Design Your Experiment (DYE) – Project-Based Learning in Fluid Mechanics Laboratory

Article history
Received
14 October 2021
Received in revised form
11 November 2021
Accepted
15 November 2021
Published online
30 November 2021

Jay Shah, Prachi Thareja*
Chemical Engineering, Indian Institute of Technology (IIT), Gandhinagar, India, 382355
**prachi@iitgn.ac.in*

Abstract
There is a need to implement an active and student-centered learning experience in the universities, which could help students expand their vision and better understand its application and concepts outside the classroom learning. This article discusses an approach of Design your experiment (DYE) project in the Fluid Mechanics laboratory to make the course more interesting for the students. We discuss various components involved in the DYE project and its learning outcomes. The reaction survey of 40 students collected through an online questionnaire shows that the DYE helps the students to enhance their fundamentals, improve their communication, leadership and team management skills.

Keywords: Fluid Mechanics; laboratory; project-based learning.

Introduction

This article discusses an active learning methodology in an engineering laboratory course for undergraduate Fluid Mechanics (FM). FM is a core subject in the engineering curriculum in several institutions around the world. The theory course of FM is generally taught in a more passive manner, where the students learn through the lectures delivered by the instructor. The assessment of the theoretical concepts is carried out with weekly quizzes, assignments and exams. However, engineers must have a practical knowledge about the subject they are studying. The theory course of FM is often considered challenging due to many complicated equations, which many students are not able to relate to its practical applications. Therefore, an FM laboratory course is included in the curriculum. FM laboratory courses help the students improve their understanding of the fundamentals studied in the classroom.

The goals of laboratory instruction in engineering education is discussed in an excellent paper by Feisel and Rosa (Feisel and Rosa, 2005). The authors claim that the role of instructional laboratories is not limited to instrumentation, lab scale models, data analysis, but also encompasses design, learning from failures, creativity, teamwork, communication and ethics in laboratory. These skills are not just confined to learnings in laboratories but are also valid in today's highly globalized employment scenarios. The engineers are expected to be technically competent along with their ability to apply the knowledge to the complex problems. Therefore, there is a need to include active learning modules where the students play a more dominant role than the instructor in laboratory courses.

Project based learning is a pedagogical approach of active learning. The engineering education has largely been taught with problem-based learning approach, which has traditionally been widespread in instruction in medicine (MILLS and JE, 2003). Mills and Treagust provide a very thorough overview of problem based and project-based learning in engineering education (MILLS and JE, 2003). The problem-based approach is centered on defining a problem and the students are required to research and acquire knowledge about the potential solutions to the problem. The project-based learning approach is focused on application and using the prior acquired knowledge. The two approaches are very similar, however there are few distinguishing features of project-based learning (1) projects typically require a longer time duration and may be performed in stages. (2) projects may be carried out along with theory courses (3) emphasis on experimentation (4) working in groups and collaboration (5) communication (Palmer and Hall, 2011) (Chua, Yang, and Leo, 2014).

Educators have implemented and reported the project based learning approach in FM instructional laboratories. Jack A Pulea, discuss a design-based FM laboratory, which encourages the students to learn beyond the traditional books and learn the concept of buoyancy and stability (Puleo Jack A., 2020). The method results in improving the hands-on experience for the students and developing their communication skills. A continuous project-based learning was implemented for hydraulic engineering students. The students were asked to start from develop a pipe network, which was then integrated with other courses during the whole duration of bachelors or masters degrees (Pérez-Sánchez and López-Jiménez, 2020). Another educator incorporated, creative assignment in FM lab in the form of development of thought problem, frugal lab, presentations and fun with fluids segment (Mandavgane, 2020).

To incorporate active learning in the FM laboratory course and motivate the students to study FM, an open-ended project, titled "Design your Own Experiment (DYE)" was introduced, where a group of students worked together and designed an experiment to understand the fundamental concepts of FM. In this paper, we describe the FM laboratory course and how the DYE project evolved over years of experience. DYE helps the students explore the subject outside the textbook and understand the real-life application of the concepts learned in the classroom. It also builds social skills, as students need to perform the experiments in groups, which helps improve peer to peer learning.

