Implementing Simulation Software to Develop Virtual Experiments in Undergraduate Chemical Engineering Education

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Abstract

This manuscript investigates the use of simulation software to create virtual experiments in undergraduate chemical engineering education. It highlights the transition from traditional teaching methods to a learner-centric approach, supported by tools such as UNISIM, DWSIM, and MATLAB/SIMULINK. These virtual labs cover key courses like Mass Transfer and Reaction Engineering, offering a platform for students to engage in experimental design and process optimization. The integration of virtual experiments has proven beneficial in enhancing student learning, reducing equipment-related anxiety, and improving teamwork and self-efficacy. The study also presents an effective assessment methodology for educational outcomes. The implementation of virtual labs, especially during the COVID-19 pandemic, has significantly improved students' problem-solving skills, teamwork, and communication abilities, underscoring their effectiveness in chemical engineering education.

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1. Introduction

Experiential learning is a powerful tool for higher education as it provides the best long-term retention. Virtual laboratories have emerged as one of the vital components in higher education research to improve metacognitive skills. They address the need for different teaching mechanisms based on varied learning styles viz verbal, visual, passive, active, sequential, and global. They provide an alternate pedagogy methodology to assess the teamwork, peer learning, and learning experience of the students. Presently, technology advances have challenged and brought in a shift in the education policies and pedagogy practices. The shift is from the traditional instructional mode of teaching to a learner-centric approach. A learner-centric approach encourages the learners to be active in selecting, designing, and performing the educational activities (Wenqian Chen, Umang Shah, & Clemens Brechtelsbauer, 2016), (James E. Corter, et al., 2007), (Luis de la Torre, et al., 2013). This paradigm shift has led the educators around the world to adapt to different approaches in higher education.

The national board of accreditation (NBA) is targeting achieving Outcomes-based education (OBE) in terms of knowledge, skills, attitudes, and behavior in institutions imparting higher education. It emphasizes that outcomes are critically dependent on the teaching-learning process followed to achieve them and the methodology for evaluating the attainment of outcomes. The Washington Accord, under its graduate attributes, suggests usage of modern engineering and IT tools, including modelling and simulation, for enhanced understanding of engineering problems. Modelling is identified as an important element of the knowledge profile of graduates (Basil Wakelin & Hu Hanrahan, 2014). Virtual labs are vital tools in higher education to improve the metacognitive skills and research ability of students. They promote collaborative experimentation and research. They offer an alternative methodology to assess peer learning, teamwork, and the learning experience of students. In the global effort to incorporate experiential learning in higher education, pioneering work in the domain of chemical engineering was done at the Department of Chemical Engineering, University of Michigan, in Ann Arbor (John T. Bell & H. Scott Fogler, 1996). A virtual reality-based educational module, Vicher, was developed for reaction engineering in the topics of catalyst deactivation and non-isothermal effects. An interactive virtual laboratory was developed in fluid mechanics at the Stevens Institute of Technology (SIT). It had animations, graphics, and result analysis for enhancing the educational experience of their students. The European Association for Quality Assurance in Higher Education (ENQA) has outlined standards that emphasize student-centred learning, teaching, and assessment. The Ministry of Education, Govt. of India, has initiated and funded the development of virtual labs by renowned institutions like IITs, Amrita University, NIT Karnataka, for different disciplines of science and engineering for students at all levels from under-graduation to research (Shivakumar R, Sreelakshmi Diddi, & Samita Maitra, 2017). Experiential learning has tremendous potential to promote enhanced learning in chemical engineering education (John T. Bell & H. Scott Fogler, 1995), (John T. Bell & H. Scott Fogler, 1995). The utilization of modern computational tools has emerged as a critical aspect in the application of the chemical engineering domain to provide solutions to societal and environmental problems.

Traditional laboratory practices do not have activities to prepare the student to be a future practicing scientist. The learner does not get an opportunity to identify a problem, seek information, develop a solution, choose between alternate solutions, evaluate the proposed solution, and communicate with the scientific community (Shalaunda M. Reeves & Kent J. Crippen, 2021). Unconstrained exploration is rarely possible. They do not address the effect of anxiety in handling sophisticated equipment and complex procedures on the self-efficacy and academic performance of the learner (Vysakh Kani Kolil, Sharanya Muthupalani, & Krishnashree Achuthan, 2020). Utilization of virtual labs in conjunction with wet laboratories has the capacity to overcome these issues. They are highly effective in simplifying and clarifying the comprehension of complex scientific concepts, provide interactive visualization of the equipment, and can be remotely operated. They give the learner an experience similar to that of working in a research laboratory. They usher in a positive change in knowledge, motivation, and self-efficacy of the learners. In addition, they help to overcome difficulties like time constraint and supervision (Vinod Vijay Kumar, et al., 2021). Virtual labs also hold promise for institutions that have a dearth of resources. Simulation is distinguished from a virtual lab in that it does not involve the rigor of handling a scientific problem from its identification to solution. It entails the manipulation of a group of parameters to study their effect on the desired output. Hence, it is a kind of passive learning experience compared to virtual labs.

This paper describes the utilization of contemporary technologies to bring experience-based learning to undergraduate chemical engineering education. Tools namely, UNISIM, DWSIM, and MATLAB/SIMULINK have been explored and implemented in core laboratory courses of chemical engineering like Mass Transfer, Heat Transfer, Process Control, and Reaction Engineering. Experiments and process simulations were developed using these tools, and the learners were guided to design process flow diagrams (PFD), simulate the developed PFD, optimize the process variables, and draw conclusions from previous experimental investigation/published literature. The methodology for evaluation of student learning is presented. A detailed analysis of the outcomes of this endeavor was showcased to highlight the positive impact on the learners.

2. Development of Virtual Experiments

Practical/laboratory experiments are an integrated part of higher education in the fields of Science, Technology, Engineering, and Mathematics. Laboratory practice is important to relate theoretical concepts, improve practical skills, motivate individuals to work in a team during the conduction of experiments, enhance their metacognitive skills, and improve the retention rate of students (R.S. Baker, J. Clarke-Midura, & J. Ocumpaugh, 2016), (Boris Bortnik, Natalia Stozhko, Irina Pervukhina, Albina Tchernysheva, & Galina Belysheva, 2017). The wet laboratories developed at the undergraduate level aim to provide an understanding of the applications of theoretical concepts learned. Virtual experiments imitate wet laboratory experiments with varying degrees of user-defined variables. Virtual labs provide the platform to perform experiments to relate the effect of different parameters on the equipment in a single operation. Estimating the effect of different parameters in a single run is practically not feasible using the wet laboratory due to logistic constraints (Jarka Glassey & Fernao D. Magalhaes, 2020), (Priyam Nayak, et al., 2019), (Lyle D. Feisel & Albert J. Rosa, 2005), (Deanna Raineri, 2001), (P. A. Kirschner & M. A. M. Meester, 1988).

Virtual experiments were developed using the Unisim Design Simulation and MATLAB/SIMULINK tools for the Chemical

Engineering domain at B.M.S. College of Engineering, Bengaluru, India. Developed virtual labs will improve the knowledge of the students, enhance their learning skills, motivate them to work in teams, help in peer learning, and assess their self-efficacy. The outbreak of the pandemic COVID-19 has forced us to depend on these developed virtual labs. These labs will give a better understanding of the experiments. Interpretation of the data after the conduction of experiments virtually is simple (Shalaunda M. Reeves & Kent J. Crippen, 2021). The software has a complete material balance to energy balance approach, which is the most crucial aspect for process engineers to estimate when any unit operation or unit process is operated. Integration of a Microsoft Excel sheet into the software is feasible. Simulated values are transferred into the spreadsheets to plot the graphs, and the effect of different parameters on the unit process or the unit operation is assessed. Figure 1 evinces the steps to develop and carry out the virtual experiments using the Unisim design software. Initially, the learner should select the components in the experiment. The next step is to select the suitable fluid package, which is a thermodynamic model compatible with the components selected. The thermodynamic model will estimate the physical and chemical properties of the components. Learners will move to develop a process flow diagram of the virtual experiment. Firstly, material streams are defined with literature/experimental values, and then these are connected to unit operations/processes, and outlet stream values will be estimated by the software. The process flow diagram will be completed, and the estimated values are tabulated. The interpretation of the virtual experimental data can be plotted using the Microsoft Excel interface (Priyam Nayak, et al., 2019), (Rahul Jain, et al., 2019), (Deanna Raineri, 2001), (Lyle D. Feisel & Albert J. Rosa, 2005).

