Improving Undergraduate Fluid Mechanics across the Curriculum

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Abstract

We initiated an NSF-sponsored workshop of Faculty and a few representatives from industry to investigate methods to increase student expectations and performance in the fundamentals of undergraduate fluid mechanics education. We originally planned to build a pool of fluid mechanics exam problems and a consortium to provide feedback on evaluation of these problems. We examined ways to initiate, maintain, and assess this process consistent with ABET. We report here our deliberations and findings from the workshop and subsequent feedback and effort. The participants, drawn primarily from the active research community in fluid dynamics, evolved a consensus "path forward" in which shared instructional resources were to be the primary outcome of an organized, new collaboration among university and industrial colleagues. The present communication details the issues considered by the participants and it presents the suggestions to enhance instruction in basic fluid mechanics.

I. Introduction

We organized an NSF-sponsored workshop of engineering faculty (and two industrial representatives) to study ways to increase student expectations and performance in the fundamentals of undergraduate fluid mechanics education. To foster and achieve optimal student performance and education, we planned to build a student-faculty teaming environment. One method of achieving this is to have exams arise from an external source (i.e., beyond the university). In this manner, it is envisioned that the course instructor becomes the ally, and not the "task master", of the students.

We initially planned to build a pool of fluid mechanics exam problems and a consortium to provide feedback on evaluation of these problems. The intended result was to be a stronger grasp, by the students, of fundamental content as measured by the ability to rationally attack and solve unfamiliar problems whose basic elements were the object of the instruction. The workshop was to develop and evolve this idea and to help bring it to fruition.

We examined ways to initiate, maintain, and assess this process consistent with ABET. By intent, the process would accommodate all disciplines that teach fluid mechanics and still respect institutional differences. The primary questions and issues addressed were:

1. What are the educational outcomes desired?
2. What is the expected level of student achievement?
3. What curriculum pedagogy should we deliver?
4. How do we measure outcomes?

We report here our deliberations and findings from the workshop and subsequent feedback and effort. The conclusions of the workshop evolved significantly from the standardized exam problem initial objectives and the attendees reached a consensus in some areas, most importantly that more frequent workshops were desirable and that more sharing of teaching resources would be of great benefit.

To review the general topic, we mention the National Science Foundation areas focussed on education and briefly discuss efforts conducted by others attempting curricular improvements. There are two National Science Foundation directorates of interest to engineering education: the Directorate of Education and Human Resources, and the Directorate of Engineering. The former directorate houses the Division of Undergraduate Education (DUE) that is relevant to our program. The latter includes the relevant Engineering Education and Centers Division that is subdivided further into Programs in Education within which is the Engineering Education Coalition (EEC). The Division of Undergraduate Education is separated into seven subsets, of primary interest is the Course, Curriculum, and Laboratory Improvement group. The EEC presently includes eight subgroups: The Academy, ECSEL, Foundation, Gateway, Greenfield Focus:HOPE, SCCEME, SUCCEED, and Synthesis. Each subgroup is comprised of several universities, colleges, and/or community colleges. Their missions vary slightly, but are centered primarily on engineering education and curriculum improvement. In addition, the research program: Fluid Dynamics and Hydraulics was a co-sponsor of the workshop and we are maintaining our contacts with that Program Director.

Although we are aware of no other study that directly parallels our effort, significant energy has been expended recently toward improving undergraduate fluid mechanics. These efforts can be divided roughly into the following three categories: integrating fluid mechanics and thermal sciences into a sequence of undergraduate courses[7, 9, 11, 14, 15]; using computational fluid dynamics (CFD), imaging (real and simulated), and computers to teach fluid mechanics[3, 4, 5, 10, 13, 17, 18]; and providing interactive textbooks for supplemental use[2, 6, 12]. Obviously these investigations are coupled to ours and will be integrated accordingly. Finally, there have been many broader attempts at improving the experience and knowledge acquired by the student during his/her undergraduate experience. Mechanical Engineering curricular changes and implementation has been discussed, for example by Incropera and Fox[8], as have those for Chemical Engineering by Shaeiwitz *et al.*[16] Likewise, complete college of engineering restructuring has been discussed, for example, by Benedict *et al.*[1]

II. The Workshop participants

The 27 workshop participants included 24 faculty from essentially all disciplines that teach fluid mechanics including Mechanical Engineering, Chemical Engineering, Engineering Science, Civil & Environmental Engineering (Coastal Engineering), Aerospace Engineering, Biomedical/ Biomechanical Engineering, and Naval Architecture & Marine Engineering. Universities with faculty in attendance included a geographic distribution of both State and Private Universities, primarily Carnegie Research-I Universities. Twenty-four faculty members, two of whom were also representatives of the National Science Foundation, two industrial representatives (employed in the automotive industry), and one Ph.D. student were in attendance.