FM Laboratory and Theory Course

Theory Course

FM theory course is offered to the Mechanical, Chemical, Civil Engineering and Material Science departments in the fourth semester of the B.Tech. curriculum. The FM course covers the fundamental concepts of the velocity field, fluid statics, law of conservation of mass/ momentum/ energy, incompressible inviscid flow, external incompressible viscous flow, potential flow, dimensional analysis, flow in pipes, boundary layer theory, Reynold- Transport Theorem and Navier-Stokes Equation.

Structure of FM Laboratory

FM laboratory is a 2-credit course in which the students have 3 hrs/week session. The course is included in the same semester as the theory course for the Chemical Engineering department. The students are given the laboratory manual, short instructional videos which have the brief background of the theory behind the experiments. In addition, reference to additional reading from the textbook of Fox and McDonalds is also provided (Robert W. Fox, Alan T. McDonald, and John W. Mitchell, 2020). Laboratory experiments were conducted in groups of three to four students.

The component of the FM laboratory consists of:

1. Pre- lab reports and viva-voce
2. Conducting experiments in the lab
3. Analysis of experimental data acquired in the laboratory
4. Writing of in- lab reports
5. DYE project

The students are required to analyze the data collected from experiments during laboratory hours. The report writing is divided into two parts.

(a) **Pre-lab reports (40 pts)** - Students need to write a pre-lab report, which helps understand the experiment's theory and concept before the actual experiment. The pre-lab report includes, abstract (5pts) and introduction (35 pts) of the experiment. This report is to be submitted before the experiment.

(b) **In-lab reports (60 pts)** - This report needs to be submitted at the end of the laboratory session, and it consists of experimental procedure (20 pts), experimental observations, calculations, results (total 30 pts), discussion and conclusion (10 pts)

Overall, both the reports help students understand, analyze, and communicate the experiments performed in the laboratory.

The course is evaluated based on the following grading policy:

In-lab reports - 25%
Pre-lab reports - 20%
Pre-lab viva-voce - 15%
Mid semester exam - 20%
DYE Project -20%

Table 1 consists of the experiments that are conducted in the FM laboratory course. The experiments elucidate experimental hands-on working of theoretical concepts of viscosity, flow meters, friction in pipes and columns, and centrifugal pumps.

Table 1: List of the Experiments in FM lab

Serial Number	Experiment
1	Viscosity by Stokes law
2	Viscosity by Efflux time
3	Reynolds Experiment
4	Bernoulli's Theorem
5	Orifice meter/ Venturi meter
6	V-notch
7	Friction in a circular pipe
8	Friction in annulus/rectangular pipe
9	Equivalent length of pipe fittings
10	Friction in a packed column
11	Characteristics of the centrifugal pump

DYE project

The DYE project involves a group of students designing and demonstrating the experiments related to FM. The budget for each student group was fixed to encourage students to implement the project frugally. Students can design the experiment based on any peer-reviewed research papers or design the experiments based on the FM theory course's concepts, write a report, and present their work to the class. A team of three to four students were formed to conduct their project.

Timeline of DYE project

The DYE project was assigned to students at the beginning of the semester; however, the students started working on it after the mid-semester exams and were given six weeks to develop, design and present their work. In the first year of the "DYE project" execution, teams needed to submit the report and presentation at the end of the semester. In the subsequent years of its execution, the DYE project was executed in two stages. In the first stage, the teams prepared a project proposal, and they were given feedback on the development and improvement of the design. The second stage involved hands-on design and execution of the experiment, report writing and presentation.

