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An Effective Laboratory Method for Thermal Fluid Mechanics Course

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Abstract

Laboratory practice plays a crucial role in engineering especially in thermal fluid education. The advancement of computational and computer technologies have ushered in a new horizon in learning and teaching of laboratory practices world-wide. Apart from traditional hands-on laboratory practice, the virtual/simulated laboratory practices are playing an increasingly dominant role. The virtual laboratory practices offer unique opportunities for students to visualise complex concepts and remove the time and location barrier. This paper presents a 3-step hybrid laboratory practice developed at RMIT University for thermal fluid course. It is evident that a combination of video clip, hands on laboratory practice and virtual/simulated laboratory practice enhances the student learning experience and learning outcomes.

Introduction

The laboratory practices, as an integral part of engineering and technology education, prepare students to apply theoretical knowledge into practice and to extract data necessary for a design, evaluate a new device, or discover new knowledge (Alam et al. [1]. Laboratory practices assist students to develop critical enquiry and problem solving skills [2-4]. The advancement of educational technology and information and communication technology (ICT) offers unique opportunities to visualise and explore further many complex phenomena in engineering especially thermal fluid education. Most engineering programs (mechanical, civil, chemical, electrical, etc.) are laboratory intensive. They require huge laboratory equipment, facilities, periodical maintenance and skilled staff that are expensive and time consuming. As public funding is gradually reducing, most universities in Australia, New Zealand, USA, Canada and other parts of the developed nations have been facing financial difficulties. Mechanical engineering program especially thermal fluid course(s) is hit hard and is forced to find alternative ways to maintain the delivery of quality education to students. Many mechanical engineering programs have been forced to reduce their expenditure on capital equipment, replacement of old facilities, operating and maintenance costs, and reduce the supporting technical and academic staff [1, 3-8]. Additionally, some engineering programs have large class sizes (200-300 students). For laboratory practice, students are required to divide into smaller group of below 10 [3-4]. Therefore, it is difficult to provide adequate practical facilities and laboratory practice time to students with increasingly diminishing limited resources. In order to provide students an opportunity to conduct hands-on laboratory practice with shorter time, exposure to relevant theories, familiarisation with laboratory equipment, and further exploration with virtual/simulated laboratory environment, a three-step laboratory teaching methodology is proposed. The three-step method consists of a video clip of the real laboratory experiment and relevant theories, hands-on laboratory practice and computer simulation.

The video clip explains all the relevant theoretical knowledge required for the hands-on laboratory experiment and equipment, as well as how to use them, by an experienced academic. All students are required to watch the video clip before they carry out the real laboratory practice. As students are familiarised with the laboratory equipment, facilities, relevant theories and safety instructions well before they undertake the actual laboratory work, the process shortens the two-hour laboratory session into one hour or less without compromising the quality of education. After watching the video clip and conducting the laboratory experiment, students perform the computer simulation using the practical laboratory parameters as input to complete the exercise (in this case, drag measurement of a circular cylinder).

Upon completion of the computer simulation, students are required to compare their results with the experimental findings. Additionally, students need to modify their computational input parameters to obtain variable results, analyse and compare them with the published data. In this process, students can further strengthen their theoretical and experimental knowledge without any extra costs to the university.

The three-step laboratory teaching concept was piloted in order to obtain students' feedback and see if the learning out comes are enhanced. The methodology was used in the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University in Melbourne, Australia for thermal fluid courses undertaken by students of aerospace, mechanical, manufacturing and automotive engineering programs. Fluid mechanics is generally considered as one of the most complex and challenging subjects as it deals with the complex nature of mass flow and heat transfer, and the basic concepts are usually difficult to understand due to the level of mathematics and physics required. A schematic of the three-step teaching and learning scheme is described in Alam et al. [3].

