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Work-In-Progress: Fluid Mechanics - One Size Fits All?

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Abstract

Institutions of higher education are under increasing pressure to balance delicate budgets. Meanwhile, engineering programs, relatively speaking, are more expensive to deliver than most other undergraduate programs. One approach to address financial constraints while maintaining quality is to employ a model of interdisciplinary core classes. Rather than have every engineering discipline offer its own class, institutions can encourage combined classes. These opportunities exist for courses like thermodynamics, fluid mechanics and heat transfer for disciplines like chemical engineering, civil engineering and mechanical engineering. The case study presented for this paper is a fluid mechanics course offered in Fall 2024 that is taught by a chemical engineer for mechanical and civil engineering students. The instructor originally delivered the course to chemical engineering students and modified it to include content like Pascal's Law of Pressure transmission, a topic that is more relevant to disciplines like mechanical engineering. This paper will share changes the instructor made to the course and describe plans for future work.

Background

The Higher Education Landscape

According to one source [1], institutions of higher education were rightsizing based on a forecasted enrollment cliff as well as state and federal underfunding and then the COVID-19 pandemic hit. Some institutions used Higher Education Emergency Relief Funding (HEERF) to address financial shortfalls, but when those funds dried up, deeper cuts followed [1]. In addition to the overall need to cut expenses, some programs are more expensive to deliver. Many institutions charge differential tuition by major to help cover the cost of the more expensive majors. The list often includes majors like engineering, business and nursing. One source offered the following explanation: "Engineering classes require specialized equipment, for instance. Business and computer science faculty expect salaries comparable to the private sector. Small classes are a must in nursing programs. And coordinating internships and clinical experiences takes a lot of university resources." [2]

When class sizes are small, the cost per credit hour can increase because the instructor salary is often a fixed cost. In engineering, courses like circuits for non-engineers are often offered to several majors as a single course. This scaling offers financial benefits to the institution. This paper explores a related, but different, concept of shared ***core*** required courses.

Fluid Mechanics: The Higher Education Landscape

The focus of this paper is fluid mechanics. Rosentrater and Balamuralikrishna [3] provide a comprehensive overview of the history of Fluid Mechanics. Courses like fluid mechanics, heat transfer and thermodynamics are often common courses across multiple disciplines. Fluid mechanics is defined as "a subject within mechanics that equips a person to solve engineering problems when the situation involves a flowing or stationary gas or liquid." [4] Mechanics is defined as "the study of forces and motions." [5] Common disciplines that include fluid mechanics are mechanical engineering, chemical engineering and civil engineering. While the principles are the same, key applications often differ. Engineering educators have shared innovations in fluid mechanics instruction. Examples are provided below and presented based on whether the course is discipline-specific or a shared course.

Discipline-Specific Courses

Faculty at University of Wisconsin Madison [6] describe an innovation in a civil engineering fluid mechanics course created because hydraulics was needed in the curriculum and wasn't taught in solid mechanics. The paper acknowledges that fluid mechanics is taught in mechanical engineering and chemical engineering, but the referenced course is specific to civil engineering. Colorado School of Mines described flipping a fluid mechanics class [7]. Cornell University shared strategies for online learning in Fluid Mechanics for a mechanical engineering course. [8] Bradley University detailed standard based grading in a mechanical engineering fluid mechanics course. [9]

Combined or Collaborative Courses

California State University, Long Beach described a curricular innovation and suggests that, at the time the paper was written, the institution offered a combined Fluid Mechanics course with mechanical, civil and chemical engineering. [10] Around 2001, the National Science Foundation sponsored a workshop to improve fluid mechanics instruction. Twenty-four faculty from "essentially all disciplines that teach fluid mechanics" participated. They included "mechanical engineering, chemical engineering, engineering science, civil & environmental engineering (coastal engineering), aerospace engineering, biomedical/biomechanical engineering, and naval architecture & marine engineering." The joint convening underscores the similarities in fluid mechanics instruction, independent of the engineering discipline. [11] The United States Military Academy described efforts to combine Fluid Mechanics and Thermodynamics into a single course. The paper suggests that the original fluid mechanics course was combined across engineering disciplines including civil, mechanical and chemical engineering. [12]