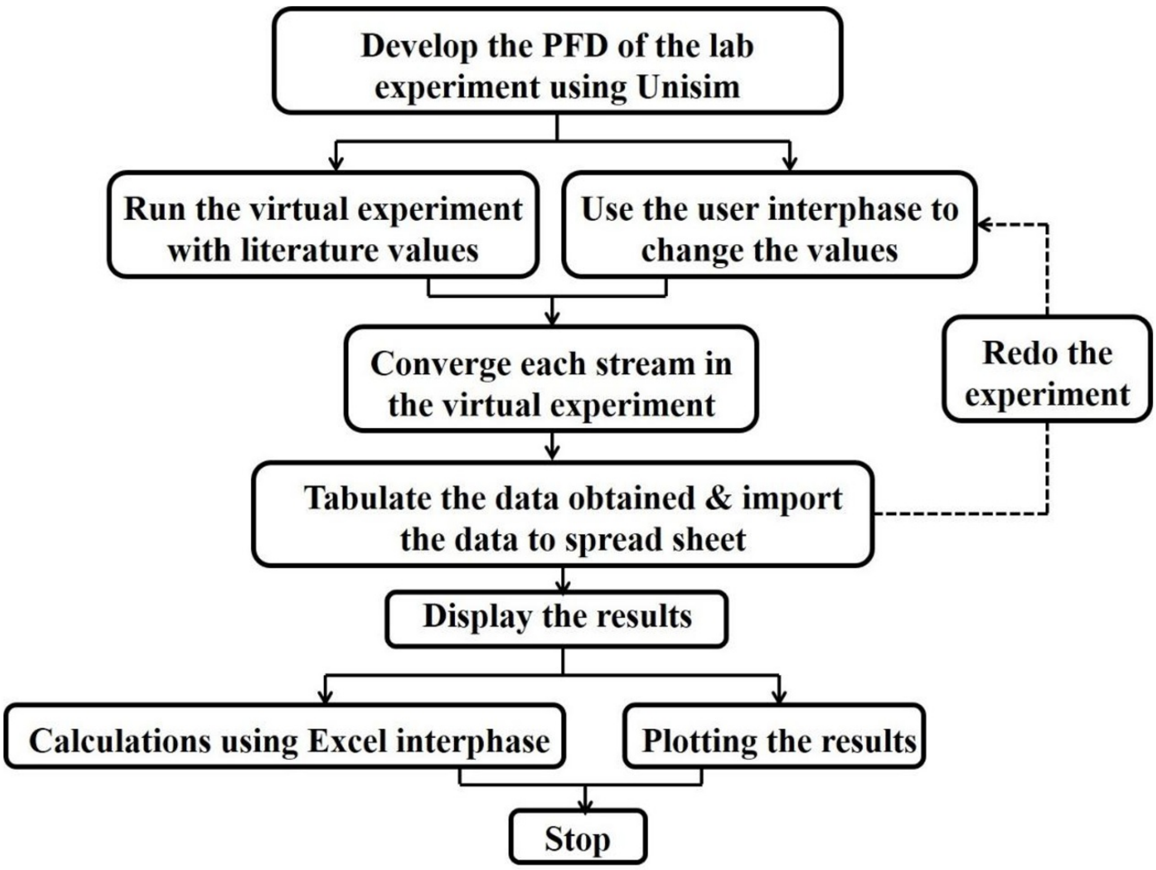

Figure 1. Sequential Steps to Conduct Virtual Experiments.

2.1. Virtual Experiments for Ideal Reactors Using UNISIM Simulation Tool

Design and interpretation of the performance of ideal reactors for different reactions are vital for process engineers. The reactions occurring in the reactors can be of diverse orders. Reactions like elementary, non-elementary, single & multistep series reactions, and single & multistep parallel reactions are studied in the reactors in most of the process industries. Undergraduates will learn the theoretical concepts behind the design equations for ideal reactors. The rate of reaction concept, the rate constant, and its changes with temperature are studied. The virtual experiment developed aims to estimate the effect of temperature and the volume of the reactors on the conversion achieved for a given reaction (Shivakumar R, Sreelakshmi Diddi, & Samita Maitra, 2017). The virtual experiment was developed using the Unisim design tool to carry out the saponification reaction of sodium hydroxide (NaOH) with ethyl acetate (EA) in a Continuous Stirred Tank Reactor (CSTR) and a Plug Flow Reactor (PFR). These virtual experiments were developed to carry out experiments at different temperatures. Conducting the experiments at different temperatures is not practically possible in a wet laboratory due to time constraints and other logistic issues. During the COVID-19 pandemic, the same virtual experiments were used to carry out the virtual labs.

The developed virtual experiment process flow diagram (PFD) is shown in Figure 2 and Figure 3. Both the reactants, NaOH and EA, of equal strength are mixed and sent into the heater. The heater is used to change the temperature of the feed before it undergoes reaction in the CSTR/PFR reactors depicted in Figure 1 and Figure 2, respectively. The Unisim design simulation software has the inbuilt fluid package, which is the thermodynamic model applied to estimate the physical properties of the chemical compounds NaOH, EA, sodium acetate, and ethanol. The selection of a suitable thermodynamic model is one of the most important criteria before we build the PFD for the ideal reactors. The reactions are defined in the reaction section; here, we have defined the kinetic reactions because the saponification reaction follows the Arrhenius law (H. Scott Fogler, 2005) (Levenspiel, 1999), (Wijayarathne UPL & Wasalathilake KC, 2014), (K. G. Denbigh & J. C. R. Turner, 1984).

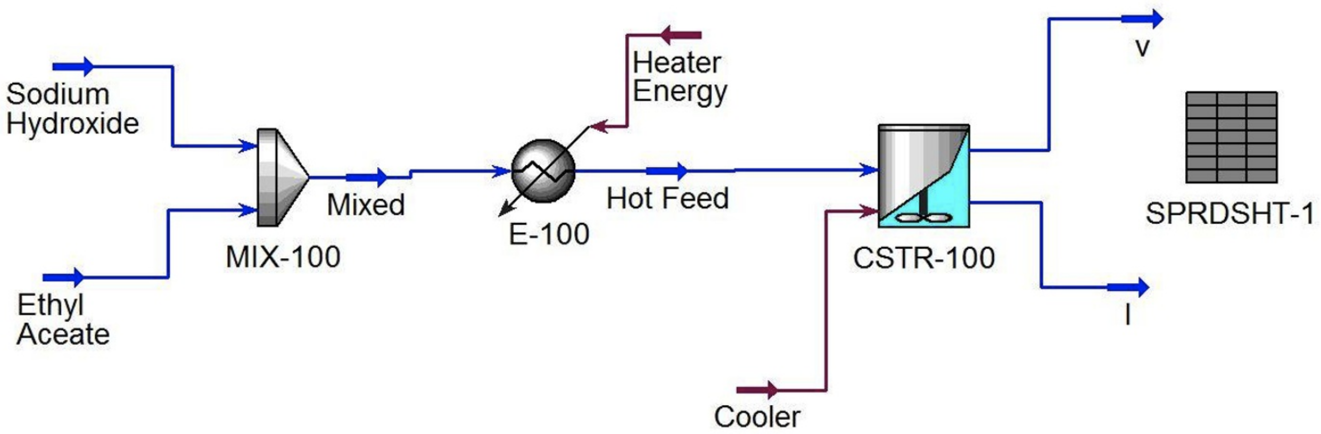

Figure 2. Virtual Experiment Process Flow Diagram for CSTR reactor

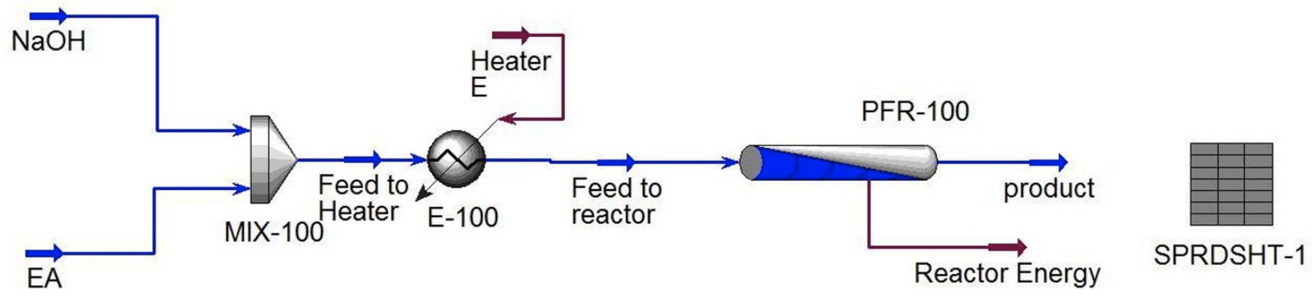

Figure 3. Virtual Experiment Process Flow Diagram for PFR reactor

Conversion obtained after the simulation is tabulated for different temperatures for a constant volumetric flow rate. The simulation is repeated for different volumetric flow rates at different temperature values. The simulated results are transferred to the Excel spreadsheet, an add-on feature available in the Unisim simulation tool. Exit concentrations of the reactants are estimated in the spreadsheet. The rate constant is estimated for the bimolecular reaction using the graph based on the kinetic rate of the bimolecular saponification reaction. The results obtained are validated with the theoretical values in the literature or from previous wet laboratory data.

