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Pedagogical Interventions in CFD Theory and Lab Courses for Energy Systems Engineering Graduate Programme

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Abstract: Use of simulation software packages based on numerical techniques has been relatively cheaper, faster and normally more ethical than conduct of real-time experiments. Computational Fluid Dynamics (CFD) that basically evolved through application of numerical techniques to physical laws of conservation of mass, momentum and energy. CFD has revolutionized solution to fluid flow, heat transfer, mass transfer and other multidisciplinary problems. CFD requires a strong mathematical base with the thorough understanding of physics behind the problems. The present work deals with delivery and assessment of CFD concepts through the theory and laboratory courses for students of Graduate Program in Energy Systems Engineering.

The delivery and assessment of the CFD courses targeted the attainment of the Graduate Attributes (GA) PO2, PO4, PO5 and PO6 prescribed for the graduate programme.

The results of pedagogical initiatives in teaching this course to heterogeneous student group imposed few challenges in delivery due to only 37.5% of the group being familiar to the course prerequisites while 62.5% of the group was alien to these concepts. The results indicated that meticulous planning and execution of the courses to the diverse group resulted in the overall average score of 61.4% and 82.04% in theory and lab course respectively.

Keywords: CFD, Graduate Attributes, Interdisciplinary course, Engineering Education.

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1. Introduction

Research is the process of moving from strongly established facts to evolve unknown answers to the existing problem. Engineering practice strives to make break through research on complex real world problems to create solutions with minimum resources and cost effective methodologies. Current market trends have made it clear that there is no excuse for incompetency in any field concerned with an engineer. It also demands strong multidisciplinary knowledge conglomeration to solve the real world problems. Theoretical solutions in case of multidisciplinary problems on virtue of being less accurate and experimental approach consume more resources and time are hence not preferred. Owing to these shortcomings of theoretical and experimental approaches, alternatives based on numerical methods with the aid of computers are developed.

The CFD tool that has evolved through numerical methods and flow physics needs a strong background of mathematics and physics. The evolution of high speed computing with an ability to handle complex engineering problems has lead engineering community to incline to numerical solutions in situations that are repetitive time consuming tasks. This has lead to CFD tool to emerge as a powerful design and research tool in fluid flow, heat transfer, electromagnetism, chemical and combustion processes. The effective CFD approach has been a result of simultaneous application of multiple streams of engineering integrated to capture their combined effect on the system behavior termed as 'multi-physics'. The corporate world today demands competent engineering graduates to address multi-physics problems that need cross domain knowledge. The industries today are heavily relying on CFD tool for research and development towards product optimization before installation or system launch. This opportunity has opened up new avenues to graduate students to partner with Industry and Academia related research to deliver some breakthrough solutions to technological problems.

The CFD tools today are deployed to characterize and optimize engineering solutions in aerodynamics, construction, electrical machine design, chemical kinetics, combustion, electro-magnetics, MEMS and space technology. The CFD course at under-graduate and post-graduate level programs has become imminent to support manpower needs to handle engineering projects in fields of civil aviation, naval architecture, construction sector and manufacturing industry at the corporate level.

The pedagogy of CFD course offers certain challenges owing to prerequisite skills in mathematics and programming. The integrated approach of teaching CFD theory and Laboratory course offers advantages like better realization of theory concepts along with hands-on exposure to use CFD tool. The CFD laboratory course is a time intensive with student performance evaluation based on active involvement to analyze independently defined tasks that connect them to real world problems and solution. The evaluation of solution methodology to current engineering problems has shifted to multi-physics arena that requires integration of different domains/streams of engineering to evolve cost-effective solution.

2. Literature Review

Teaching CFD Theory and laboratory course for an interdisciplinary pupil group has found to be a challenging task in presence of pupil groups alien to the concepts of the numerical methods and physics of the problem. These challenges made some researchers to work on different pedagogical transforms in teaching CFD. Some of that kind research works have been studied and reviewed in this section.

Modern engineering society has to face the situation where it needs to address the problems in a cost effective way. Modern computational tools plays a key role in finding cost effective solution for a particular problems with enhanced level of competence in handling the tool to solve the problems pointing GA 5 [2]. Approach to address GA 5 in CFD laboratory with considering a real life problem always has a default advantage of motivating students to understand the problem. Comparing the solutions obtained with commercial tools available and coding the same problem always helps to understand the advantages and limitations of the computational tools. The challenges in introducing graduates to complex real world problems is to make them attend longer sessions so as to spend time on discretization and post process steps of the solution [3].