The Three-Step Teaching Method

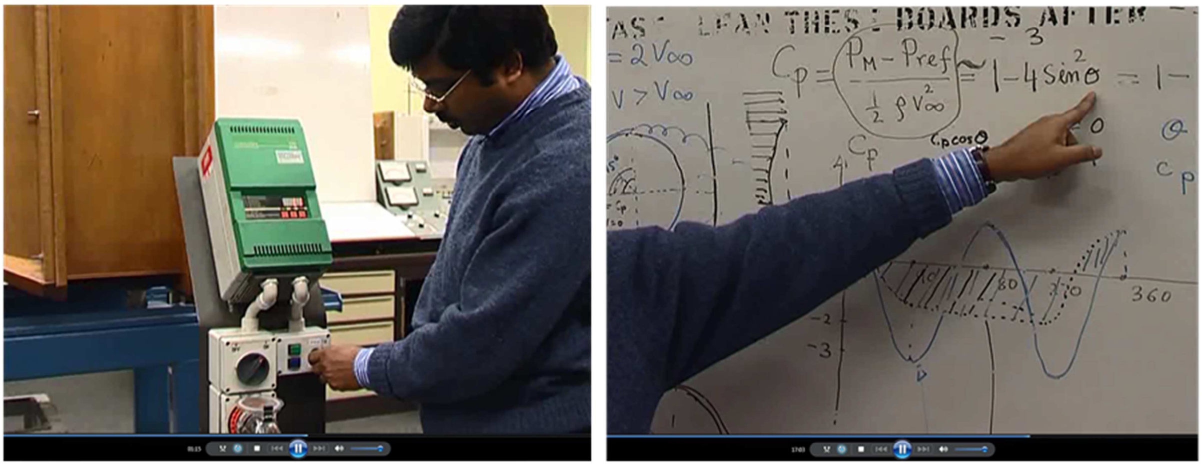
The laboratory practice selected for this method is an experiment "Drag Measurement of a Circular Cylinder using pressure integration method" of thermal fluid mechanics course.

Step One: Video Clip of the Practical Laboratory

A video film was made about the drag measurements of a circular cylinder laboratory experiment with the assistance of audio/video professionals. An experienced academic explained all the relevant theory, step-by-step description of laboratory equipment and experimental procedure. The video film was converted to a Virtual Laboratory Video (Figure 1) and linked with the course web interface as shown in Figure 2. Students can visit the course website and play the video clip of the laboratory at their convenience before conducting real laboratory practice. The video clip can be replayed as many times as the student wishes before the class. In order to make sure that a student has watched the video clip before conducting the real laboratory, a set of quizzes has been designed with the Virtual Laboratory video clip. Sample questions are shown in Figure 2. Students need to pass the quiz to proceed to the next step. If anyone fails to pass the quiz, then he/she needs to watch the video again until pass the quiz test. The test encompasses all aspects of the video clip including theory, experimental procedures, equipment and safety protocols. However, the conduct of real laboratory experiment needs to be carried out according to the lab schedule.

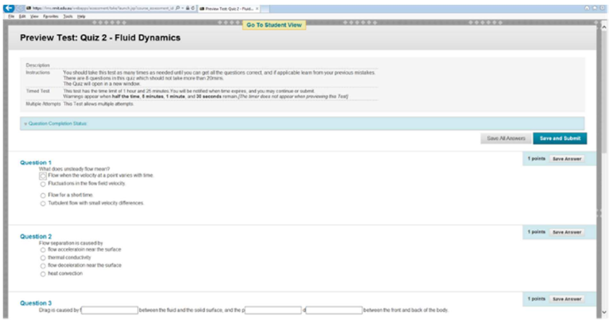
a) Alam explains about wind tunnel b) Alam explains about reference pressure

c) Alam describes about explains about circular cylinder d) He explains various features about manometer



e) Alam shows how to operate wind speed controller f) Alam explains theory related to the this experiment

Figure 1. Video clip describing relevant theory, equipment and lab demonstration.



Preview Test: Quiz 2 - Fluid Dynamics

Description
Instructions You should take this test as many times as needed until you can get all the questions correct, and if applicable learn from your previous mistakes. There are 8 questions in this quiz which should not take more than 20mins. The Quiz will open in a new window.
Timed Test This test has the time limit of 1 hour and 25 minutes. You will be notified when time expires, and you may continue or submit. Warnings appear when **half the time**, **5 minutes**, **1 minute**, and **30 seconds** remain. *[The timer does not appear when previewing this Test]*
Multiple Attempts This Test allows multiple attempts.

