on the diagnostic quiz, pre (blue) and post (red).

Table 1. Final survey questions with percent of students providing each answer in parentheses.

1. If you were to do this again, would you rather run:
(a) only physical experiments (3%), (b) only simulations (3 %), (c) one physical experiment and many simulations (22 %), (d) 3 physical experiments and many simulations (53 %), (e) more than 3 physical experiments and fewer simulations than we did (19 %)

2. Using the simulation software was: (a) very difficult (0 %), (b) difficult (0 %), (c) neither difficult nor easy (44 %), (d) easy (42%), (e) very easy (14 %)

3. The COMSOL simulation helped me to understand PID control, in general: (a) not at all (0 %), (b) just a little (0 %), (c) somewhat (28 %), (d) much (53 %), (e) very much (19%)

4. The COMSOL simulation helped me to understand PID tuning methods: (a) not at all (0 %), (b) just a little (3 %), (c) somewhat (44 %), (d) much (30 %), (e) very much (22 %)

Conclusions: A laboratory exercise to learn PID controller tuning could be time consuming and taxing on the equipment. A purely equation-based, virtual controller tuning exercise might not be interesting or seem relevant to real world processes. Combing COMSOL simulation with a physical experiment appears to be interesting, enjoyable, and effective in teaching practical aspects of process control.

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