The intention of learning CFD theory is to avoid students from using CFD tools as a black box and to understand in detail how the fundamental conservation laws deal with the problem physics. This way of learning helps to understand procedures and methodology of CFD and promote students to learn it in detail. Development of a course which follows CFD procedures connected to Experimental Flow Dynamics (EFD) examples helps users to understand the process of CFD more effectively. [4]

Commonly observed challenges in computer related courses can be addressed by the content design technique. A computer related course can be effectively taught by group activities, case study based learning (Project execution) and experiential learning techniques which force students to be in active learning atmosphere. [5]

The use of open-source computational tools in CFD is also in trend for lower level flow analysis. The general advantage of open source computational tools over commercial tools is that they are available for no cost which makes academia to incline towards open source tools over commercial tools. The open source tools have some limitations like user interface issues and inability to handle complex flow problems because of the small support community. [6]

CFD has found its applicability in wide range of engineering domains such as Aerodynamics, Fluid flow, Heat and mass transfer, Electro magnetics, MEMS, Building constructions, Electrical machine design, combustion, chemical kinetics. These domain areas has several fields where calculating each parameters in design process is laborious which makes the engineers to show less interest in considering those parameters while design the projects. The studies on teaching on-line course to architecture students also showed the difficulties of the students in mastering the physical model development, understanding numerical methods and grid generation which are key points of the CFD. [7]

The commercial CFD packages available has some limitations which can be understand by the learner as he/she progresses in using CFD for further research where the commercial CFD packages fail to simulate all requirements of the whole problem or to obtain accurate answers. This condition mandates the learner to develop the code which can enhance the commercial CFD package's capabilities with additional programs. [8]

The contemporary CFD research areas like analysis of passive decay heat removal in scalable liquid metal-cooled small modular reactor, renewable energy harvesting systems focusing mainly on solar and wind energy systems, Internal combustion engines and micro electro-mechanical systems keep students abreast with the latest technologies and research domains where they can contribute.[9,10]

3. Problem Based Approach To Cfd

The conventional teaching-learning procedure involves rote-based learning cycle with minimal room for original thinking. This system imposes ideas on students creating mental block that defer new source of interest on the concept studied. The projects have proved to be wonderful learning tools as they make teaching-learning process more student- centric. Project has become integral part of the modern pedagogical reforms leading to greater levels of collaborative efforts that enhance learning levels in students. The well defined project objectives aided by excellent execution fosters thorough learning of concepts. The role of teacher has been vital as a facilitator in assisting student choose an appropriate topic and defining objectives and expectations. The clearly stated rubrics also play a major role in the success of problem based approach ensuring student to be an active element of learning cycle. The clear connection of assigned project topic with the concept studied having a reasonable scope for creativity and originality should be the guiding framework for project based learning. The approach can be implemented as a group activity or individual activity based upon the context whatever is relevant to the situation. The project executed as a team activity promotes collaborative learning imbibing team learning attributes. The individual project normally practices at graduate level demand scholastic involvement in its assessment. The present work discusses project based learning in the context of CFD theory and Laboratory courses offered at PG program in Energy Systems Engineering (ESE) that caters to needs for competent energy engineers who fit in to wide range of roles like energy related sectors, Academia and research sectors. The ESE program intensively focuses on renewable energy conversion systems such as solar and wind energy systems. The program has 45% of credits to be earned through project based courses. The use of CFD plays vital role in the Research and Development sectors of reputed energy related industries. In view of its importance as a numerical tool in design process, Engineers competent in handling CFD tools have a great demand in Industrial R&D sectors.

The multidisciplinary nature of the program has an advantage that students with different graduate background try to work together which enhance student's ability to effectively participate in multidisciplinary teams. CFD course is also a multidisciplinary subject which helps the students to work on wide range of research areas related to energy systems. CFD tools are capable to handle multi-physics related problems which adds more value to the student projects and it reduces time and cost required to design optimized systems.

The CFD Theory course content was designed to mainly address Graduate Attributes PO2 and PO4 in various levels of Blooms taxonomy. During course delivery informal peer teaching strategies were used to promote students of mechanical engineering stream assist their counterparts from electrical science background. The In-semester Assessment (ISA) marks were grouped in to three parts constituting 15-

15-20 (minor 1-Minor 2-Assignments). The exams Minor-1 and Minor-2 designed in written format were each based on 40% of course content with a weightage of 30% marks. The remainder of the ISA had weightage of 40% assessed through Assignment segment designed based on problem based teaching. The assignment segment included student presentation based on minor exam papers and review of research articles on contemporary issues in CFD. The ISA process involved a critical peer review strategy where student assessed response sheet / presentation of peer followed by self-assessment of the response sheet. The weightage of marks have been divided in to 50% for ISA and 50% for End semester Assessment.