III. The initial survey results

To obtain information on some basic questions and issues prior to the workshop, an initial survey was made available to our attendees through our website. Eighteen of the twenty four faculty members that eventually attended the workshop responded. The questionnaire and its salient results are as follows.

Prerequisite knowledge for students enrolled in the first undergraduate fluid dynamics course was the first issue: deemed important were dimensions and units, particle dynamics, rigid-body dynamics, and vectors and velocity fields; deemed unimportant were continuum concept, tensors and stress fields, fluid properties, and flow classification. The second question concerned the knowledge the student should retain from the class, and the most important topics were fluid properties, flow classification, continuum concepts, fluid statics, fluid kinematics, control volume approach (mass, momentum, and energy), differential approach for mass and momentum, dimensional analysis and similitude, inviscid flows, incompressible viscous flow, boundary layers, and viscous flow in ducts. Those topics considered less important included the differential approach for energy, incompressible potential flows, inviscid flows, (Euler's Eq.), exact solutions of Navier-Stokes equations, momentum integral, vorticity equation, turbulent flows, magnetohydrodynamics, open channel and hydraulic flows, chemically reactive flows, non-Newtonian flows, turbomachinery analysis, waves/currents/free surfaces, isentropic/compressible flows, normal and oblique shock waves, unsteady flows, computational methods, non-inertial coordinate systems, multiphase flows, diffusivity and mass transport, and heat conduction and convection. Obviously, these categories are skewed greatly by the preponderance of mechanical engineers responding to the questions. Surprisingly, the breakdown of courses that have concurrent, subsequent, or no laboratory component were about 37%, 44%, and 19% respectively. The average number of students in a course according to the respondents was 37. In addition, the ONLY teaching evaluation method used was student evaluations. Regarding evaluation of course outcomes, 37% used ABET, 31% used their own surveys, and 31% had none. Unanimously, the weakest area was considered mathematics, with physics second. The majority felt that students entering the undergraduate fluids course were educated marginally. Finally, a few respondents did not consider the questions asked appropriate or well posed.

IV. The initial meeting, results, and feedback

After introductory presentations of the goals and objectives and results from the survey (discussed above), working groups of approximately five persons were formed to investigate the following five issues considered by the steering group to be most relevant to the workshop: (1) desired outcomes of a newly minted undergraduate fluid mechanics course and of the workshop; (2) motivation for faculty participation in such a program; (3) course and workshop assessment; (4) use of multimedia in the classroom and beyond; and (5) administration and pedagogy of the course and the consortium. Workshop participants were free to chose their working group.

We report the findings of the subgroups. The first group considered the desired outcomes of a new course, and of the workshop. The new course material included a national pool of high-quality case studies, problems, team and individual competitions, and short visuals and clever physical demonstrations. By developing this new material it was felt that the students would benefit from a wider range of experiences, particularly intelligent students might be attracted to the fluid mechanics discipline, the professors would be stimulated because of the breadth of examples, there could be official recognition for contributors to the material, and it could provide a means for screening students. Regarding the outcomes of the workshop, it was believed that a national survey of fluid mechanics education would be a by-product (i.e. the state of fluid mechanics), and that a future workshop with a wider range of participants from industry and academia would be beneficial.

The second subgroup discussed the various motivating factors to encourage faculty participation in the end product of the workshop. The list of primary motivating elements included: a ready data bank of real problems; a flexible structure that is voluntary and allows faculty members to retain autonomy; synergy between research and teaching of undergraduate fluid mechanics; industry members would provide timely real-world problems as well as seminars emphasizing the importance of fluid mechanics (serves the students also); industry would be provided an additional measure of student merit for enrollment in a consortium course; foster inter-university/ departmental interaction; provide benchmark for the instructor; and an aid in motivating students to pursue graduate study.

Assessment was the topic of discussion of the third subgroup. Initially, the subgroup concentrated on student (rather than workshop, programmatic, or teaching) assessment. It arrived at the following five areas: intuition or insight; speed and efficiency of completing straightforward problems; application of fundamental mathematics to setup problems; quantitative result; and understanding whether an answer was reasonable and sensible. Obviously, these areas can be used in problem construction. The assessment could use fundamental problems for homework and exams, short open-ended design problems for homework, long open-ended problems through projects (preferably suggested by industrial partners), classroom group problems, laboratories, design competitions, and web-based self-assessment. There was general agreement that the emphasis should be on the physics (general understanding) rather than the mathematics (problem-solving methodology). The subgroup agreed that assessment of open-ended problems remained a challenge. Discussion of a comparison of today's students with those of a generation ago led to no obvious solutions or insights.