Role of the instructor in DYE project

The instructor's role is of a facilitator and a guide at various stages of the exercise. The students are required to present their initial proposal about the project to the instructor. The instructor ensures that the DYE is feasible in the laboratory with given resources and the time frame. The instructor does not provide the solution to the students, but instead points them to the relevant articles, textbooks which provide the technical background. The instructor also interfaces with the laboratory staff in case supplies are to be procured for the implementation of the DYE project.

Evaluation of DYE project

The DYE project was evaluated based on the presentation and report. The students were given the following instructions for presentation:

1) A maximum of 12-minute presentation. Every member must speak. Exceeding 12 minutes would lead to a penalty of 10 points.
2) Presentation would be judged on the originality of the experiment, introduction, analysis, and discussion of results.
3) Presentation should have conclusions slide and a slide highlighting the contributions of each member.

DYE Projects completed in FM lab course

The students' teams have worked on many innovative ideas for the DYE project. The groups worked on the fundamentals that were taught during the laboratory sessions. The list of the projects and its learning outcome is tabulated in Table 2.

Reaction Survey of DYE Project

After the completion of the FM laboratory course, an online questionnaire was sent to students for feedback on DYE projects. The students were asked to submit their opinions and the learning impact they had from the project.

Table 3 shows the questions in the survey along with the choice of responses. A score was attached to each response to quantitatively analyze the reaction survey. The questions reflect the learning outcomes from the DYE project. In this online survey, we received 40 responses from the students who took the course over the years.

Table 2: DYE Projects as part of FM lab course

Serial Number	Project Title	Learning Outcomes
1	Calculation of power consumed by centrifugal pump	Calculation of the head developed and power consumed by the pump.
2	Steady and unsteady discharge of a v-notch weir	Calculation of the coefficient of discharge V-notch for steady open-channel flow maintained using a centrifugal pump and calibrate flow rate with respect to Height
3	Verification of velocity profile for a closed laminar flow	Observation of the radial velocity profile for a fluid flowing through a circular pipe and verifying the relation with Navier Stokes Equation
4	The validity of the creep flow assumption	Investigate the creep flow of steel balls of different diameters under the influence of the wake of the steel balls of varying numbers dropped in the column of castor oil.
5	Determine the internal diameter of the pipe in a turbulent flow regime	Comparison of the experimental result of calculating the internal diameter of pipe using Colebrook's equation
6	To measure the coefficient of surface tension of a given fluid	Calculating the surface tension using a force balance
7	Rope coil effect	Experiments to study how the coils formed change as the height of the point of efflux varies.
8	Accelerating fluid	Experimental verification of the formula $\tan \theta = a/g$, when the fluid in the container has acceleration equal to 'a'.

9	Predictive capabilities of Bernoulli's Equation using efflux time	To understand the assumptions in the Bernoulli equation.
10	Hydraulic lift	Experiment to verify the Pascal law and understand it applications
11	Characteristics of centrifugal pump	To determine the performance characteristic of the pumps connected in series and parallel.
12	Centre of pressure on a submerged lane surface	Experimentally locate the center of pressure of a vertical, submerged plane surface.
13	Jet impact on flat and curved surfaces	Experimentally determine the force acting on the flat and curved surfaces with respect to the jet velocity.
14	Metacentric height of a floating body	Determining the metacentric height of a floating body and establishing a relation between the metacentric height and heel angle.
15	Head loss in circular pipe	Experiment to calculate minor head loss coefficient and determine the variation with Reynold Number
16	Comparative study of friction factor in annulus\rectangular\circular Pipe	Determine the relationship between Reynold's Number and Fanning's friction factor.
17	Coefficient of Drag	Understand the variation of the coefficient of Drag with respect to the Reynolds Number of different objects.
18	Finding velocity field using Open CV	Analysis of streakline through hydrogen bubble flow.
19	Determining viscosity of a solution using Ostwald viscometer	To determine the viscosity of a polymer using Ostwald viscometer
20	To study the impact of jet stream	Calculate the reaction force due to change in momentum of the fluid flow when a jet of stream strikes a flat plate or curved surface and compare with the computational result.
21	Comparing heat transfer in turbulent and laminar Flow	Proposing an experiment for comparing heat transfer in Turbulent and Laminar flow
22	Drag reduction in Newtonian Fluid	Verify the drag reduction phenomenon

