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A three-step teaching and learning method in laboratory experiments for a thermal fluids course

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ABSTRACT: The teaching of thermal fluids subjects is always challenging due to its complex nature and the mathematics involved. In order to teach students the basic concepts, a range of hands-on laboratories, computer simulations and professional staff are required. Due to the reduction of government funding, it is difficult to achieve effective teaching and learning outcomes. Therefore, the primary objective of this paper is to develop a three-step teaching method that can greatly enhance students' learning outcomes, and be cost effective, user-friendly and attractive. The method comprises a real laboratory video clip, conduction of a real laboratory and a computer simulation. The proposed three-step teaching and learning method can be applied to other subject areas as well.

INTRODUCTION

Some engineering programmes, such as mechanical engineering, need hands-on laboratory and workshop facilities for the achievements of their academic goals compared to other engineering programmes. Industry and research organisations want to have graduates with hands-on practical and theoretical knowledge who are ready for immediate work assignment without even induction training. Engineering institutions have huge responsibilities to educate and train undergraduate students with hands-on knowledge. Therefore, these institutions need to have vast engineering workshops and practical laboratory facilities to keep up with industry demands.

Only engineering educational establishments in the developed world could maintain these facilities to educate students with the required technical, real world, hands-on knowledge and skills. However, these facilities are virtually non-existent in developing countries due to their financial hardships. It may be noted that vast majority of educational institutions for engineering education are generally funded by governments from public funds. However, publicly funded universities in Australia, New Zealand, North America and other parts of the developed world have been facing severe financial difficulties as a result of government funding reductions. Mechanical engineering programmes are hit hard and are forced to find alternative ways to maintain the delivery of quality education to students. Many mechanical engineering departments 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 [1-4].

Today, many universities have large class sizes (up to 250 students). For laboratory practice, students need to be divided into a smaller group of below 10 (see ref. [1]). Therefore, it is difficult to provide adequate facilities and time to students with increasingly diminishing limited resources. In many western universities, postgraduate students supervise and conduct laboratory experiments. There are challenges associated with the induction and training of laboratory assistants. Moreover, as they are gradually trained and experienced, many leave after the completion of their courses (Masters and PhD). Therefore, subject coordinators need to start all over again in training newly commencing postgraduate students. In order to provide all students with opportunities to conduct hands-on laboratory work within a reasonable time and with laboratory supervision/ demonstration consistency, a three-step laboratory teaching methodology is proposed. The three-step method comprises a video clip of the real laboratory experiment, hands-on conduct of the Experimental Fluid Dynamics (EFD) laboratory and computer simulation using commercially available Computational Fluid Dynamics (CFD) software utilising the real experimental variables as input.

The video clip explains all the relevant theoretical knowledge required for the hands-on laboratory experiment and all 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 experiment. As students will be familiarised with the laboratory equipment, facilities, relevant theories and safety instructions well before they undertake the actual laboratory work, it shortens the two-hour laboratory session into one hour or less without compromising the quality of education. Additionally, it would help to reduce operational and supporting technical labour plus other logistic costs. After watching the video clip then conducting the practical laboratory experiment, students perform the computer simulation using the practical laboratory parameters to complete the exercise (in this case, drag measurement of a circular cylinder).

It may be mentioned that many engineering educational institutions are progressively introducing computer aided learning packages as an alternative to hands-on practical laboratories and field experiments. Hands-on practical laboratories help students to understand complex theoretical problems and apply theoretical knowledge in practice [5]. However, there are some mechanisms or phenomena that are difficult to visualise due to technical constraints and/or operational safety reasons. Thanks to the tremendous progress in computational power over the last decade, these complex and difficult phenomena can be visualised with the help of powerful computational tools. However, a virtual laboratory cannot be a replacement of real laboratory as many laboratory works cannot be accurately simulated and students may not be able to get a real *feel* that hands-on practical experience can offer. Hands-on experience is a necessary requirement to tackle real world engineering problems effectively. Therefore, both hands-on laboratory experiments, computer-based simulations and Web-based visualisation are required. However, a balance between simulation and practical work is also required to provide students with an appropriate level of simulated and hands-on laboratory experience. To the authors' knowledge, no studies on the appropriate balance between simulation and practical works have been reported in the open literature.