CFD Laboratory course content was designed considering the students as beginners in the subject. The course content developed had a flow similar to the flow of typical CFD solution process which makes an easy understanding opportunity for the students in order of Geometry Creation, Grid generation, Specifying initial conditions, and Specifying Boundary conditions, Selection of appropriate solution scheme and Interpretation of the results obtained. The course content were designed to address the Graduate Attributes PO4, PO5 and PO6. The pupil size selected for the present study had majority of the students (62.5%) from electrical science background less familiar with the modeling tools. The students from electrical science background needed a bridging knowledge to pick up with the basics of CFD but introducing the bridging to whole class had a challenge to keep students from mechanical science background in flow. To overcome this challenge an informal peer teaching strategy has been adopted where mechanical science students demonstrated hands on classes to the electrical science background students on modeling simple geometries in modeling tools. To enhance the active learning atmosphere 6 groups were created such that each group has one mechanical science background student in it. To encourage the students who are not familiar with the tool a shift from lecturing to training mode has been done. At the end of the course the each team of students have analyzed different problems such as effect of ice deposition on drag and lift coefficient of the aerofoil structure, effect of angle of attack on the HAWT and VAWT aerofoil structures and comparative study on different aerofoil structures have been analyzed by the students and the assignment was submitted in the form of research articles.

4. Results and Discussions

This section deals with indicators that reflect attainment of the course outcomes identified in terms of quantitative and qualitative measures. The qualitative evaluation was judgmental based upon the questionnaire prepared to identify effectiveness of teaching-learning process and executed through Google-forms. The presented quantitative indicators are arrived at using the student collective performance in the In-semester Assessment (ISA) and End semester Assessment (ESA).

The Fig. 1 and Fig. 2 indicated the assessment of teaching learning with reference to the CFD theory course based on the qualitative and quantitative assessments measured based upon the perception of students and their performance assessment based on ISA and ESA respectively. The qualitative attainment of PO2(a), PO2(b) and PO4 as revealed by Fig 1 indicated that more than 75% of the student respondents strongly agree or agree with realization of attributes while 15% of the respondents strongly disagree with the realization of PO2(a). The Fig 2 indicated the performance of students in the theory course that contradicted the assessment made by the qualitative assessment. The students performing top grades was limited to 5 as compared to the rest of 11 students who scored a lower grade that possibly could be attributed to poor interpretations of theoretical concepts by students with alien nature to fluid flow concepts and mathematical concepts. This strongly indicated the importance of laboratory exposure to understand the concepts of any field of science or engineering.