General Engineering

Harvey Mudd offers a single engineering major and offers a common STEM core for all majors. There is a four-credit hour course, Introduction to Engineering Systems, with the following course catalog description, "An introduction to the concepts of modern engineering, emphasizing modeling, analysis, synthesis, and design. Applications to chemical, mechanical, and electrical systems." [13] Harvey Mudd College is accredited by ABET under Engineering, General Engineering, Engineering Physics and Engineering Science and similarly named engineering programs. While the program is renowned, the structure may not be directly applicable to many programs because the accreditation is under general engineering.[14]

At large institutions with enrollments that support multiple courses, it is prudent to divide along disciplinary lines. However, the argument for disciplinary courses is not as strong at small institutions with enrollment sizes of 20 students or fewer in disciplinary courses.

Case Study: Fluid Mechanics (MAE 331) – Fall 2024

Historical Background

Mechanical and civil engineering students at West Virginia University Institute of Technology take Fluid Mechanics (MAE 331). Chemical engineering students take a separate course, Transport Operations (CHE 316), that is four credit hours and includes Heat Transfer. The course has traditionally been offered in the fall of junior year. It is posited that the combination of Fluids and Heat Transfer and the fall offering for chemical engineering majors are the primary reasons for separate courses. Mechanical, civil and chemical engineering programs at West Virginia University Institute of Technology have been ABET-accredited since 1968, 1968 and 1972, respectively. [14] Overall, classes sizes in engineering are small and typically don't exceed 20 students. Figure 1 shows combined enrollment data for MAE 331 and CHE 316 for the last 10 years. The chemical engineering class is only offered in the fall semester. The average combined class size is 20 students.

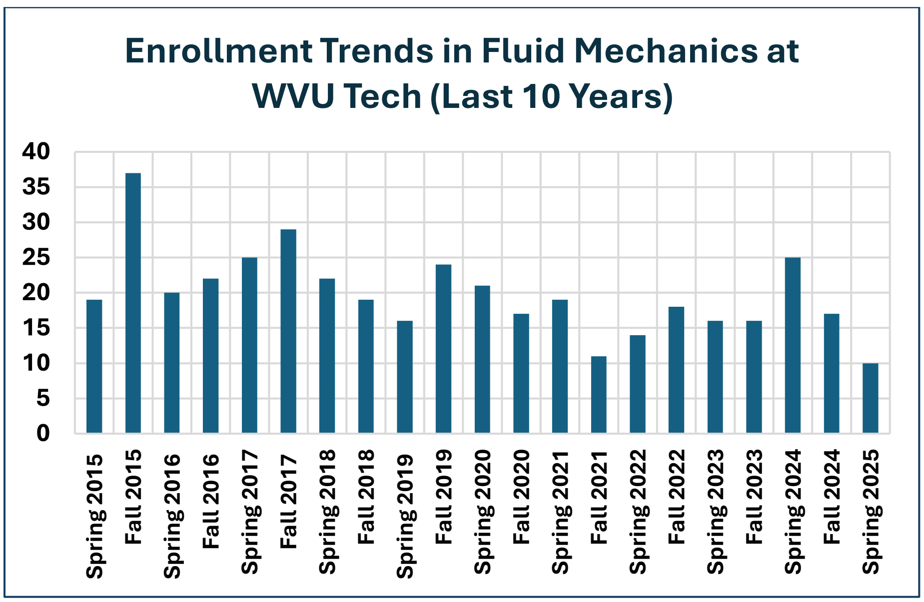


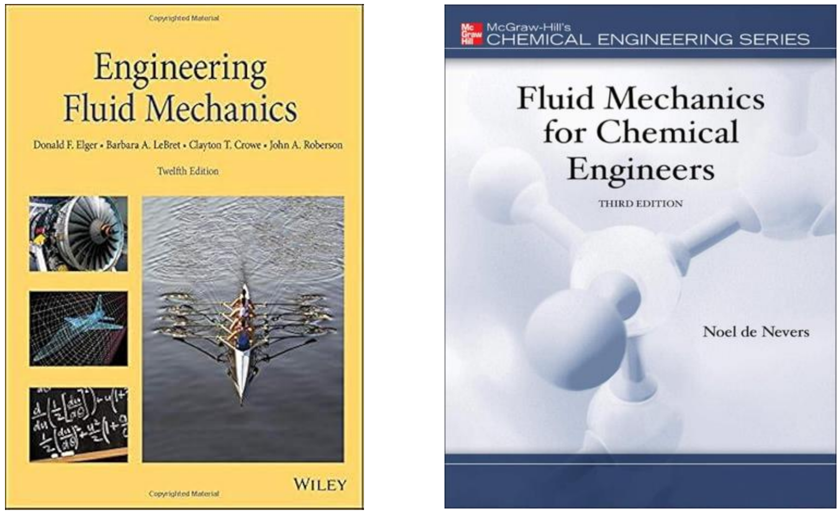
Figure 1: Enrollment Trends in Fluid Mechanics at West Virginia University Institute of Technology (WVU Tech)

