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Integration of Design in the First Course in Fluid Mechanics: Experience and Evaluation.

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Abstract

For more than ten years, design has been integrated into the first course in fluid mechanics in our department. This concept is a part of an educational philosophy that distributes design experience across the curriculum before it culminates into two capstone-design courses in the senior year. This paper discusses the main reason that led to the introduction of design in this course, the process that was followed to achieve integration of design, examples of projects that were carried out by students, the benefits and disadvantages that have been identified, and the author’s assessment of the whole experience.

1. Reason for adding design into the course: Need for reform

Design was added to the first course in fluid mechanics to respond to the criticisms of engineering education that were prevalent in the literature at the end of the 1980's and the beginning of the 1990's. People who wanted reform criticized engineering education. They charged that graduates of American Engineering schools were deficient in at least four major ways: in oral and written communication; in experience and practice with working in groups; in technical literacy related to practical matters; and in design experience. A particularly vexing concern was that engineering education at the undergraduate level put too much emphasis on analysis and that this emphasis has been achieved at the expense of experience in design [2,3,5,6,13,16,20]. As a consequence, they concluded, many graduates of American engineering schools entered the work force without the skills that were necessary for them to function as practicing engineers.

There is considerable documentation of these criticisms and the ensuing debate in the literature on engineering education. Three examples will illustrate this point: Palmer, Marra, Wise, and Litzinger[19] identified several national reports that have suggested that the current preparation of engineering students fell short of the skills and competencies that would be required of practicing engineers and called for reform in engineering education. Kolar, Muraleetharan, Mooney,Vieux, and Gruenwald[14] state that "Evaluations of existing undergraduate engineering programs continually cite many weaknesses: lack of technical literacy; lack of oral and written communication skills; and lack design experience and limited experience with working in groups." Finally, Moser, Bluhm, Garrett, and Goodman[18] put it this way: "We have a problem in engineering education. Our pragmatic engineering students want to know why before they are motivated to learn. But engineering curricula typically wait until senior design and capstone courses to show them. By not tapping into the students' motivational core at the beginning of their university education, we have missed one of our best educational opportunities. This separation of theory from practice carries through into industry affecting innovation and quality-engineered systems."

2. Samples of institutional responses

In response to these criticisms, and to make engineering curricula increasingly relevant to the lives of students and the needs of society, engineering faculty across the country started to reconfigure their curricula from the Freshman to the Senior levels. Many of these efforts have been published throughout the 1990's. We briefly sketch six examples below.

At Penn State University, University Park. Penn State University, University Park, launched a mechanics-reform project: Interactive Mechanics/Dynamics, for the enhancement of undergraduate engineering courses via the use of interactive learning and computers in the classroom[4]. This project involved the introduction of teamwork, projects, simulation, visualization, and experiment in a course that traditionally containing none of these.

At Kansas State University, Manhattan. Moser, Bluhm, Garrett, and Goodman[18] reported the development, implementation, and testing of the prototype of a program that integrated applications in the curriculum of their architectural engineering program.

At MIT and Loyola Marymount Univ, Los Angeles. In order to meet the needs of industry and to address reform in engineering education, courses on product design and development were introduced in the curriculum at MIT and at Loyola Marymount University, Los Angeles.[17]

At the University of Colorado, Boulder. The College of Engineering and Applied Science at the University of Colorado at Boulder initiated a college-wide reform that was designed to model the real-world of engineering. It expanded teaching methods to integrate team work, active and group learning, project-based design, and problem-solving experiences[1].