2.2. Virtual Experiments for Distillation Operation using UNISIM Simulation Tool

Unit operations involving a change in the composition of solutions are termed mass transfer operations. Chemical processing plants use intense mass transfer operations for the preliminary purification of raw materials or the separation of products from byproducts. The distillation process is one of the major mass transfer operations for the separation of components in a solution by distributing the components through vaporization or condensation between a gas and a liquid phase during the operation. Undergraduates will have a detailed laboratory course on mass transfer operations. Students conduct experiments on simple distillation, packed bed distillation, and steam distillation operations for understanding the extent of separation that can be achieved. Virtual experiments developed using the Unisim design tool are simple distillation and steam distillation (Coulson & Richardson, 1999), (R. Byron Bird, Warren E. Stewart, & Edwin N. Lightfoot, 2022), (Robert Ewald Treybal, 2017).

Steam Distillation is a physical separation process. This is the most frequently used laboratory method for purification of organic aromatic compounds and extraction of essential oils. To demonstrate this experiment in the wet laboratory, the use of aromatic compounds like nitrobenzene, aniline, paraffins, naphthene, and a complex mixture of terpenes is not feasible as the inhalation of aromatic compound vapors for a longer duration is a health hazard. The use of essential oils extracted from plants and fruits is expensive for laboratory demonstration. Hence, the developed virtual lab replicating the actual experimental set up will help the students to understand the separation principle for all organic compounds and essential oils. Simple distillation is an experiment to demonstrate the principle of separating a binary component mixture. The separation is based on the boiling point difference of the components in the binary mixture. The aim of simple distillation is to verify Rayleigh's Equation (Robert Ewald Treybal, 2017), (Perry R.H, Green D.W., & Southard M.Z. , 2018).

Initially, a suitable binary system is selected using the Unisim design simulation software. Presently, for demonstration, the simple binary mixture of the Methanol-Water system is selected. A suitable fluid package is selected to estimate the physical properties of the components selected. During the wet laboratory, different mole fractions of methanol mixed with water were prepared by mixing in different volumes. The specific gravity of each mole fraction of methanol, pure water, and pure methanol was measured using a specific gravity bottle. A calibration chart for estimating the mole fraction from the known value of specific gravity was prepared (Perry R.H, Green D.W., & Southard M.Z. , 2018). An unknown mixture of methanol-water was distilled in a simple distillation still in the laboratory. After the distillation, the specific gravities of the feed, cooled residue, and cooled distillate were measured to estimate the mole fraction of methanol in the feed, residue, and water. These values are used to verify Rayleigh's Equation by graphical method to estimate the area under the curve from the plot $1/(y^* - x)$ versus x. The values of x and y^* are the equilibrium data for the binary system selected from the Perry handbook (Perry R.H, Green D.W., & Southard M.Z. , 2018).

Pure water and pure methanol components are mixed using a mixer operation as depicted in Figure 4. The specific gravities of methanol and water are tuned to get the same value of specific gravity for the mixture as obtained in the laboratory. After the mixing operation, the mixture is heated to the bubble point of the mixture. The bubble point was experimentally measured in the laboratory during the experiment. The hot stream leaving the heater is fed into the flash separator. The flash separator is separated into vapor (distillate) and liquid (residue) phases. The resulting specific gravities and mole fractions of methanol in the distillate and residue streams are tabulated in the Unisim spreadsheet. Rayleigh's Equation is verified using the simulated values. The virtual experiments can be repeated for different binary components and different thermodynamic models (fluid packages) (Priyam Nayak, et al., 2019), (Wijayarathne UPL & Wasalathilake KC, 2014).

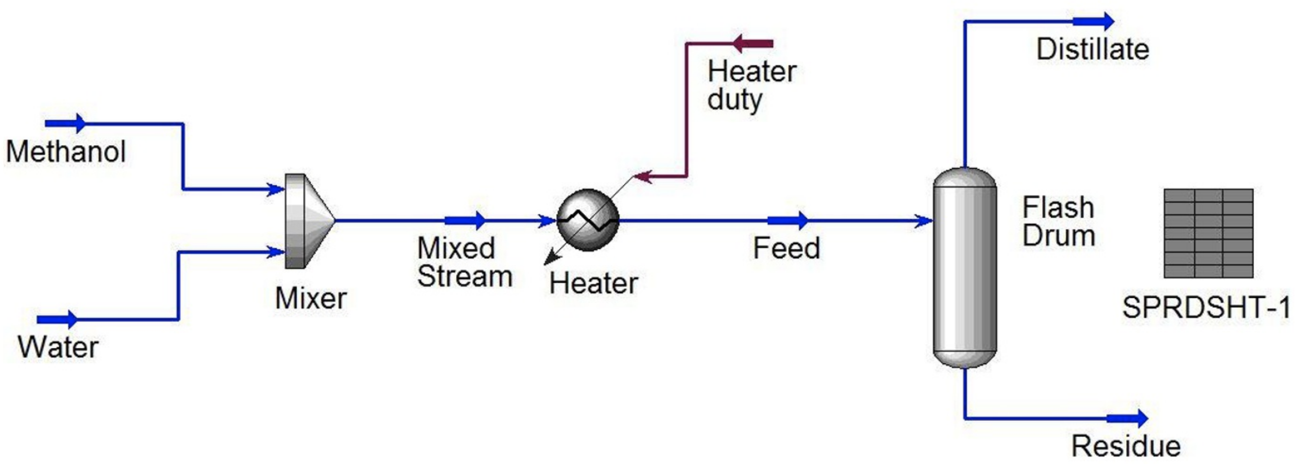

Figure 4. Virtual Experiment Process Flow Diagram for Simple Distillation

In the wet laboratory, the steam distillation experiment is carried out using aniline or nitrobenzene as organic solvents. Here, the organic solvents are separated from non-volatile impurities using steam. The steam is generated in a small boiler and allowed to flow into a round bottom flask containing a known volume of nitrobenzene/aniline. The pressure of the steam entering the round bottom flask is noted to estimate the steam properties using steam tables. The organic solvent starts to vaporize after being contacted with steam in the round bottom flask. Vapors of the organic solvent are cooled using a condenser, and the distillate is collected. The boiling point of the organic solvent is noted during the experiment. Finally, the distillate and residues are taken into a separating funnel to separate the water and organic liquid layers. The volumes of water & nitrobenzene in both the distillate and residue are estimated. The specific gravities of each layer from the distillate and residue are estimated to evaluate the mass of each component in the distillate and residue. A virtual laboratory is mimicked to produce the same values as in the laboratory experiment. Figure 5 shows the PFD for the steam distillation virtual experiment. The virtual experiment is demonstrated for the water-nitrobenzene system. Initially, steam is generated in the virtual experiment by heating the water component in a heater to a suitable temperature. The ideal liquid volume flow is tuned to result in the exact density value of water as measured. The temperature of the vapor stream flowing out from the heater is equal to the steam temperature in the wet laboratory. The steam and nitrobenzene are mixed in a mixer operation, where we observe a rise in temperature in the outlet stream of the mixer. The outlet stream from the mixer is passed into a cooler, where condensation occurs. The temperature in the condenser is set to the value 113 °C. The temperature set in the condenser is equal to the measured temperature in the round bottom flask during the actual experiment. The outlet stream from the condenser is fed into a flash separator operation. The stream is separated into vapor (distillate) and liquid (residue) streams in the separator. The results are tabulated, and the masses of the water and nitrobenzene components in the distillate and residue are tabulated. Steam required, thermal efficiency, and vaporization efficiency are estimated using spreadsheet calculations. The values resulted in the virtual experiments were close to the actual experiment values.

