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Hands-On CFD Educational Interface for Engineering Courses and Laboratories

Background:

It is important to integrate computer-assisted learning and simulation technology into undergraduate courses and laboratories as simulation based design, and ultimately virtual reality, become increasingly important in engineering and scientific practice. Most curriculum development and research have addressed computer-assisted learning and systems-based simulation technology. Curricula must be developed for physics-based simulation technology, such as computational fluid dynamics (CFD), but diverse learning objectives and limited research are complicating factors for successfully incorporating CFD into the curriculum. Over the past 35 years, graduate student level CFD courses have become well developed and common in most graduate programs. More recently, educators have additionally focused on teaching CFD at the undergraduate level. Integrating specialty or commercial CFD software for the non-expert user into lecture and/or laboratory courses can facilitate comparisons with experiments and analytical methods. The objective is to enhance the curriculum through the use of interactive CFD exercises, multi-media, and studio models for teaching fluid mechanics, including heat transfer and aerodynamics. However, there remain many unresolved issues: (1) When is the hands-on and discovery-oriented approach to be preferred over demonstration? (2) When does CFD detract from, rather than aid, the development of deeper knowledge of fundamental fluid mechanics concepts? (3) How can student perception of CFD as a black box be avoided, and understanding of detailed CFD methodology and procedures be promoted? (4) Should specialized educational software replace the use of commercial software? (5) How can the steep learning curve required for practical engineering applications be mitigated? (6) What are the best approaches for introductory vs. intermediate undergraduate and intermediate vs. advanced graduate level courses? (7) When is lecture and laboratory course teaching more appropriate than the studio and multi-media models? (8) What is the best curriculum content for teaching code developers vs. expert users?

Research Questions:

The most effective curricula to achieve optimal CFD education remain unspecified. This study focused on the following research questions: (1) What will be the best way to develop, implement, and evaluate of an effective curriculum for students to learn CFD in introductory and intermediate undergraduate and introductory graduate level courses/laboratories? (2) How should the curriculum be designed for use at different universities with different courses/laboratories, learning objectives, applications, conditions, and exercise notes? (3) What is the best approach to teach students CFD from novice to expert users who are well prepared for engineering practice? (4) How can the steep learning curve and students' treating the software as a black box be avoided while allowing students' early hands-on experience? This study aims to address all the research questions and some of the unresolved issues.

Method:

The CFD Educational Interface (CFDEI) is designed to teach students systematic CFD methodology and procedures through hands-on, user-friendly, interactive implementation of practical engineering applications, while not requiring computer programming. The CFD process is automated, following a step-by-step approach which leads students seamlessly through setup and solution of the initial boundary value problem appropriate for the application at hand. A hierarchical system of predefined active options facilitate the use of exercises at both introductory and intermediate levels, and encourage students' self-learning. Enough information is provided to ease the student transition from this intermediate level to using the full industrial CFD code directly. Generalization of internal and external flow templates to inter and multi disciplinary applications facilitates their use at different universities having different objectives, applications, conditions, and exercise notes. The hands-on CFDEI has the following features: (1) user-friendly and interactive interface; (2) exact fit to the "CFD Process"; (3) no requirement for advanced computer language skills; (4) stand-alone application; (5) compatible with Microsoft operating systems; (6) different depths of CFD templates; (7) hands-on activities; (8) self-guided studies; (9) powerful and accurate solvers; (10) powerful virtualization tools; (11) CFD uncertainty analysis and (12) a sketch window.

The CFDEI has been implemented at different universities with different courses/laboratories, learning objectives, applications, conditions, and exercise notes for introductory and intermediate undergraduate, and introductory graduate level courses and laboratories over the past three years in conjunction the development of Teaching Modules (TMs: lectures, CFDEI, and exercise notes). Faculty partners are from colleges of engineering at large public, small private, and small historically minority private universities in departments of mechanical and industrial, aerospace, mechanical and aerospace, and mechanical engineering. Faculty partners developed TMs for their respective courses/laboratories using the same CFDEI.