Instructor

The instructor for Fall 2024 taught Fluid Mechanics for approximately 10 years to chemical engineering students. The instructor earned a B.S., M.S. and Ph.D. in chemical engineering and is a licensed professional engineer. The instructor volunteered to teach the mechanical/civil engineering section to begin to explore offering a combined course with all three disciplines.

Textbooks

Figure 2 shows the covers of the textbooks used for the two disciplines. The content is very similar, but the organizations of the books are different. Table 1 compares the chapter titles for the two textbooks. Most topics are covered in both books, but the difference is how the courses were structured for the different disciplines.



(a) (b)

Figure 2: (a) Engineering Fluid Mechanics 12th Edition adopted for the mechanical and civil engineering course (b) Fluid Mechanics for Chemical Engineers adopted for the chemical engineering course (Source: www.amazon.com)

Notable Chemical to Mechanical Course Additions

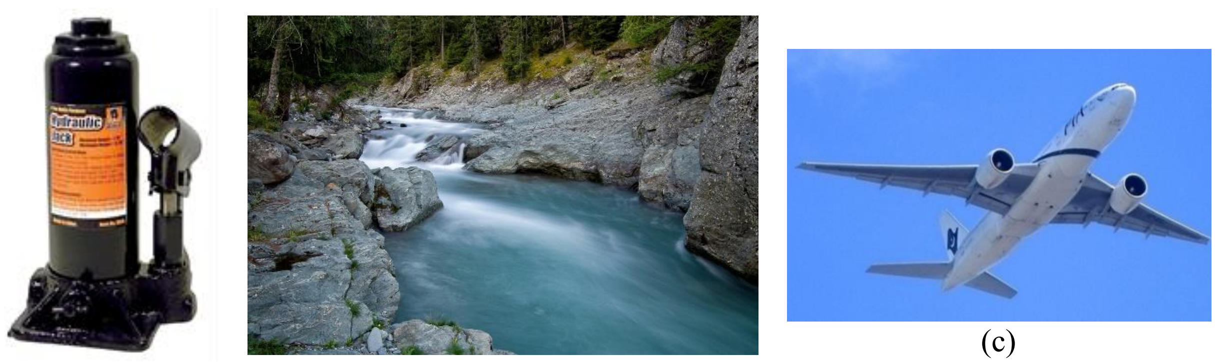
The instructor added several topics, some of which are illustrated in Figure 3, that were not previously covered in the chemical engineering version of Fluid Mechanics. Pascal's Law of Pressure Transmission is one example of a concept that is very important for mechanical and civil engineers, but it is not as important for chemical engineers. A mechanical engineer may be expected to design a hydraulic system and a civil engineer would likely encounter a hydraulic system in a public works application. However, such may not be the case for a chemical engineer. While chemical engineers and mechanical engineers working in a plant environment might encounter confined flow, civil engineers in public works applications would be more likely to encounter open channel flow. The section for mechanical/civil engineers included several flight and automobile applications that the course did not include for chemical engineers.