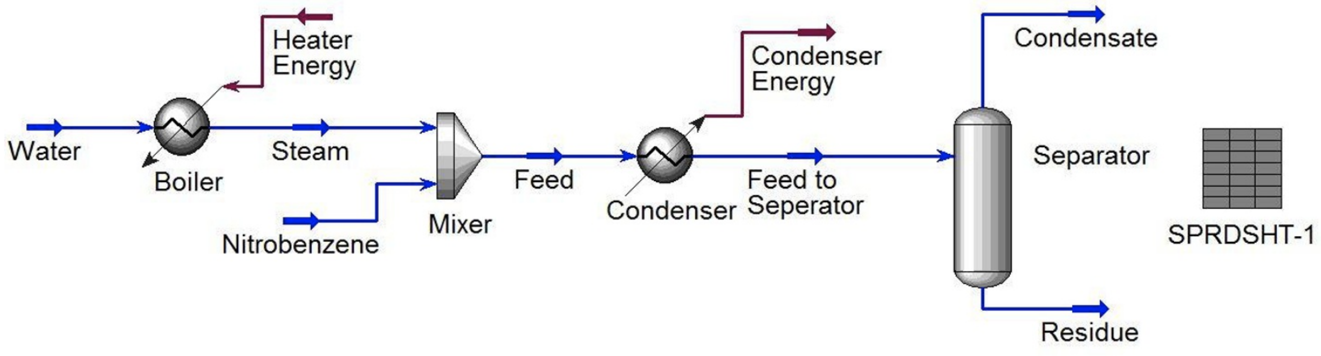

Figure 5. Virtual Experiment Process Flow Diagram for Steam Distillation

2.3. Virtual experiments utilizing MATLAB/SIMULINK Tool

Virtual experiments play a major role in engineering studies. Virtual experiments are useful to visualize critical engineering concepts and analyze the effect of various parameters on an engineering process. In the Chemical Engineering discipline, a few virtual lab experiments were created by MHRD like Heat Transfer, Fluid Mechanics, Reaction Engineering, etc. It is required to develop virtual experiments for other important/critical subjects like process control engineering. Experiencing and visualizing the real-time behavior of a process is found difficult by Chemical Engineering students. In this context, a set of virtual experiments was created for the process control engineering course using MATLAB/Simulink software tools, and it was found to be useful for a better understanding of the course (Coulson and Richardson, 2006), (Steven E. LeBlanc & Donald R. Coughanowr, 2009).

2.3.1. *Feedback control system*

A feedback control system consists of a process, a measuring element, a controller, and a final control element (see Figure 6). The response of the process is measured by measuring elements and sent to the controller. In the controller, the response is compared with the desired set value by the user. The difference between the set point and the measured value is called the error. The controller takes a control action based on the error signal. The controlled signal is received by the final control element, and the final control element takes corrective action to maintain the process response close to the set value.

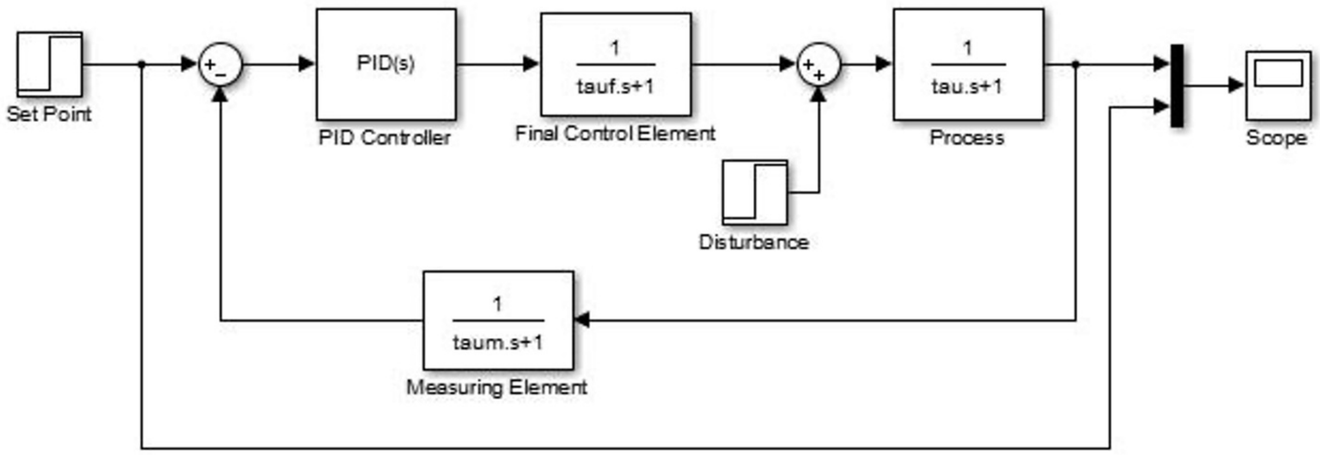

Figure 6. Block diagram of a feedback control system

The control action depends on many factors in the control system, like controller parameters, time constant of the measuring device, and characteristics of disturbances in the system. In this virtual experiment, we are interested in visualizing the effects of controller parameters like Proportional gain, Integral time constant, and Derivative time constant in a closed-loop feedback control system using the MATLAB Simulink tool (Steven E. LeBlanc & Donald R. Coughanowr, 2009).

2.3.2. *Feedback response for proportional controller for servo and regulatory problems*

Response for the closed-loop feedback control system was studied for different values of proportional controller gain for servo and regulator problems. In this study, a first-order system with a time constant τ_P = 5 min and a steady-state gain K_P = 1 was selected. A unity transfer function for the final control element and measuring device was selected for simplicity. A step input of amplitude 5 was introduced in the set point, and no change of disturbance was made to study the servo problem. In the controller, the proportional controller gain of K_c = 5, 10, 20, and 50 was set to study the offset for different values of proportional gain. Responses for different proportional gains are shown in Figures 7 and 8. The response curves for different proportional gains show that the offset decreases with an increase in gain. In the servo problem, where the set point changed with a step input of 5, the ultimate response reaches close to the desired value of 5 for a higher K_c value (see Fig. 7). Similarly, in the regulator problem, where the load changed with a step input of 5, the ultimate response reaches close to the desired value of 0 for a higher K_c value (see Fig. 8). The higher values of proportional gain give better results, but they cannot remove the offset completely for both the servo and regulator problems. The study can be repeated with a wide range of K_c values for both the servo and regulator problems, and similar control behavior can be observed with the help of the virtual lab.