Upon completion of the computer simulation, students need to compare their results with the experimental findings. Additionally, students need to modify their computational input parameters to obtain various results, then 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 pilot-tested in order to obtain students' feedback and to check whether it helps students to achieve the desired learning outcomes in a relatively difficult subject in a mechanical engineering programme. In aerospace, mechanical, manufacturing and automotive engineering programmes, fluid mechanics is one of the common subjects for undergraduate students. 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 shown in Figure 1.

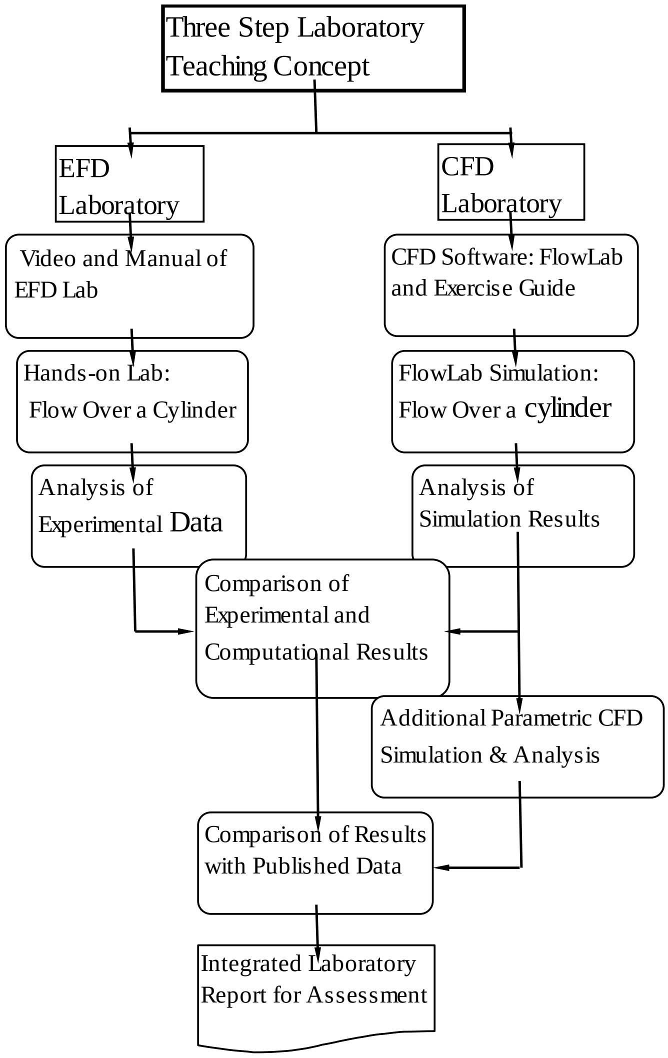

Figure 1: A flow chart for the three-step teaching concept.

THE THREE-STEP TEACHING METHOD

In order to get students feedback on the proposed three-step teaching method for laboratory work, a pilot test of the instructional video clip was conducted in a third year fluid mechanics course as it is common for mechanical and automotive engineering students. The laboratory work selected for the trial was called *Drag Measurement of a Circular Cylinder* using the pressure integration method. This laboratory was selected as it is common in a fluid mechanics course in other engineering programmes as well.

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 basic theory and step-by-step description of all equipment and laboratory procedures. The video film was converted to a Virtual Laboratory Video (see Figure 2) and linked with the course Web interface as shown in Figure 3. Students can visit the course Web site and play the video clip of the laboratory at their convenience before conducting real laboratory work.

Figure 2: A still picture from the EFD video clip.

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 quiz has been designed with the Virtual Laboratory video clip. 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 passing 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 schedule.

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 eight students. A laboratory supervisor assists students if required. The real laboratory experiment on the drag measurement of a circular cylinder are conducted using a portable wind tunnel, which is shown in Figure 2. 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 pressure measurement data from the experiment.

Step Three: CFD Simulation

The CFD computer simulation is conducted using *FlowLab*. A CFD laboratory guide is provided specifically for this exercise. The physical parameters (eg diameter of the cylinder), operating and boundary conditions (eg fluid velocity) from the real experiment are used as input variables. The result of the CFD simulation is then compared with that of the real experiment. Additional parametric investigations (ie modify input variable) are also required to further students' understanding of 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 CFD software. Utilising the visualisation capability of the CFD software can help students to understand the complex nature of fluid flow, as well as provide an exciting platform to enhance their learning experience. It may be noted that students can undertake CFD simulation individually or in the same group as in the experimental laboratory work. A Web-based CFD interface has been developed, a snap view of which is shown in Figure 3.