Table 1: Textbook Chapter Comparison

Chapter	Engineering Fluid Mechanics 12th Ed	Fluid Mechanics for Chemical Engineers 3rd Ed
1	Introduction	Introduction
2	Fluid Properties	Fluid Statics
3	Fluid Statics	The Balance Equation and the Mass Balance
4	Ther Bernoulli Equation and Pressure Variation	The First Law of Thermodynamics
5	The Control Volume Approach and The Continuity Equation	Bernoulli's Equation
6	The Momentum Equation	Fluid Friction in Steady, One-Dimensional Flow
7	The Energy Equation	The Momentum Balance
8	Dimensional Analysis and Similitude	One-Dimensional, High-Velocity Gas Flow
9	Viscous Flow Over a Flat Surface	Models, Dimensional Analysis, and Dimensionless Numbers
10	Flow in Conduits	Pumps, Compressors, and Turbines

11	Drag and Lift	Flow through Porous Media
12	Compressible Flow	Gas-Liquid Flow
13	Flow Measurements	Non-Newtonian Fluid Flow in Circular Pipes
14	Turbomachinery	Surface Forces
15	Flow in Open Channels	Two- and Three-Dimensional Fluid Mechanics
16	Modeling of Fluid Dynamics Problems	Potential Flow
17		The Boundary Layer
18		Turbulence
19		Mixing
20		Computational Fluid Dynamics (CFD)

Teaching across disciplines highlights historical differences like the Darcy friction factor for mechanical and civil engineers and the Fanning friction factor for chemical engineers. The friction factors refer to resistance for pipe flow, but they differ by a factor of four. Notations for relative roughness and coefficients for pipe fittings also differed. The Euler Equation was observed to be more of a focus in the mechanical/civil engineering section whereas Navier Stokes Equation, which does not assume inviscid flow, is more important for chemical engineers. Lastly, the energy equation seems to be preferred by mechanical engineers whereas Bernoulli's equation was observed to be preferred by chemical engineers to solve similar problems.



(a) (b) (c)

Figure 3: Sample Notable Content Additions (a) Pascal's Law of Pressure Transmission and Hydraulic Lift Examples (Image Source – Tractor Supply Co.) (b) Open Channel Flow (c) Aerospace and Automobile Applications

The Future of Shared Courses: Emerging Themes from West Virginia University Institute of Technology

The case study course outcomes were promising and prompted further consideration of the idea of shared courses. Several themes emerged from in depth discussion of shared courses. The challenges are captured in course formulation or course structure and presented with a solution.

<u>Course Formulation</u>

Successful course formulation requires a collaborative process to identify core topics and develop a common syllabus. All departments should be involved to confirm that course coverage is satisfactory and includes content for students to be successful in (1) careers, (2) taking professional exams like the Fundamentals of Engineering (FE) exam and (3) graduate study. It will be key to identify multi-disciplinary problems for students. The formulation of a course committee emerged as a key recommendation to ensure that the course is formulated properly. The textbook will also need to be chosen carefully to ensure that it covers all topics or as many as possible so that limited supplemental material will be required for core topics.

Course Structure

One potential challenge is that students would need to learn topics that are not a priority for their disciplines. The idea of modular courses emerged from this concern. Two credits of a course are shared, and one credit is unique to the discipline. Heat transfer, thermodynamics, controls and senior design are also candidates for this structure.

Another challenge is the course title. To maintain equity, shared course titles could be renamed from a disciplinary reference to a shared course reference such as ENGR. Course enrollment caps may also need to be adjusted to accommodate enrollment fluctuations.

Skill development is another consideration. Each discipline should identify what skills within analytical, experimental and computational domains are most important. Some disciplines may offer courses at different levels. This could impact course delivery because courses are expected to go higher on Blooms Taxonomy through the four years of the engineering program.

Course Delivery

The issue of having someone from another discipline is acceptable if the instructor is familiar with all disciplines and a strong instructor. Discussions became enthusiastic around the idea of strategically deploying the most effective instructors and not being limited to instructors within a specific discipline. Lastly, it will be important to include appropriate assessments to determine the impact of the revised course design on student learning.

Benefits

Resource efficiency is the primary benefit of shared courses. Class sizes are larger and meet minimum requirements. Shared courses could also provide opportunities for faculty members to take earned sabbaticals and for course releases to enhance scholarly productivity. Also, the chemical engineering version of the course is only offered in the fall semester. Moving to a shared course would allow students to take the course both semesters.

Concluding Remarks

Institutions of higher education are under increasing pressure to deliver a quality education with declining resources. Because engineering programs require specialized equipment and compete with industry and government for faculty, they are resource intensive. Strategies that use resources efficiently, like offering combined core courses, represent a good faith effort to preserve resources and deliver quality programs while meeting the demand for engineering professionals.

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