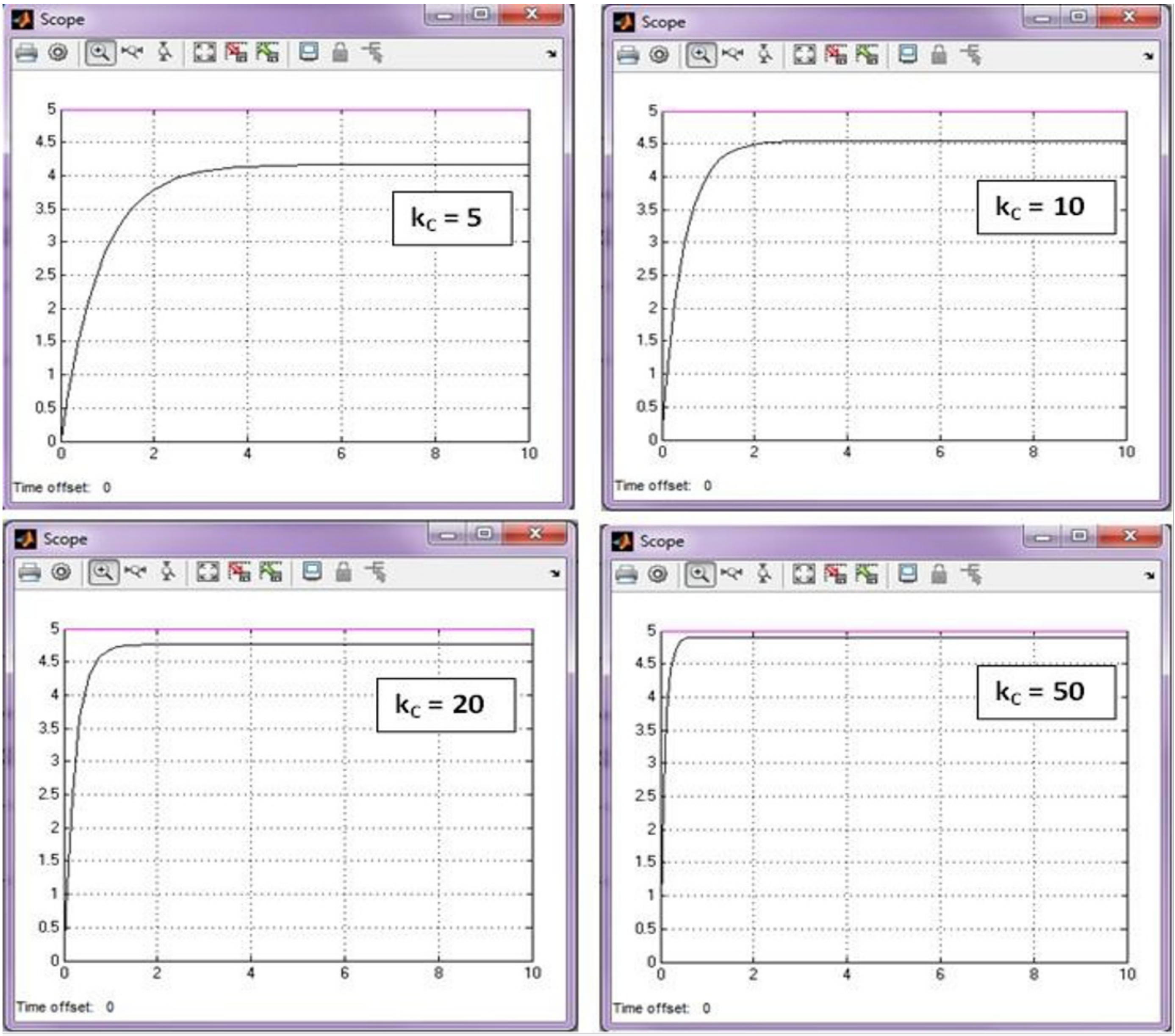

Figure 7. Response for different proportional gains for servo problem

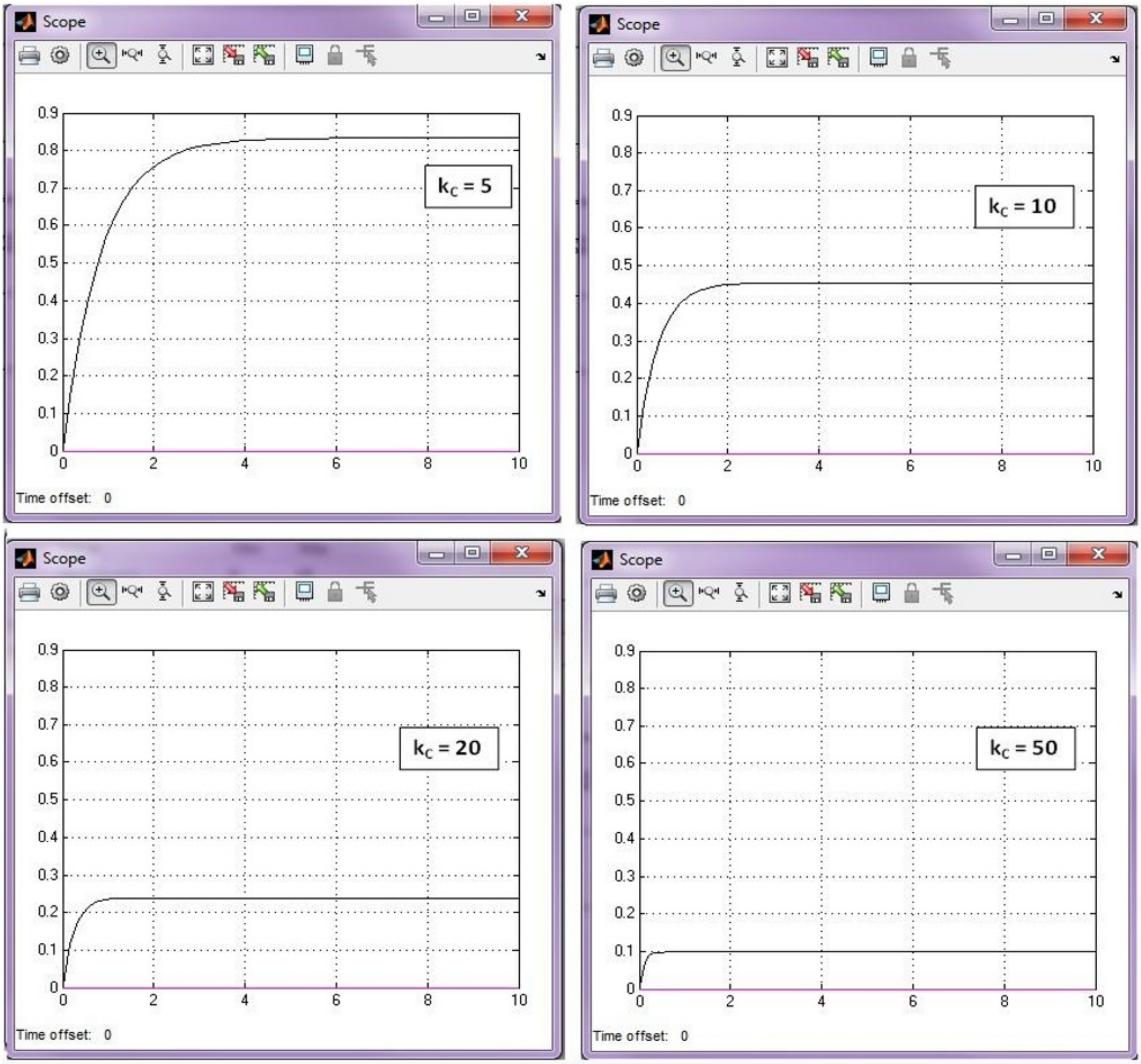

Figure 8. Response for different proportional gains for regulator problem

2.3.3. *Feedback Response for Proportional Integral (PI) Controller for Servo and Regulatory*

Response for the closed-loop feedback control system was studied for different values of the integral time constant with a constant proportional gain value for servo and regulator problems. A step input of amplitude 5 was introduced in the set point, and no change of disturbance was introduced to study the servo problem. In the controller, a proportional controller gain of K_c = 10 and four different integral time constant values of τ_I = 0.5, 1, 2, and 5 were set to study the effect of τ_I on process control response. The response for different integral time constants is shown in Figures 9 and 10. The response curves for different integral time constants for the servo and regulator problems are shown in Figures 9 and 10. In the servo problem, where the set point changed with a step input of 5, the ultimate response matched the desired value of 5 for all τ_I values. Similarly, in the regulator problem, where the load changed with a step input of 5, the ultimate response matched the desired value of 0 for all τ_I values. It is observed that the maximum deviation from the desired value decreases with a decrease in τ_I for both the servo and regulator problems. However, a decrease in τ_I leads to more oscillatory behavior of the system response for both servo and regulator control. Similar control characteristics can be observed for a wide range of τ_I values.