Table 3: Questions in the reaction survey for DYE

Question Number	Questions	Choice of responses	Score
1	In general, the end semester project enhanced my learning in the lab	1) poor, 2) fair 3) satisfactory, 4) very good, 5) excellent	poor = 1; fair = 2; satisfactory = 3; very good = 4; excellent = 5
2	The project motivated me to go a step beyond the regular lab exercises	1) poor, 2) fair 3) satisfactory, 4) very good, 5) excellent	poor = 1; fair = 2; satisfactory =3; very good = 4; excellent = 5
3	Working on the project fostered collaboration and team spirit	1) strongly disagree 2) disagree 3) neutral 4) agree 5) strongly agree	strongly disagree = 1; disagree = 2; neutral = 3; agree = 4; strongly agree = 5
4	Report writing or presentation helped improve my communication skills and increased my confidence	1) strongly disagree 2) disagree 3) neutral 4) agree 5) strongly agree	strongly disagree = 1; disagree = 2; neutral = 3; agree = 4; strongly agree = 5
5	My favorite part of the project	N/A	N/A

DYE project enhanced learning in the lab

According to the feedback from students, the DYE project helps them brainstorm ideas on the topic they learn during the course and understand the applications in real life. The project serves as a bridge between the concepts learned in the lab and the industrial application. It encourages the student to assimilate knowledge systematically by observation, experimentation and logical reasoning. Over the years, many students find the DYE project to be satisfactory, which adds additional learning and knowledge of the subject. As per Figure 1, more than 50% of the students feel that the DYE project helps them enhance their learning in the lab. The weighted average score as per Table 3 for question 1 is 3.6 ± 0.6.

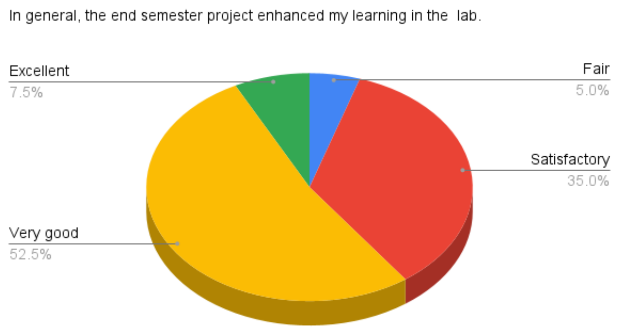

Figure 1. Students' feedback for enhanced learning through DYE project

Motivation to learn beyond the books

41% and 33% of the students rate the DYE project to be very good and satisfactory respectively as indicators of motivation to learn beyond classroom teaching as shown in Figure 2. The project encourages the students to read research papers, articles from journals and read chapters from the relevant books. Reading the scientific paper is the first-time experience for many of the students. The weighted average score as per Table 3 for question 2 is 3.5 ± 0.8.

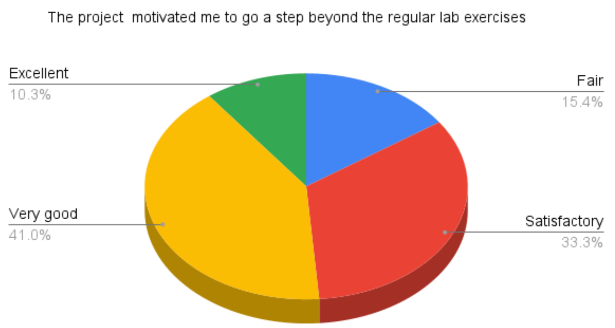

Figure 2. Students' feedback for motivation to learn beyond the regular lab

Collaboration and Team Spirit

Working on the DYE project in collaborative groups develops team spirit and leadership qualities. As per Figure 3, none of the students disagree that the project fosters collaboration and team spirit, indicating a positive impact of the DYE project on developing interpersonal relationships among students in groups. The weighted average score as per Table 3 for question 3 is 4.0 ± 0.6.