Question 1
What does unsteady flow mean?
○ Flow when the velocity at a point varies with time.
○ Fluctuations in the flow field velocity.
○ Flow for a short time.
○ Turbulent flow with small velocity differences.

Question 2
Flow separation is caused by
○ flow acceleratoin near the surface
○ thermal conductivity
○ flow deceleration near the surface
○ heat convection

Question 3
Drag is caused by f ______ between the fluid and the solid surface, and the p ______ d ______ between the front and back of the body.

Figure 2. Test questions for students after watching the laboratory video clip.

Step Two: Conducting the Real Laboratory Experiment

After watching the Virtual Laboratory Video Clip, students proceed to the real laboratory experiment in groups of six to ten students. A laboratory supervisor assists students if required. The real laboratory experiment on the drag measurement of a circular cylinder is conducted using a portable wind tunnel, which is shown in Figure 1. It has a rectangular test section of nominal size 300 x 300 x 500 mm (width, height and length, respectively). Flow is drawn through the tunnel by an axial fan located at the tunnel exit. A circular cylinder with a traversing mechanism is mounted in the test section. A Pitot static tube is mounted on a traversing gear that can move vertically up and down to measure the local value of velocity behind the cylinder. For the experiment, in addition to the wind tunnel with a probe traversing mechanism, a circular cylinder with a tiny hole and a protractor, a Pitot static tube with flexible plastic tubing, two manometers, a thermometer and barometer (to measure the ambient temperature and pressure, respectively) are required. The drag coefficient of the circular cylinder is then calculated from the measured pressure data from the experiment.

Step Three: CFD (FlowLab) Simulation

The computer simulation is conducted using FlowLab (see Figure 3). A FlowLab laboratory guide is provided specifically for this exercise. The physical parameters (e.g., diameter of the cylinder), operating and boundary conditions (e.g., fluid velocity) from the real experiment are used as input variables. The result of the FlowLab simulation is then compared with that of the real experiment. Additional parametric investigations (i.e., modification of input variables) are also required to further the relevant concepts. The results from these extended studies are then compared and validated against published data. The visualisation of the phenomena can be shown easily using the FlowLab. The visualisation capability of the FlowLab helps students to understand the complex nature of fluid flow as well as provide an exciting platform to enhance their learning experience.

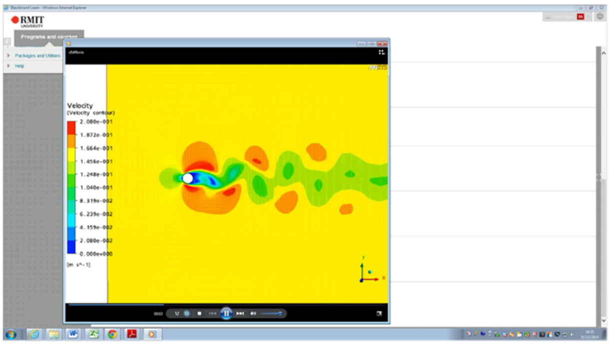


Figure 3. Flow simulation around a circular cylinder using FlowLab simulation.

Pilot Study

A group of 40 students was selected for the pilot trial of the three-step laboratory teaching method. The participation of students was entirely voluntary. All student participants had gone through all three steps. They watched the video clip first, then conducted the real laboratory experiment and simulated the same laboratory conditions using CFD/FlowLab on a computer. Students analysed the data obtained from experimental and CFD simulation and compared them. Later, they modified the simulation variables in order to acquire further knowledge. Finally, the students submitted a comprehensive laboratory report. Selected students were given a set of survey questions to evaluate their impression of the three-step teaching concept to obtain feedback. The survey was structured to gain insight into students' perception regarding the following: the instructional video clip; hands on lab module effectiveness; effectiveness of FlowLab to reinforce concepts introduced by hands on lab; and relevance of the experimental and computational components of the course. A general comments section, designed to capture additional student feedback, was also included in the survey.