The multimedia group considered the use of computer-based multimedia material as a way to enhance fluid mechanics education. The use of short movie clips of experimental flow visualizations and the flow visualization of both simple and complex numerical solutions were discussed. Similar work by Homsy, et al. Multimedia Fluid Mechanics was viewed as a good starting point. However, much more could be done by basing this material on a central web site so that it could be viewed easily, used, and appended by faculty and students. In addition, different kinds of virtual fluid mechanics laboratories could be constructed on this web site where a student could interact with a fluid flow and ask what-if questions to facilitate learning. Local web-based course supplementation (i.e. notes, problems, solutions, and previous exam problems) could also be added to the site and shared with other faculty. It would energize and encourage university-level students to learn fluid mechanics, and it would help students in distance-learning programs. Finally, having such a web-based facility could encourage high school students to pursue an engineering and fluid mechanics career.

Lastly, the group discussing administration and pedagogy focused primarily on pedagogy. It was concluded that by increasing the rigor of the problems both in classroom teaching and for exams and homeworks, and posing more difficult questions following more straightforward ones would lead the highly-motivated student toward greater accomplishments. Lecture, homework, and exams require additional focus on fundamental ideas and notions. Iteration and feedback throughout the lecture, homework, and exam process are necessary and beneficial. In addition, it was decided that classroom demonstrations and experiments that exhibit physically the salient points of a lecture discussion would be a tremendous asset, as would industrial examples to which the students could relate. None of these ideas are revolutionary; however, the facilitation of these goals in today's world of essentially barrierless communications would benefit greatly by having a website established expressly for this purpose. Two administrative details that were discussed were security issues and consistent grading within the consortium.

The afternoon session evolved from the originally planned two sessions to one session during which four groups discussed example problems indicative of the level of competence expected of students at the conclusion of a basic fluid mechanics course. The attendees discussed problems in the following areas: control-volume analysis; dimensional analysis; inviscid flows and kinematics; and fully-developed viscous flows and piping. There appeared to be general agreement regarding the level and types of rigorous problems that attendees felt their students should be capable of solving.

Feedback forms were distributed at the workshop's conclusion, and are discussed next. Overall, the feedback received from the attendees was strikingly similar, and appropriate. Generally, persons felt that a pool of exam and homework problems and calibrated/standard exams were not as important as a high-quality website where a faculty member (and to a more-limited extent students) could find physical demonstrations, good homework and example problems, virtual demonstrations and flow visualizations, and other teaching tools that would serve to improve fluid mechanics instruction and learning. Everyone felt that the dialog regarding education was a much-needed starting point. There was general agreement that a larger cross-section of departments that teach fluid mechanics should be included in discussions (we already knew this to be the case, but intentionally started with a more limited participation for the initial workshop). More importantly, there was consensus that additional industry representatives are crucial to the success of this program (also known at the outset). There was overwhelming support for establishing, nurturing, and developing a website with oversight. It was decided that formal committees equivalent to those for journals would be necessary to qualify problems, experiments, etc. through a review process prior to placement on the site, and that an effort to work toward eventual acceptance of these publication contributions by college administrators was necessary. Several concerns were voiced by attendees, especially regarding the possible misuse of exam scores in the event of pools of exam questions (e.g. direct comparison between intra/inter-departmental instructors and inter-university instructors) and the administration nightmare and implementation costs that these efforts would entail.

V. Impromptu second meeting

An impromptu second meeting was held during the 52nd annual meeting of the Division of Fluid Dynamics of the American Physical Society. Attended by 20 persons with a 16-person overlap from the Workshop, the ideas that were an outgrowth of the workshop were discussed and decisions made regarding the future of the initiative. There was considerable discussion of a new website authored by A.J. Smits and R.J. Adrian entitled *eFluids.com* and how an NSF-sponsored consortium could contribute to a commercial web venture. The considerable effort required to maintain and provide quality assurance of incoming contributions may require collaboration with a company (such as a publishing company for text books).

VI. Concluding remarks

The workshop was an educational experience for all participants because, although we were well aware of each other's research approaches, we had never systematically discussed teaching approaches. Hence, the workshop was provocative and provided new insight.

There was considerable discussion about the participants' desire to attract more students into the general area of fluid mechanics. The field suffers from an "old-fashioned" image that relies heavily on difficult mathematics and concepts. We need to develop new approaches that show students the relevance and importance of fluid mechanics not only in the traditional areas of transportation, environment, and processing, but also in the "high-tech" areas of electronics, nano- and bio-technology. To accomplish this, we need to make fluid mechanics "more fun." We trust that the initiatives brought forth in this workshop will accomplish this.

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