At the University of Oklahoma, Norman. The School of Civil Engineering and Environmental Science (CEES) at the University of Oklahoma, Norman, OK, initiated a systemic reform that incorporated four themes throughout the curriculum. 1) A common design project, entitled 'Sooner City,' that is introduced during the freshman year and continues for the entire curriculum; 2) the design project was to be taught using the just-in-time learning paradigm; 3) courses were restructured to incorporate team learning and group presentations; and 4) each classroom became a networked computer lab and all incoming engineering freshman were required to have a laptop computer to enable them to use the classrooms.[14]

At Indiana University -Purdue University Fort Wayne (IPFW), Indiana, the author's institution. We distributed design content throughout the curriculum in such a way that the semester-credit hours required for it amounted to about 15% of the whole. The distributed design experience culminated in a two-semester senior course, which is the capstone design project. The remainder of this paper details how design content was added to the first course in fluid mechanics.

3. The Process of Adding Design into the Course

Description of the course. The first course in fluid mechanics is required of all Mechanical Engineering students. It consists of a lecture and a laboratory. The lecture part is worth three semester-credit hours and the lab component, one semester-credit hour. The lab session meets for three consecutive hours, once a week. The program introduced design into the course by assigning open-ended problems at the beginning of the semester. Students were required to choose a result or concept of fluid mechanics that was learned during the semester and design a device that either works according to, incorporates, or demonstrates that result. Students also had the option of designing an experiment that would illustrate or demonstrate a concept, or a result, that is integral or directly related to the course. A third option was for students to redesign an existing experiment for the purpose of improving it. In the latter case, they needed to identify the existing flaws that needed to be fixed, discuss how they were planning to fix them and actually carry out their plan. All projects required a preliminary report that discussed the choice that had been made, the preliminary work that led them to believe that their project was feasible and a detailed plan of future work including timelines and cost estimates. Preliminary reports were due about two-thirds of the way into the semester, while the final reports were due at the end of the semester. Final reports of projects included oral presentations given in class, written reports that were submitted for grading, and a demonstration of designs in class.

The existing course was originally designed in the Purdue-University system to follow the organization and format of the textbook entitled *Introduction to Fluid Mechanics***,** written by

Purdue Professors Robert W. Fox and Alan T. McDonald[23]. It was divided into twelve units as shown on Table A. However, the addition of a design component to the course, as described above, necessitated the omission of items that were part of the content of the course up to that point in order to make room for design in the course and still keep the work load challenging, yet reasonable. The decision regarding which materials to omit and which to keep was a difficult one, indeed. In the end, it was based upon two considerations: 1) whether or not the material to be omitted could be covered by another course
(required or elective) that already existed in the curriculum; and 2) material that was absolutely essential for the courses for which fluid mechanics was a prerequisite had to be kept. Accordingly, three chapters were omitted: open-channel flows and compressible flows in the earlier editions of the book and fluid machinery and compressible flows in later editions. These chapters and the corresponding topics are identified as such in Table A.

Table A. Outline of Topics Covered.

Chapter	**Topic**	**Number of sections**	**Sections kept/omitted**
1	Introduction	**7**	All sections kept
2	Fundamental Concepts	**7**	All sections kept
3	Fluid Statics	**8**	All sections kept
4	Integral Formulation	**10**	All sections kept
5	Differential Analysis	**5**	All sections kept
6	Flow of an Incompressible and Inviscid Fluid	**7**	All sections kept
7	Dimensional Analysis and Similitude	**7**	All sections kept
8	Internal flow of an Incompressible, Viscous Fluid	**13**	All sections kept
9	External flow of an Incompressible, Viscous Fluid	**9**	All sections kept
10	Fluid Machinery (new)	**6**	Chapter omitted and moved to another course
10	Open-Channel Flow (earlier editions)	**9**	Chapter omitted and moved to another course
11	Introduction to Compressible Flow	**5**	Chapter omitted and moved to another course

12	Steady One-Dimensional Compressible Flow	**8**	Chapter omitted and moved to another course

It can be seen in Table A that three out of twelve chapters were omitted from a four-credit course. This made the design experience worth one-semester credit. Devoting one credit hour to design was meant to underscore its importance in engineering education as well as the substance and effort that were expected to be put into carrying out design assignments.