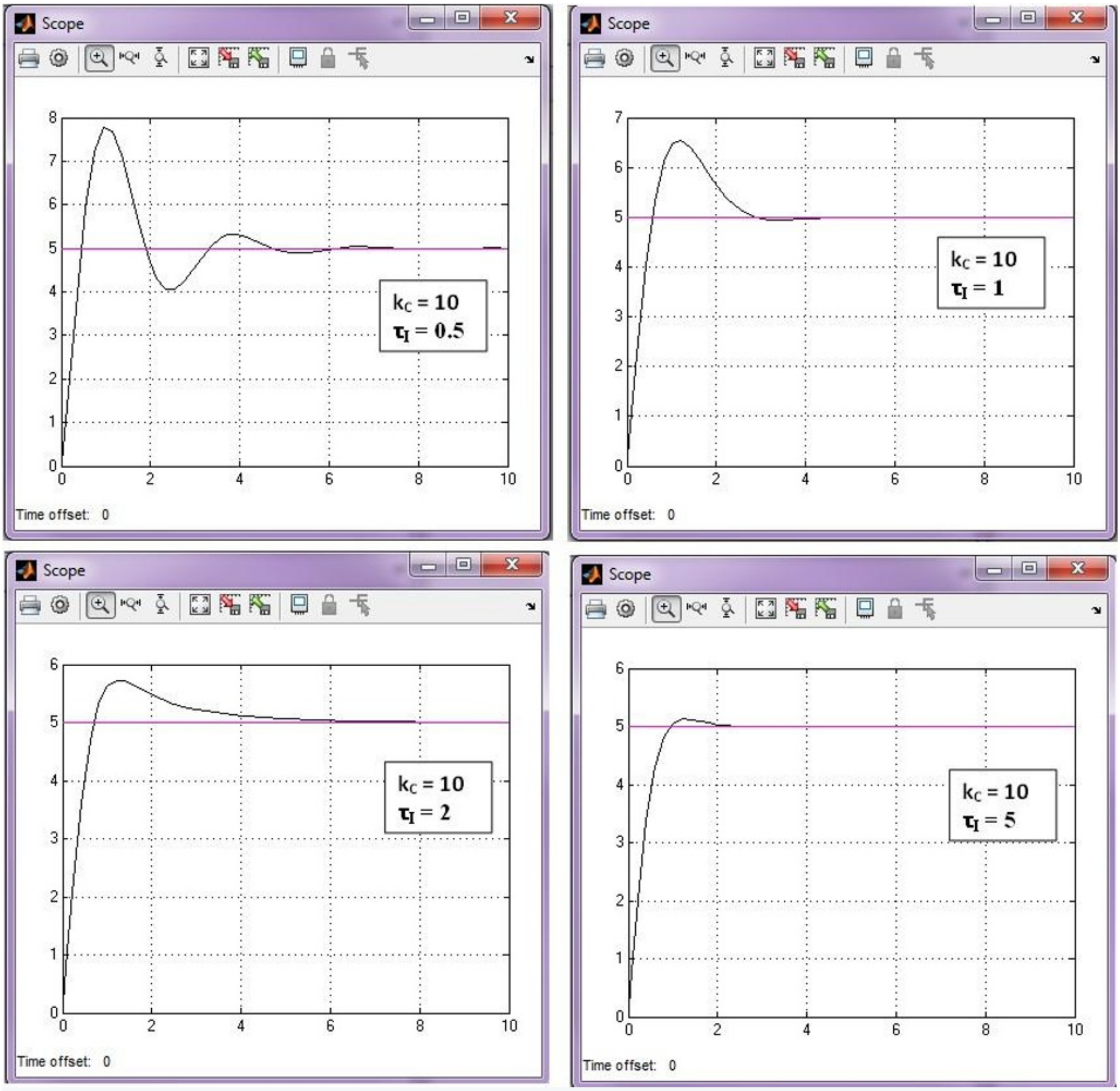

Figure 9. Response for integral time constant values for servo problem

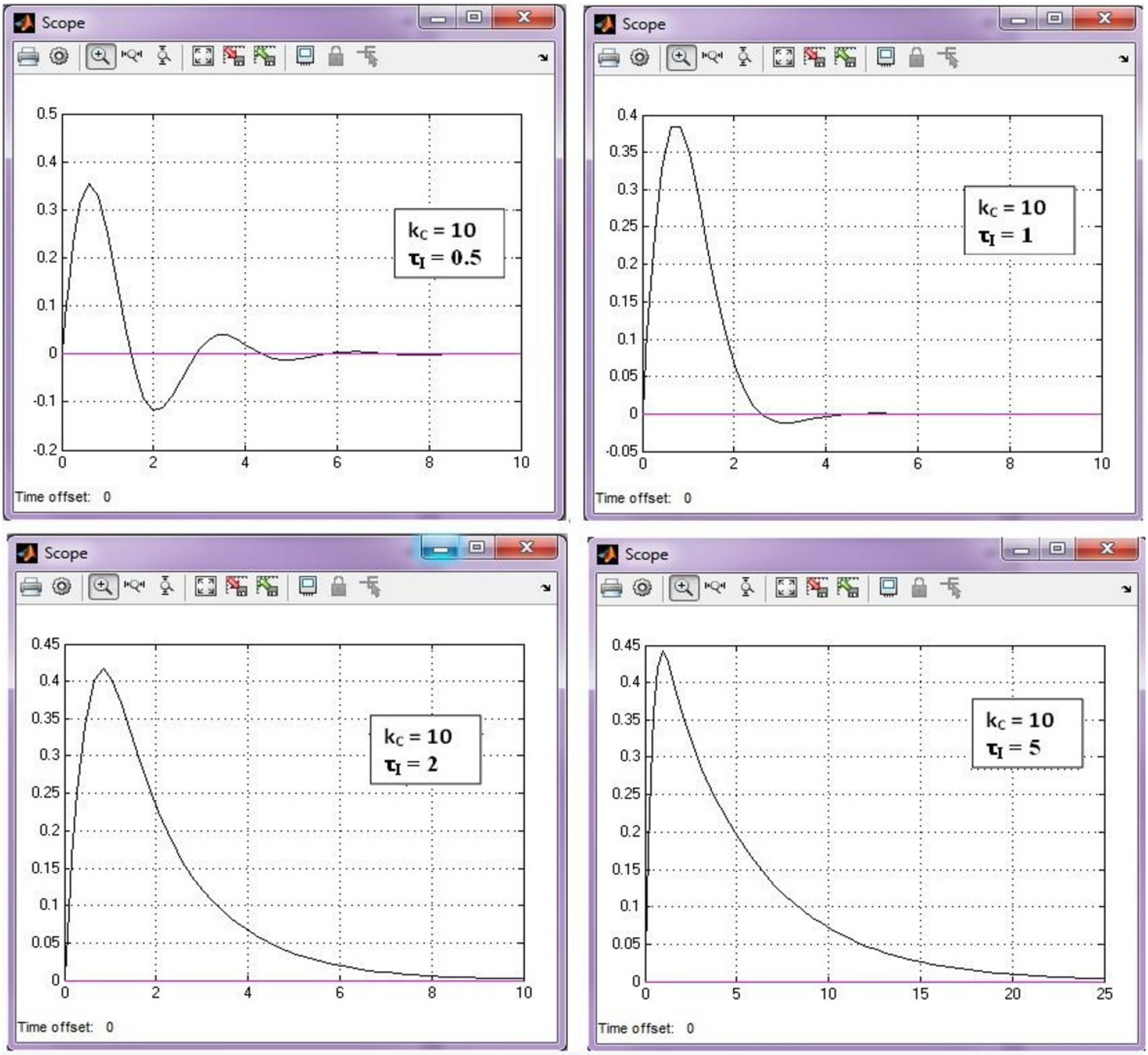

Figure 10. Response for integral time constant values for regulator problem

2.3.4. *Feedback Response for Proportional Integral Derivative (PID) Controller for Servo and Regulatory Problems*

Feedback control system response was studied for different values of derivative time constant with a constant Proportional gain and integral time constant value for servo and regulator problems. A step input of amplitude 5 was introduced in the set point, and no change of disturbance was introduced to study the servo problem. In the controller, a proportional controller gain of K_c = 10, an integral time constant of τ_I = 0.5, and four different derivative time constant values of τ_I = 0.5, 1, 2, and 5 were set to study the effect of τ_D on process control response. Responses for different derivative time constants are shown in Figures 11 and 12. In the servo problem, where the set point changed with a step input of 5, the ultimate response matched the desired value of 5 for all τ_I values, and the offset was found to be zero. Similarly, in the regulator problem, where the load changed with a step input of 5, the ultimate response matched the desired value of 0 for all τ_D values and the offset was found to be zero. The study shows that the excess overshoot can be arrested by incorporating the derivative mode. The response becomes less oscillatory with the addition of the derivative mode. It is observed that the maximum deviation from the desired value decreases with an increase in τ_D for both the servo and regulator problems. It is also observed that the increase in τ_D reduces the oscillation of the system response. Similar control characteristics can be observed for a wide range of τ_I values.