Over the 4-year period of the project ISTUE (Integration of Simulation Technology in Undergraduate Engineering), the third party evaluator, The University of Iowa Center for Evaluation and Assessment (CEA), implemented separate evaluation subprojects for each course at each university. The evaluation design for this project included both formative and summative focuses. The formative evaluation included students anonymous pre- and post-surveys, CFD lab reports, and faculty perceptions. The summative evaluation required an objective measure of student outcomes, which was accomplished by using pre- and post-tests. In order to rule out test version specific learning, students took either an A or B version of the pre-test but took both the A and the B as the post-test. These summative data demonstrated that students engaged in this implementation of CFDEI gained important practical and theoretic knowledge about aspects of fluid dynamics and how they are modeled in the CFD, conceptual and experimental fluid dynamics (EFD) frameworks they are learning.

Findings:

The project has been successful in developing a CFDEI for a wide range of internal and external flow problems. The interface effectively matches students' learning needs. The interface design provides students with hands-on experience, gained through an interactive and user-friendly environment, and encourages students' self-learning. The CFDEI has been proven to be an effective and efficient tool to help students learn CFD methodology and procedures following the CFD process, and as a useful training vehicle to prepare students for using CFD in their future careers. The developed prototype of The CFDEI provides a solid base for developing more effective and more efficient next generation CFD educational software. Both on-site and independent CEA evaluation and assessment showed that significant progress was made in training CFD expert users at the intermediate level fluid mechanics course, and partially successful in training CFD novice users at the introductory level undergraduate fluids mechanics course. The results of the present study enable the authors to address the issues posed before:

(1) Both introductory and intermediate level students like "hands-on" experiences. Especially for students at the intermediate level, a hands-on and self-discovery oriented approach is preferred over demonstration. (2) CFD can detract from the development of a deeper knowledge of fundamental fluid mechanics concepts if the software interface and the accompanying curriculum materials are not carefully designed. It was observed that the confusion of students caused by too many options extraneous to the application can be reduced by the development of appropriate teaching modules, but the authors further propose that a more optimal solution exists through the use of an Educational Interface in conjunction with well thought out supporting materials. (3) Using a generalized CFDEI with complementary TM materials will be necessary for students to avoid the perception of CFD as a black box and promote a detailed understanding of CFD methodology and procedures. (4) The correct selection of an educational CFD software package will depend on students' backgrounds and their CFD knowledge. For introductory and intermediate undergraduate level students, to use a specialized educational software package such as the CFDEI seems to be the optimal choice. (5) The authors attribute the steep learning curve associated with industrial CFD tools to the lack of a structured learning interface. The ideal CFD educational software seems to have a generalized interface and a different level of depth for different levels of users, allows for hands-on access, and possesses all other features that the current CFDEI has. (6) The best approach for introductory level undergraduate students is to focus on overall CFD process and flow visualizations and to use CFD as a tool to help students understand the fundamental fluid mechanics concepts related to fluid physics and classroom lectures with the aid of complementary EFD labs. The best approach for intermediate level undergraduate students is to practice a deeper and broader range of CFD methodology and procedures, including numerical methods, modeling, uncertainty analysis, and to encourage students' self-learning with the aid of exercise notes and a series of CFD lectures. The best approach for an intermediate or advanced graduate level course may be to focus on CFD code development. (7) Lecture and laboratory course teaching is more suitable for introductory level undergraduate students. For intermediate undergraduate/graduate level students, studio and multimedia models seem to be more appropriate since students at this level prefer to work, think, and learn alone with the help from TAs and lab instructions. (8) Traditionally, CFD curriculum has focused

on code development while not training expert users. Students are asked to either partly or completely develop their own CFD research code using the CFD theory they learned. The authors think the current approaches are the best way to train expert CFD users. However, it may be best to use a combination of both approaches to teach CFD, with different weights for different levels of students.

In order to assess faculties' interest in national dissemination of the CFDEI, a workshop was held on July 14, 2005 at Iowa Institute of Hydraulic Research, supported by NSF supplemental funding. Evaluation by CEA indicated that participating faculty found the workshop valuable and verified their interests in implementing and if necessary further developing and/or adapting the CFDEI for their respective courses and laboratories.

Future Work:

There are still many ways to improve the CFDEI and its implementation: (1) improving the CFDEI to be more user-friendly and providing wider accessibility through the internet; (2) developing extensions that facilitate further student self-learning and inter/multi disciplinary use; and (3) implementing these improvements with site testing and evaluation. Ideally, future generations of CFDEI will be closely tied to expert-user industrial software interfaces.

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