4. Classification of projects undertaken by students

Typically, the course enrolled between eight and twenty-four students per session. However, the average enrollment was about twelve students per session, per semester. The number of projects carried out and completed is 178 over twelve years. Table B shows the distribution of projects by course topics. It also shows whether the project was intended to design a device/product that works according to a concept learned in or related to the course, a demonstration, or a lab experiment to be used in the course at a future date.

Table B. Distribution of Topics Chosen by Students

Topics	Number of projects	Devices or products	Demo.'s	Experiments
Fluid properties: viscosity, density, surface tension	**5**		**1**	**4**
Flow visualization	**4**		**4**	**4**
Hydrostatics: Pressure and forces on surfaces	**15**			**15**
Hydrostatics: Buoyancy	**23**	**23**		
Linear momentum	**15**		**15**	**15**
Angular momentum	**2**			**2**
Energy conservation: Bernoulli's equation	**25**	**5**	**4**	**16**
Energy losses	**8**			**8**

Internal flow: flow rate	**6**			**6**
Internal flow: boundary layers	**3**			**3**
External flow: drag	**17**		**7**	**10**
External flow: wake studies	**2**			**2**
External flow: boundary layers	**3**			**3**
Vorticity	**11**	**10**	**1**	
Open-channel flows	**3**		**3**	
Hydraulic jumps	**3**	**3**	**3**	**3**
Fluid-structure interaction	**4**	**4**	**4**	**4**
Miscellaneous & multi-topics	**29**	**21**	**25**	**4**
Total	**178**	**66***	**67***	**91***
*** indicates possible multiple use: as device, demo, and/or experiment.**				

Based upon the oral and written reports as well as on the demonstrations of projects to the class, it was determined that approximately 64% of the projects met either most, or all, design objectives set by the designers at the beginning of the process; about 12 % failed to meet any major objectives, while 26 % met some but not most design objectives. Table C exhibits specific examples of projects that were carried out by students. They were selected from among those that were successful. The last column of that table summarizes the assessment of the projects by the instructor.

Table C: Examples of Projects Undertaken by Students

Project Title	Basic concepts that were involved in the project	Was a model built ?	Was a model tested ?	Reports (oral and written?)	Assessed completed project as
Hot-air balloon	buoyancy, ideal gas law	yes	yes	yes	Excellent
Hygrometer	buoyancy, and stability	yes	yes	yes	Excellent
Design and use of weirs	Measuring flow rates	yes	yes	yes	Good

Airflow in a mobile home	Measurement of pressure distribution	yes	yes	yes	Excellent
Reamers in fracture surgery	Fluid-structure interaction	yes	yes	yes	Very Good
Roughened circular cylinder	Effects of roughness on the pressure in wakes	yes	yes	yes	Very good
Vortex tube	Energy equation	yes	yes	yes	Good to Excel.
Exit losses from an orifice	Measurement of Minor losses	yes	yes	yes	Excellent
Effects of dimples on the drag on a golf ball	Drag forces on a rough sphere	yes	yes	yes	Excellent
Boundary layer in a test section	Determination of Velocity profiles	no	yes	yes	Good
Flow deflector on a wooden truck	Relate shape, flow, pressure, and drag; delay of separation	yes	yes	yes	Good
Circular hydraulic jump	Momentum and energy	yes	yes	yes	Excellent
Flow visualization	Surface tension in 2-D flow	yes	yes	yes	Very Good
Transducers for hydrostatics	Pressure measurements	yes	yes	yes	Excellent

5. Reactions of professor and students to the introduction of design.

My teaching style prior to the integration of design was based strongly on lecturing and it followed a simple, cyclic format, which consisted of 4 steps: 1) at the beginning of class, I would entertain questions on previous lectures, reading assignments, and assigned practice problems; 2) then I would lecture on the topics of the day; 3) after the lecture, I would work out illustrative examples on the board, giving students opportunities to ask those questions that did not come up spontaneously during the lecture; and 4) finally, I would assign a set of practice problems to be done outside of class as well as a new reading assignment covering material to be presented next time. At the beginning of the new session, I would repeat this cycle with new concepts and topics. After so many topics, I would administer an exam. Then, I would proceed to a new group of units to be taught and learned.