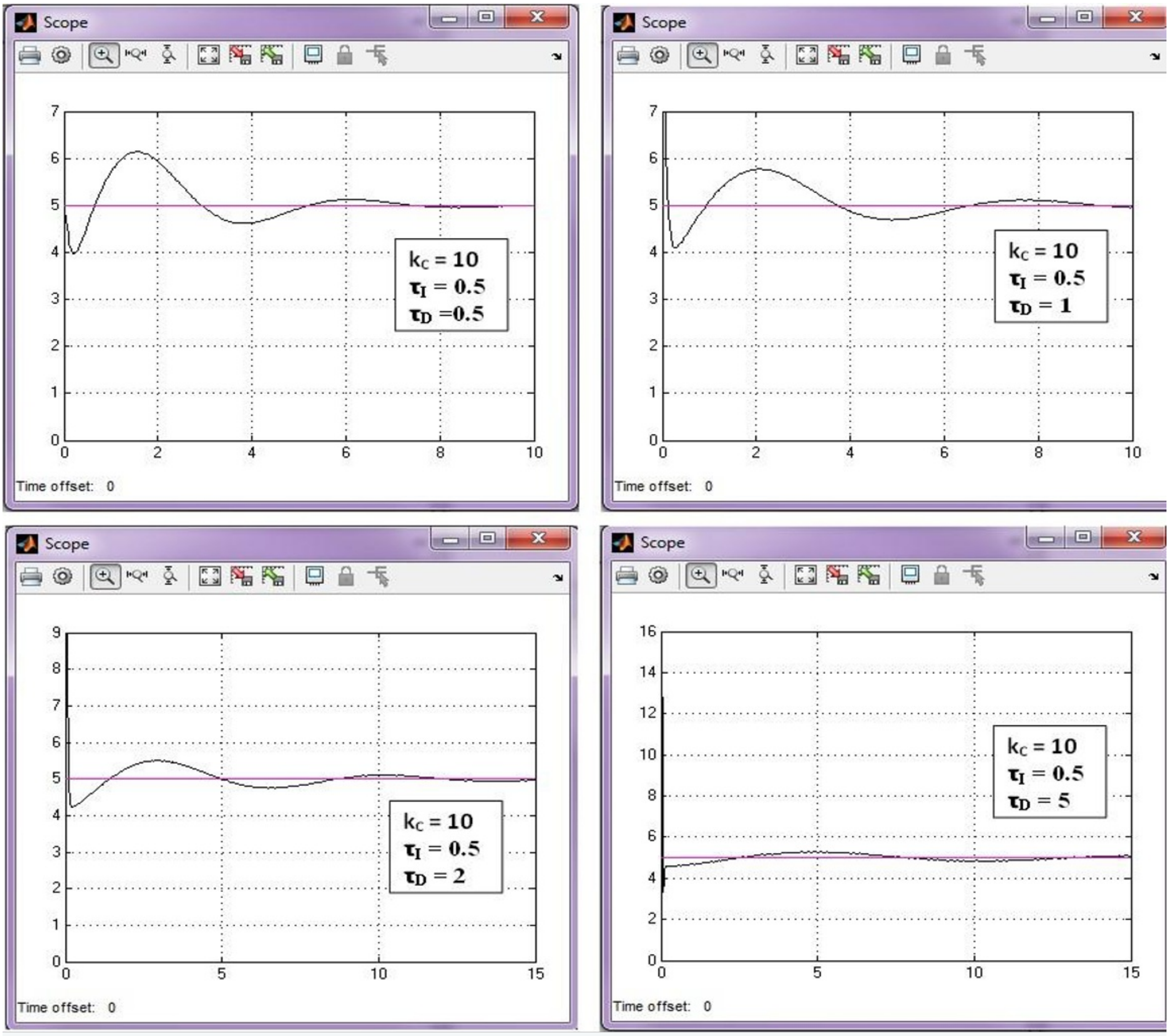

Figure 11. Response for derivative time constant values for servo problem

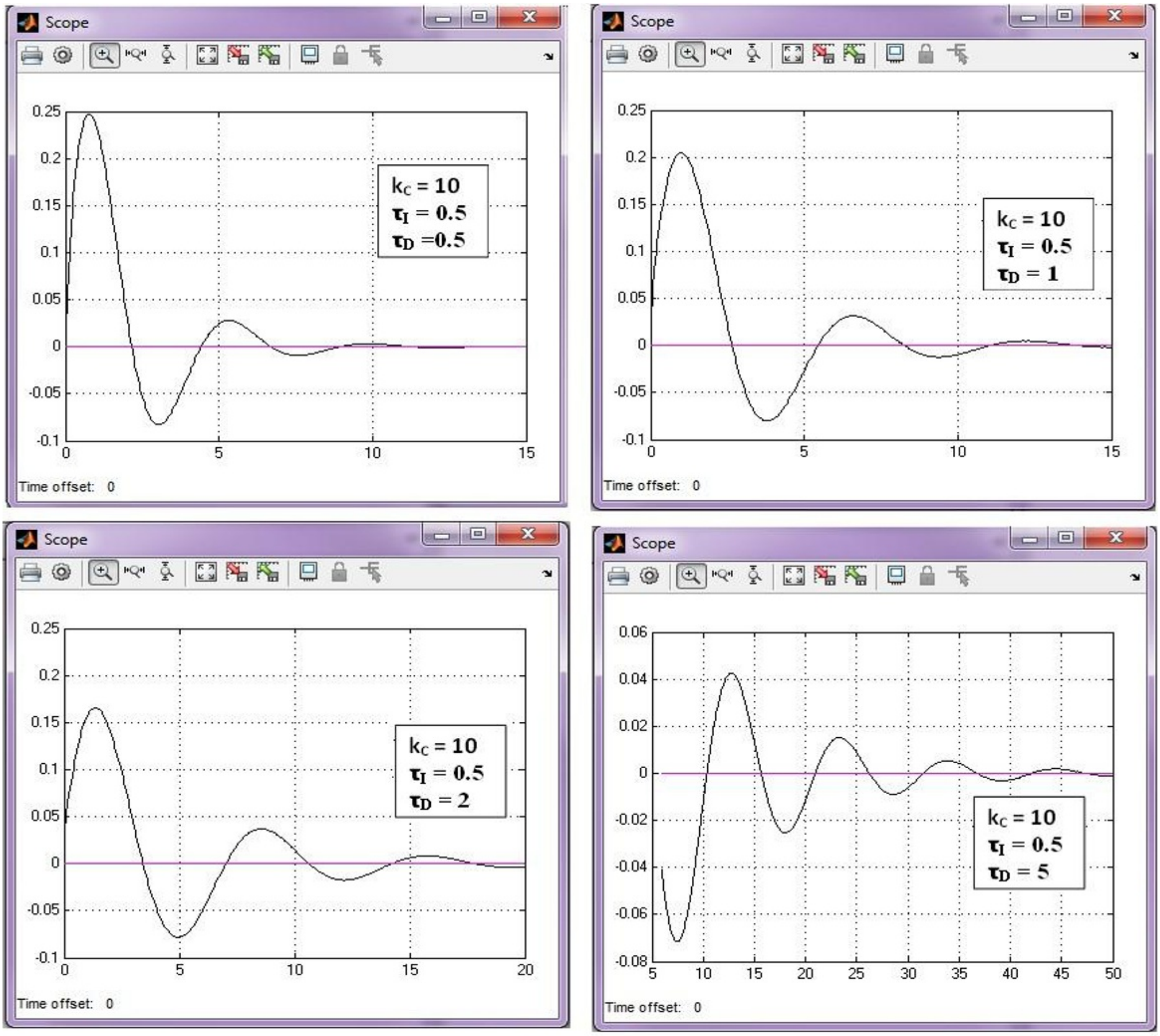

Figure 12. Response for derivative time constant values for regulator problem

3. Assessment Methodology for Learning Outcomes

Assessment is an effective tool to measure the impact of the virtual lab on the competence level of graduate students. The competence level was assessed under three categories of learning objectives: knowledge, skills, and attitudes, which relate to cognitive, psychomotor, and affective learning domains. Figure 13 illustrates the assessment categories and the parameters used to measure those learning domains (Wenqian Chen, Umang Shah, & Clemens Brechtelsbauer, 2016).

The competence assessment of each learning domain was evaluated through the Continuous Internal Evaluation (CIE) process at each stage. The students were graded to measure the cognitive, psychomotor, and affective learning domains acquired during the virtual lab development. The assessment levels are designed to assess the learning domains of the students at different stages of the course. Assessment levels are designed considering the practical aspects to measure the learning domains as discussed in Figure 13. Assessment methods and criteria are made available to students at the beginning of the semester. The performance of the students in the semester-end examination for the core courses from the past three academic years was assessed and presented in Figure 14. Figure 14 manifests that the performance and skill set of the students improved. The maximum average score by the students in AY 2018-19 and AY 2019-20 was around 80 to 70 marks, which improved between 90-80 marks for AY 2020-21 after the implementation of virtual labs.