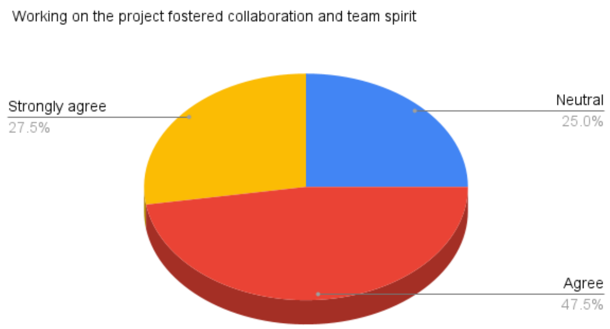

Figure 3. Students' feedback on collaboration and team work

Report writing and Presentation

The teams must submit a final project report, which consists of the aim of the project, a literature review, design and results of the experiment and its application. According to the survey, 32.5% of students strongly agree and 45% agree that the report writing, and presentation improves their communication and increases their confidence. However, 2.5% of students also disagree that report writing and presentation has contributed to their communication skills. The weighted average score as per Table 3 for question 4 is 4.0 ± 0.7.

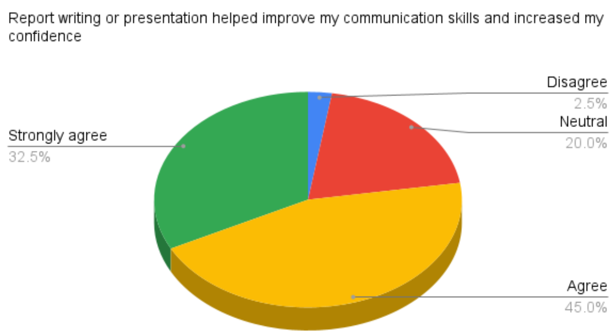

Figure 4. Student feedback for report writing and presentation

My Favourite Part of the Project

Several students listed their favourite part of DYE as tabulated in Table 4.

Table 4: Students favourite part in the project*

Experiment learning
Trying to explore beyond the listed experiments and think of something practical related to the subject
Brainstorming on how to use the experimental set-up to understand the validity of assumptions in the experiment
This project exposed me to research methods and scientific communication.
Presentation part
Designing a new experiment and preparing a report on it
The project helped me to understand the importance of the experiment.
Final presentation
To make the set-up and write the lab report.
Presentation and report
Searching for different parts
Carrying out the experiment and making the video.
To successfully experiment without external help from TA.
Tackle the surprise problems encountered during the experiment.
The presentation
The project required us to make improvisations in case of unplanned circumstances.
Assembling the setup
Making the apparatus work
Working with the team

* Reproduced from the students' reaction survey

The DYE project described here, is similar in outlook to the approaches described by other educators (Hrenya, 2011; Wicker and Quintana, 2000; Kim and Panta, 2012; Wei and Ford, 2015). In general, the DYE project in previous studies is conducted throughout the semester as a stand-alone exercise. In these studies, a particular problem statement or a set of topics to choose is assigned in implementing active learning in the FM courses. However, DYE project discussed in this paper relies on students to find a problem statement and the corresponding experiment which they can work as part of this activity.

The performance of the students in DYE project was independent of their scores in theory FM course. This indicates that DYE project is a beneficial learning tool for students who may not be able to grasp the concepts in the class lecture-style mode of instruction.

Challenges

The integration of DYE project in the laboratory courses can be challenging. According to the reaction survey, some students feel that the time required (~ 6 weeks) to complete the DYE project is not enough along with the regular experiments in the lab course. More manpower in terms of teaching assistants along with multiple instructors may be beneficial to help and guide the students on a weekly basis and to monitor their progress.