This pattern of teaching came under attack in the eighties for two reasons: It devotes too much class time to lecturing. Critics say that lecturing is not good for learning[15]. They argue that the professor should not be "a sage on the stage"delivering wisdom through a lecture. Instead, the professor should be "a guide on the side" that sets a framework, an environment, and guidance that allows the students to become excited about learning the subject matter of the course, becoming engaged learners, and exploring new ideas[11]. They argue that students should move from a teaching-centered mode to a learning-centered mode. In the former, students are passive, while in the latter, they are active participants. The second objection is that the teaching style I was using is entirely devoted to teaching analysis(engineering science) to students and leaves no room for students to learn engineering design. Indeed, critics argue that it relegates design to its own specialty course, somewhere during the senior year. Although, I was reluctant to introduce design into fluid mechanics, it has been my experience that it has generated more participation, more interest, and more engagement from my students than I had observed before. It has also generated some confusion, even frustration, in some students, and certainly, more "headaches" and more " work and interaction with students outside of class" for the instructor. The benefits and disadvanges that we identified are presented below.

6. Benefits of integrating design

Twelve main benefits have been reported by students and observed by the professor over the years:
1)Students became acquainted with important steps in the design process. Over many years, seniors and alumni reported that what they learned in this course proved valuable for their capstone design.
2)They report more depth of knowledge in the area chosen for design.
3)Their experience with doing work in teams was enhanced.
4)Technical writing skills and oral presentation skills were promoted, supported, and developed.
5)Skills and comfort in the use software for preparing technical reports and oral presentations were strengthened.
6)Peer teaching was encouraged and it did take place within teams demonstrably.
7)Students with special interests and abilities in design discovered this aspect of

themselves. Also, those who were weak in analysis but strong in design now had an opportunity to shine.
8)Students who did not like design discovered this tendency in themselves as well.
9)Students had the opportunity to work with engineers in local industry in many cases.
10)Students learned to focus on the essentials of a design problem.
11)The professor learned the struggle of how to assist dysfunctional teams become functional.
12) More interaction among students and between the professor and the students.

7. Disadvantages of integrating design

Six main issues that can be considered disadvantages have been identified over the years:
1) Reduction in the extent of topics covered. Three chapters were dropped as shown in Table A.
2) Topic choice was uneven. Design topics chosen by students tended to involve topics that were covered in the first two-thirds of the course and fewer design projects came from the last third.
3) Confusion was observed about what design is, how to go about doing it and dealing with open-ended problems.
4) Funding of the projects was problematic. Generally, students had to fund their own projects.
5) Needs to use lab space by students at times when they wanted to work on their projects increased and meeting these needs while keeping technicians happy became a challenge. Technicians viewed this increase as an arbitrary encumbrance.
6) Determining the scope of projects was often a difficult issue for students. Some projects were quite simple. In some cases, students simply chose an example, or an exercise, already worked out in class, in the textbook, or in some reference book, and built something around it. Other projects proved to be too ambitious to be completed in one semester.

8. Conclusion

Overall, integrating design into the fluid mechanics course has proved successful. It has increased the level of interest, participation, and learning, and in some cases, excitement, by students. For this reason, it has been continued and it is now a permanent part of the course. It has also been introduced into other courses taught by the instructor. The Curriculum Committee of the Department has recently recommended the inclusion of design of experirments into all lab courses. However, it must be noted that adding design into a course involves more time and commitment in working directly with students and solving many related problems that arise in the course of their work. Finally, it has been reported to the author by a generous reviewer of this manuscript that "One key problem institutions who adopt novel first-year experiences find is building on them in subsequent courses." The reviewer indicated that, perhaps, this paper suggests a way that can be used at other institutions to build upon, and sustain, design experiences that were introduced in the first year.

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