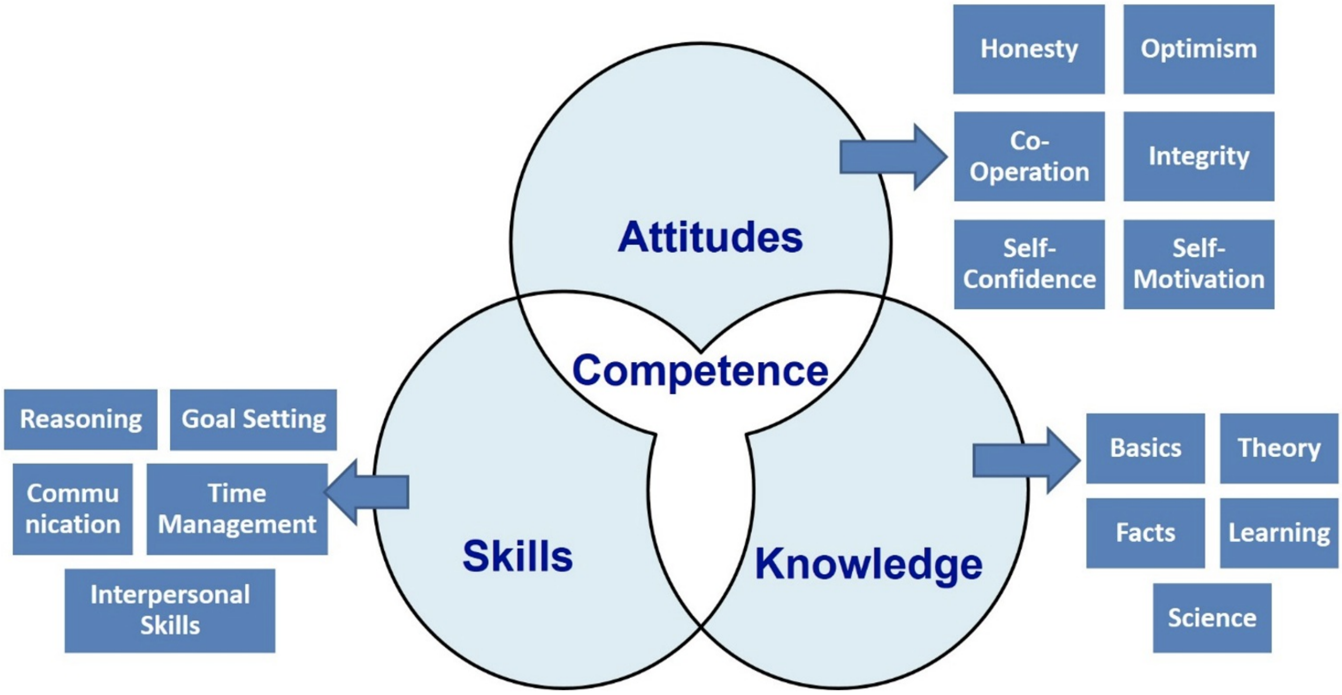

Figure 13. Cognitive, Psychomotor, and Affective learning domains for competency

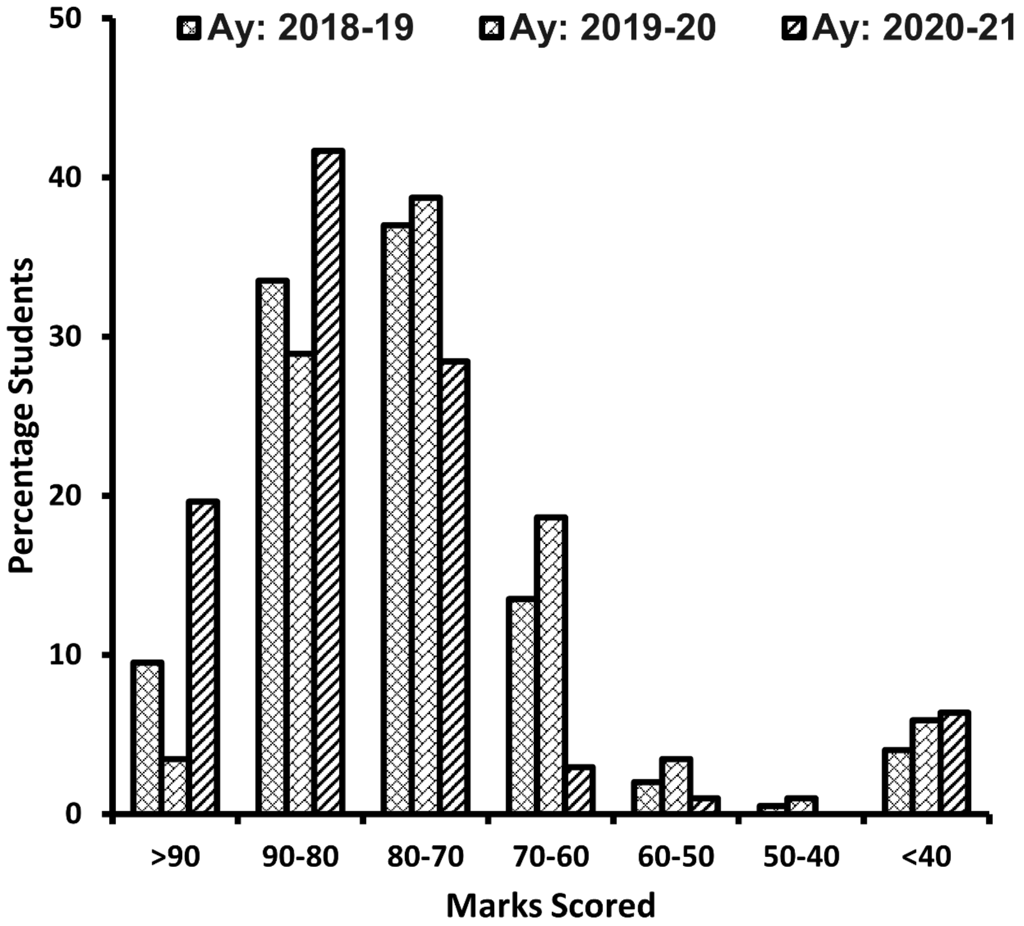

Figure 14. Performance of the Students in SEE

Laboratory course assessment was evaluated continuously. The virtual experiments conducted by the students were assessed for the results, plots, and a detailed observation was submitted by individual students. Finally, students will submit a comprehensive lab record and take a partial exam cum viva voce. The student survey was conducted for three academic years. The questionnaire was framed to include all aspects of student learning, viz., motivation, self-efficacy, understanding of complex scientific concepts, inquiry skills, peer learning, communication skills, and teamwork, to name a few. The summary of the student feedback is shown in Figure 15.

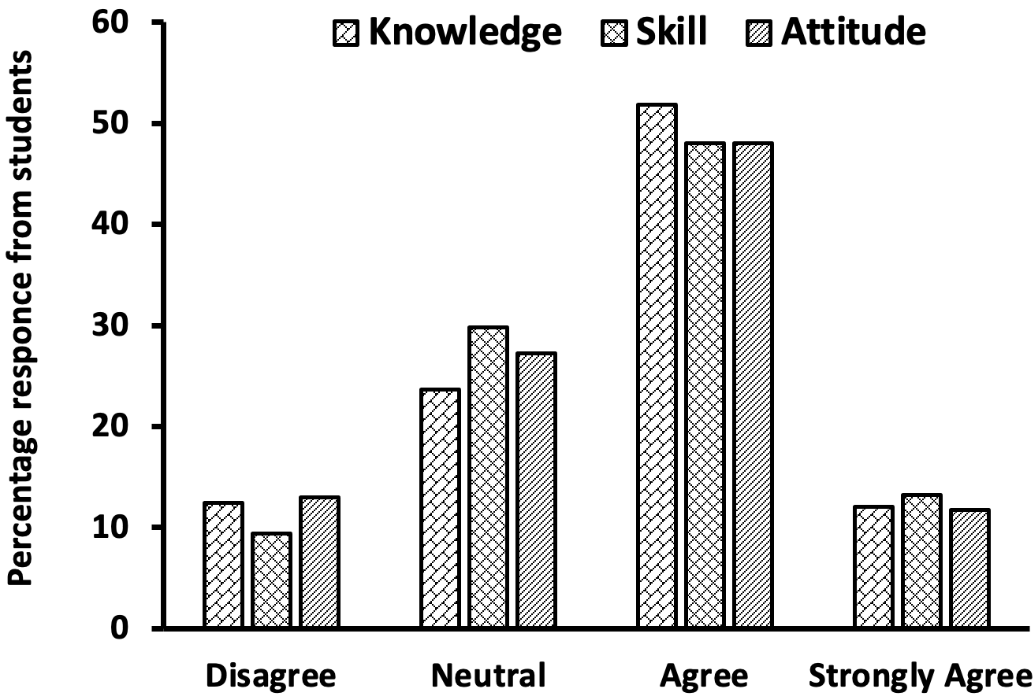

Figure 15. Summary of the Student Survey

4. Conclusion

This paper deliberates on the implementation of Virtual Laboratories for undergraduate engineering education. Proprietary software viz. UNISIM and MATLAB/SIMULINK and open-source software DWSIM were used to design virtual labs in Chemical Reaction Engineering, Mass Transfer, and Process Control engineering courses of the undergraduate Chemical Engineering discipline. The results obtained were validated using either literature data or previous wet laboratory data. Students were encouraged to develop steady-state process simulations of various industrial processes. Some of these projects were also submitted to FOSSEE and were subsequently published.

These approaches were implemented for some years in conjunction with wet laboratories. However, the COVID-19 pandemic situation gave the opportunity to try these as the only laboratory instruction in a couple of courses. The course survey results before and after implementation showed that the students are capable of selecting real-world problems, solving and analyzing them to give sustainable solutions in teams. These acquired skills will help the students in the future to work in diversified teams, carry out projects, communicate effectively, and apply a systematic engineering approach to solve the problems assigned in the future.

Statements and Declarations

Ethical Approval

The work was to develop virtual labs using the software. There is no ethical approval from any committees required. The authors give their consent to publish the article in your journal. The authors feel that the aim of the journal matches the scope of the paper.

Author's Contribution

- Dr. Shivakumar R conceived of the presented idea, developed the theory, and performed the computations for virtual labs using UNISIM Software. He took the lead in writing the manuscript.
- Dr. Sreelakshmi Diddi contributed to writing the article, editing the manuscript, and implementing the virtual labs in the laboratory.
- Mr. Soumen Panda developed the theory and performed the computations for virtual labs using MATLAB Software. All authors discussed the results and contributed to the final manuscript.

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Declaration of Interest Statement

The authors hereby declare that the disclosed information in the article is correct and that no other conflict of interest is known to the authors. Authors confirm that there are no known conflicts of interest associated with this publication and that there has been no significant financial support for this work that could have influenced its outcome.

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