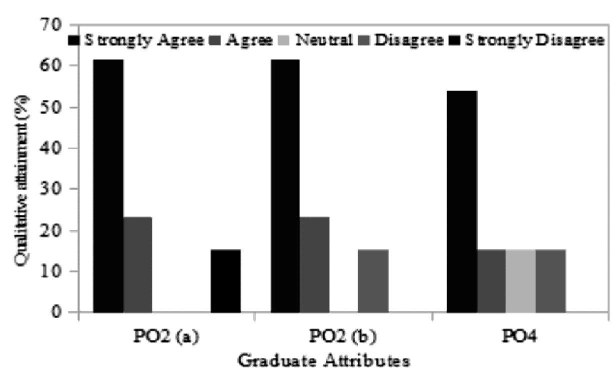

Fig.1. Attainment of Graduate Attributes through CFD Theory course

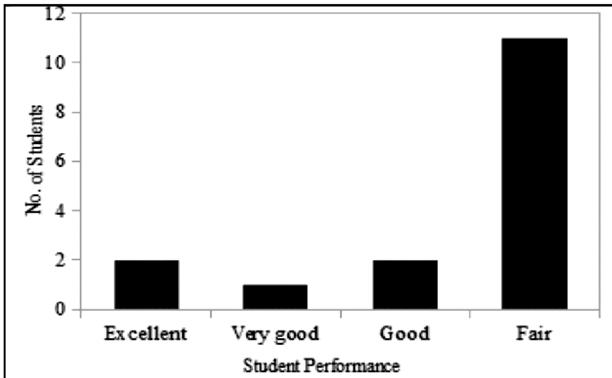

Fig. 2. CFD Theory course student performance

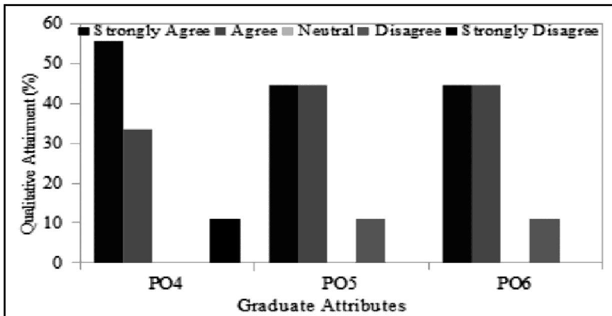

Fig 3: Qualitative assessment of CFD Lab course

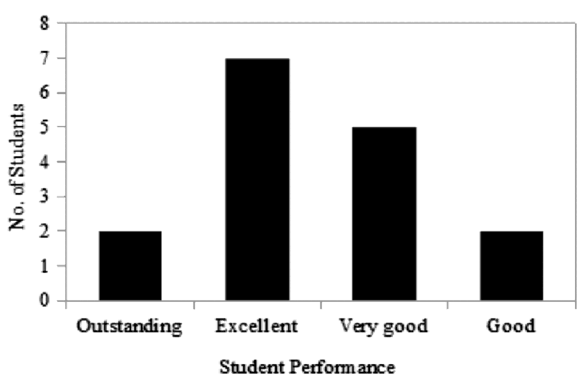

Fig. 4: CFD Laboratory course student performance

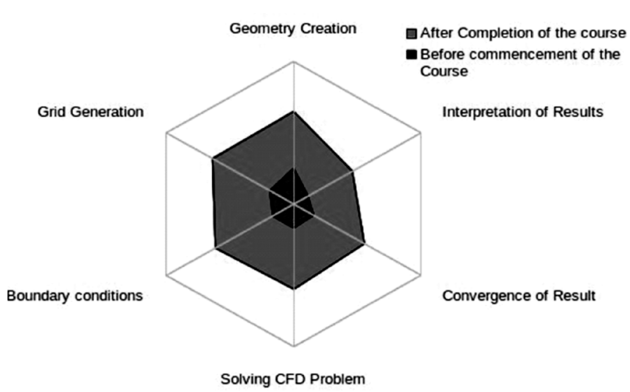

Fig. 5: Value addition through the CFD Laboratory course

The representation made by Fig. 3, Fig. 4 and Fig. 5 indicate qualitative, quantitative assessment and value addition with respect to the student performance in CFD Lab course respectively. The PO4, P05 and PO6 were targeted through the lab course that indicated a very good attainment with respect to all the attributes except for 10% indicating a strong disagreement with respect to PO4 attribute. The Fig. 5 termed as value addition through CFD laboratory course that indicates the changes observed in 6 important skill-sets with reference to CFD tool. The results indicated that the CFD Lab course has made a overall positive impact in the field of all 6 skill sets referred in study except for the 'Interpretation of Results' should a relatively lower attainment as compared to other five skill sets. This could be attributed to the experience in usage of CFD tool that was essential for better interpretation of CFD results. In convergence with the results of Fig. 3 and Fig. 4 the student performance of students in Lab course has been reported to be excellent unlike the observation in their performance in theory course.

Thus based on the current study it can be concluded that a combination of theory and lab can create value to the course rather than teaching the course only as a theory course or a lab course. This observation is support Keller plan as reported in literature that practical concepts make the understanding of concepts better compared to study restricted only to theory.

5. Conclusions

The conclusions drawn through the qualitative and quantitative analysis of the present study include,

- The Problem based learning or Project based learning gives ample scope for developing a free though on the concept that possibly is difficult through the conventional approach of deliver of concepts. This clearly lays emphasis on the thought that Experiential learning is the only way of learning and rest other methods are only restricted to information

- The performance of students in CFD theory course was with an average mark of 61.4 with standard deviation of 9.75 and coefficient of variance 0.16. The students appreciate concepts better if they are introduced in terms of practical concepts rather than abstract mathematical concepts.

- The performance of students in CFD Laboratory course was with an average mark of 82.06 with standard deviation of 7.09 and coefficient of variance 0.09. The results indicated practical concepts are better learnt as compared to theoretical concepts.

- The combination of theory and practical sessions give an integrated approach to learning concepts better and thereby improved the learning levels of the concept involved.

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