Conclusions and Future Directions

DYE is an effective tool which can be incorporated in laboratory courses to engage students and help them get over the monotonous setting of the course. It also helps the students to forge inter-personal relationships, coordination and teamwork.

However, during the hybrid or online offering of the laboratory course, it would be beneficial to include a simulation-based exercise ahead of the DYE project. Another variation of DYE project can be based on experiments in Journal of Visualized Experiments (https://www.jove.com/) and National Committee of Fluid Mechanics Films (http://web.mit.edu/hml/ncfmf.html).

The students may be instructed to expand the knowledge gained from the published experiments; define and perform another experiment.

Acknowledgement

We are grateful to the anonymous reviewers for their insightful comments. We thank the Discipline of Chemical Engineering, IIT Gandhinagar for funding. We also thank the staff and teaching assistants associated with FM laboratory for their assistance. We thank IIT Gandhinagar library for providing many useful research articles on engineering education pedagogy.

Disclosure Statement

The authors declare that they have no conflict of interest.

References

Chua, K. J., W. M. Yang, and H. L. Leo. 2014. "Enhanced and Conventional Project-Based Learning in an Engineering Design Module." International Journal of Technology and Design Education 24 (4): 437–58. https://doi.org/10.1007/S10798-013-9255-7/FIGURES/5.

Feisel, Lyle D., and Albert J. Rosa. 2005. "The Role of the Laboratory in Undergraduate Engineering Education." Journal of Engineering Education 94 (1): 121–30. https://doi.org/10.1002/J.2168-9830.2005.TB00833.X.

Hrenya, Christine M. 2011. "Active Learning in Fluid Mechanics: Youtube Tube Flow and Puzzling Fluids Questions." Chemical Engineering Education 45 (2): 114–19. https://journals.flvc.org/cee/article/view/122162.

Kim, Hyun W., and Yogendra M. Panta. 2012. "Fostering Students' Capability of Designing Experiments through Theme-Specific Laboratory Design Projects." ASEE Annual Conference and Exposition, Conference Proceedings. https://doi.org/10.18260/1-2--21403.

Mandavgane, Sachin. 2020. "Fun with Fluid: An Innovative Assignment in Fluid Mechanics." Education for Chemical Engineers 30 (January): 40–48. https://doi.org/10.1016/J.ECE.2019.11.001.

MILLS, and JE. 2003. “Engineering Education-Is Problem-Based or Project-Based Learning the Answer?” Australas Phys Eng Sci Med 4: 1–16. https://ci.nii.ac.jp/naid/20001056499.

Palmer, Stuart, and Wayne Hall. 2011. “An Evaluation of a Project-Based Learning Initiative in Engineering Education.” https://doi.org/10.1080/03043797.2011.593095 36 (4) : 357–65. https://doi.org/10.1080/03043797.2011.593095.

Pérez-Sánchez, Modesto, and P. Amparo López-Jiménez. 2020. “Continuous Project-Based Learning in Fluid Mechanics and Hydraulic Engineering Subjects for Different Degrees.” Fluids 2020, Vol. 5, Page 95 5 (2): 95. https://doi.org/10.3390/FLUIDS5020095.

Puleo Jack A. 2020. “A Design-Based Fluid Mechanics Laboratory.” Global Journal of Engineering Education 22.

Robert W. Fox, Alan T. McDonald, and John W. Mitchell. 2020. Introduction to Fluid Mechanics . 10th ed.

Wei, Tie, and Julie Ford. 2015. “Enhancing the Connection to Undergraduate Engineering Students: A Hands-on and Team-Based Approach to Fluid Mechanics.” Journal of STEM Education: Innovations and Research 16 (2). https://www.jstem.org/jstem/index.php/JSTEM/article/view/1933.

Wicker, Ryan B., and Rolando Quintana. 2000. “An Innovation-Based Fluid Mechanics Design and Fabrication Laboratory.” Journal of Engineering Education 89 (3): 361–67. https://doi.org/10.1002/J.2168-9830.2000.TB00537.X.