Results of the Pilot Study

Since the instructional video clip was pilot tested for the first time, the focus of the analysis was on the students' appraisal of the video clip (both conceptual and operational). Nevertheless, additional questions regarding overall course content and its components were also fielded. Owing to the small number of samples, this study primarily used descriptive statistics collated from the survey results.

Students' Perceptions of the Video Clip

Students generally agreed that the concept of the instructional video clip for the hands on laboratory component of the course was a good idea. They considered that it was also a useful tool to familiarise students with the instrumentation and proper procedures to conduct laboratory experiment competently and safely. Students' additional comments indicated that the pilot video clip needed to be brief and concise as the video clip was done by an amateur personnel. In order to address this issue, a professional video clip has been developed and is ready for use. The use and effectiveness of the video clip will facilitate the eventual reduction of the time devoted to the conduct of the experimental laboratory without compromising the quality of instruction – even with minimum supervision.

Effectiveness of the Hands on and FlowLab Modules

The respondents gave favourable agreements with the two questions fielded relating to the effectiveness of the hands on and FlowLab modules. On the issue of time allocation, the mean response of 2.54 indicates that the respondents felt that the hands on module was not optimised time-wise. Reflections from the general comments show that students preferred a shorter instructional video. However, all student groups doing the hands-on experiment have no difficulty finishing the conduct of the experiment in less than an hour. Students were also asked if they felt that they were actively involved in the learning process. Their response was far from agreement (mean = 2.31), which indicates that though the importance of the whole module is recognised, some of its components (e.g., video clip) fell short of student's expectations. Other comments indicate that the experimental component was important for fully understanding the theoretical concepts. The respondents generally appreciated the added value of virtual/simulated component (FlowLab) to enhance understanding of the concepts behind the experimental work and simulated work as an additional tool to explore and further their learning experiences (response means = 1.92 and 2.0). The FlowLab simulation was a fast and attractive method for doing parametric studies as opposed to the cumbersome and time-consuming prospect of repeating the actual experiment.

Relevance of the Hands on and Simulated (FlowLab) Components

Three questions were formulated to assess students' opinion whether simulated component can replace experimental component as a learning tool for this course. Majority of the respondents disagree (response means = 3.38 & 3.69) that simulated laboratory can fully replace the hands-on experiment. Although simulated lab (FlowLab) is an exciting new tool, it may not be wise to dispense with the actual experiments since computer models are still evolving and most real life engineering thermo-fluid applications are not yet fully understood. When asked if FlowLab can achieve the same learning outcomes compared with actual experiment, the response was neutral (response mean = 3.0). This is cognizant of the fact that the accuracy of the computer simulation results are still suspect, though for simple or well defined cases, simulation results are in close agreement with experimental measurements. Additional respondent feedback collated from open ended questions provided interesting insights. Majority of the respondents (69.23%) prefer a time allocation of 50-60% for the hands-on experiment module and the rest for the computer simulation. This observation is contrary to the 30% actual laboratory time and 70% virtual laboratory plus computer simulation time allocation as originally proposed for this course [Alam et al 2004]. Respondents recognise that the hands on and computer simulation components of the course are equally important. While computer simulations can be fast and cost effective, it is unlikely to fully replace actual laboratory experiments. The hands-on learning experience is important because some respondents claim that they can remember the concepts better when they did the actual experiment.

Conclusions

The three-step method received positive feedback from a self-selecting group of volunteer students. The video clip has the potential to help students enhance their experimental and theoretical knowledge about the laboratory. However, the video clip needs to be precise and have better quality.

For effective teaching and learning, both hands-on laboratory and computer simulation are preferred as they are complementary to each other and students prefer more allocated time for hands on laboratory practices.

A comprehensive trial of the three-step teaching method needs to be completed with all students' participation. A better designed student feedback questionnaire needs to be developed to reflect students' overall satisfaction.

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