Figure 3: Snapshot of the course Web page.

PILOT STUDY OF THE THREE-STEP TEACHING CONCEPT

A group of 20 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. Primary survey questions are shown in Figure 4. The survey was structured to gain insight into students' perception regarding the following concerns: the EFD instructional video clip; EFD module effectiveness; effectiveness of CFD to reinforce concepts introduced by EFD; and relevance of the EFD and CFD 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

The pilot study results are shown in Figure 4. Since the instructional EFD 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 EFD Video Clip

Students generally agreed that the concept of the instructional video clip for the EFD 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 experiments 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 professional people. In order to address this issue, a professional video clip was made 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 EFD and CFD Modules

The respondents gave favourable agreements with the two questions fielded relating to the effectiveness of the EFD and CFD modules. On the issue time allocation, the mean response of 2.54 indicates that the respondents felt that the EFD 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 (eg video clip) fell short of

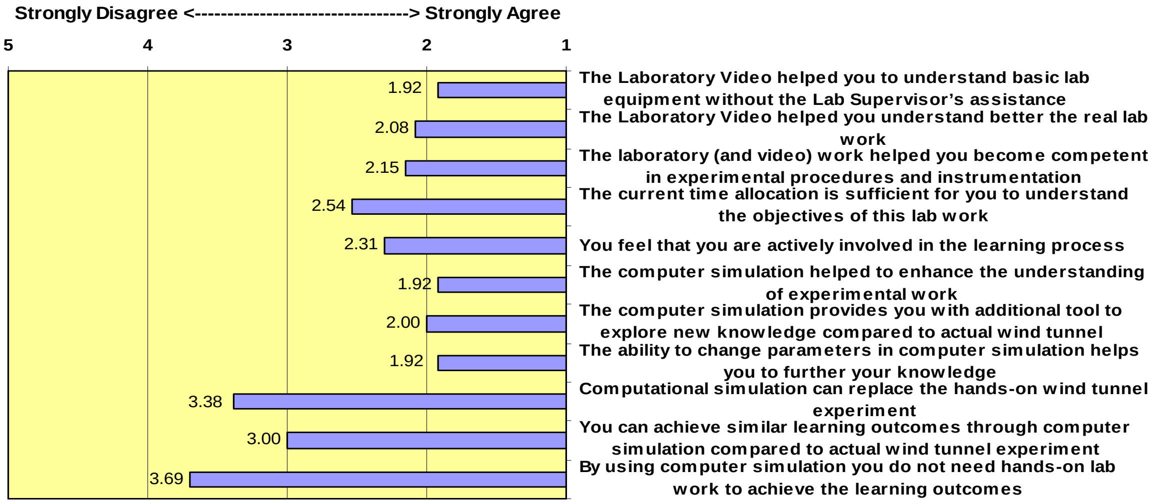

Figure 4: Students' feedback: descriptive statistics.

student's expectations. Other comments indicate that the EFD experiment was important for fully understanding the theoretical concepts. The respondents generally appreciated the added value of CFD to enhance understanding of the concepts behind the experimental work and CFD as an additional tool to explore and further their learning experiences (response means = 1.92 and 2.0). The CFD 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. Exploiting this unique feature of CFD helps students understand the relationship between physical variables and their impact on the overall behaviour of the phenomenon being investigated.

Relevance of the EFD and CFD Components

Three questions were formulated to assess students' opinion whether CFD can replace EFD as a learning tool for this course. Majority of the respondents disagree (response means = 3.38 & 3.69) that CFD can fully replace the hands-on experiment. Although CFD 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 CFD 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 CFD simulation. This observation is contrary to the 30% actual laboratory time and 70% virtual laboratory plus CFD simulation time allocation as originally proposed for this course [1]. Respondents recognise that the EFD and CFD components of the course are equally important. While CFD simulations can be fast and cost effective, it can never fully replace actual laboratory experiments. The EFD learning experience is important because some respondents claim that they can remember the concepts better when they did the actual experiment.

CONCLUSIONS AND FUTURE WORK

The following conclusions have been drawn from the work presented here:

- 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 CFD simulation are preferred;
- CFD simulation cannot fully replace hands-on laboratory work and students prefer more allocated time for EFD;
- 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;
- Significant monetary savings could be achieved (up to 40%) with the introduction of the proposed three-step teaching method.

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