2024 IL-IN Section Conference
University of Illinois Chicago | April 13, 2024

Work in Progress: Lesson Plan Redesign for Interdisciplinary Education in Undergraduate Fluid Mechanics Course

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Abstract

To develop the interdisciplinary problem-solving capability of undergraduates, the authors' interest is to add interdisciplinary education to undergraduate fundamental engineering courses. An introductory fluid mechanics course is selected as a framework to explore the redesign of the lesson plan for the objectives of interdisciplinary education. The pedagogies of PBL (Project-Based-Learning) and RBL (Role-Based Learning) are used to design a semester-long team project that allows students to determine the topics and tasks of their interest. The semester-long team project is integrated into the existing learning activities for the objectives of interdisciplinary education. The details of the redesigned lesson plan are presented, after a brief introduction to the existing lesson plan. The challenges of the redesigned lesson plan are also discussed.

Introduction

The issues of energy, environment, medicine, economy, and society are increasingly intricate and often lack clear definitions. Addressing such complex and open-ended problems necessitates the knowledge and skills of multiple disciplines. Individuals with the capacity for interdisciplinary problem-solving are essential in tackling these challenges. Consequently, interdisciplinary education (IE) has gained prominence in higher education, with previous studies comprehensively exploring its implications [1], [2]. In the realm of engineering education, the majority of current curricula and courses are crafted within a single discipline, despite the emergence of new majors embodying interdisciplinarity, such as bioengineering, medical engineering, and robotics. To equip students in traditional engineering disciplines—such as mechanical engineering, civil engineering, and chemical engineering—with the necessary skills for future complex challenges, educators in higher education have undertaken various initiatives towards interdisciplinarity. A study conducted at UNEMAT/Tangará da Serra from 2015 to 2019 underscores this shift, demonstrating the integration of interdisciplinary pedagogical practices in civil engineering courses and emphasizing the significance of collaborative and interdisciplinary approaches [3]. While these initiatives highlight the growing recognition of the importance of interdisciplinary education in engineering, it is crucial to delve deeper into the specific methodologies and educational outcomes of such endeavors. Previous literature reviews [1], [2] and studies at UNEMAT [3] provide valuable insights into the potential benefits of interdisciplinary approaches, yet there is a valid critique that the literature lacks detailed information on the methodologies and specific impacts on educational outcomes. This paper aims to address this gap by delving into more comprehensive examinations of interdisciplinary engineering education, with a focus on specific studies, methodologies, and their impacts on educational outcomes. Such an exploration is essential for a nuanced understanding of the effectiveness of interdisciplinary learning environments in higher engineering education.

To develop the interdisciplinary problem-solving capability of undergraduates, the authors' interest is to add interdisciplinary education to undergraduate fundamental engineering courses. The challenges are (1) to achieve the objectives of interdisciplinary education, (2) to reasonably integrate into existing content, and (3) to improve the learning outcomes of the course topics.

The authors select the undergraduate introductory fluid mechanics course as a framework to explore the redesign of the lesson plan for the objectives of interdisciplinary education. The reason for selecting this course lies in the fact that fluid mechanics has numerous applications in various disciplines which reduces the challenge of finding out the topics for interdisciplinary education; additionally, this course has students from various departments in the engineering college, and the students can easily form a team consisting of students from different departments to facilitate the implementation of interdisciplinary education. The pedagogies of PBL (Project-Based-Learning) [4] and RBL (Role-Based Learning) [5] are used to design a semester-long team project for the objectives of interdisciplinary education. The details of the redesigned lesson plan facing the challenges abovementioned are presented, after a brief introduction to the existing lesson plan.

Existing lesson plan

The introductory fluid mechanics course is designed to build up the students' knowledge and skills which make them able to identify, explain, analyze, and design for common scenarios involving fluid at rest or in motion. The content of the introductory fluid mechanics course covers 10 chapters: introduction, fluid statics, elementary fluid dynamics, fluid kinematics, finite control volume analysis, differential analysis, dimensional analysis, internal flow, external flow, and open-channel flow. The pre-written plus live notes are used to deliver the lecture. The iClicker is used to run classwork for quick feedback from students and to enhance student engagement in class. The weekly homework assignments have around 7 problems each time. Both classwork and homework are designed as low-stakes formative assessments. Two midterm exams and one final exam are used as high-stakes summative assessments.

Redesigned lesson plan

1. Learning objectives

Besides the learning objectives specifically for the fluid mechanics subject mentioned in the above section, the redesigned lesson plan adds the interdisciplinary problem-solving capability to the learning objectives. The redesigned lesson plan is expected to build up students' mindset of systems thinking for real-world interdisciplinary problems, the skills to integrate the knowledge and skills from different disciplines to solve one problem, as well as the team management and communication skills involved in collaboration for the common goal. The learning objectives regarding interdisciplinary education are not limited to fluid mechanics, although the teaching materials used for these objectives are related to fluid mechanics.

2. Materials, resources, and activities

Many studies have explored and endorsed the pedagogy of PBL and RBL for interdisciplinary education [2], [3], [6] - [8]. PBL is a student-centered pedagogy where students learn by exploring real-world problems and challenges individually or in a team. RBL is characterized by students learning in the context of specific roles. In the redesigned lesson plan, the learning activity is a team project aligning with the pedagogies of PBL and RBL.

The existing lesson plan comprises 10 chapters, with the first 7 covering the basic theory of fluid mechanics and laying the foundation for the subsequent 3 chapters, which delve into 3 typical flow scenarios in various real-world applications. The redesign seeks to seamlessly integrate interdisciplinary education into the existing content. The initial teaching materials, activities, and assignments for the first 7 chapters remain unchanged, culminating in two midterm exams. However, the statement of the interdisciplinary team project is released at the course's outset, stimulating students' motivation to explore project topics from the semester's start.

While studying the basic theory of the first 7 chapters for around 10 weeks, students concurrently work on setting up interdisciplinary project topics and defining targets and corresponding tasks aligned with their interests and disciplinary backgrounds. The topic must involve fluid mechanics in the analysis and can be any flow scenarios in any real-world applications of students’ interest. By the end of the initial 7 chapters, students reach a milestone in their semester-long project, having completed the setup of the project's topic, targets, and corresponding tasks. This self-directed approach promotes autonomy and accountability in learning [8].

Post completion of the basic theory, instructional materials for three typical flow scenarios are provided, covering internal flow, external flow, and open channel flow. Students independently study these materials, focusing on two of the three scenarios of their choice. Simultaneously, they work on project tasks, delving deeper into the specific flow scenarios relevant to their chosen topics. Besides fluid mechanics, the knowledge and skills of various disciplines are expected to be applied to conduct the calculation, analysis, and design involved in the tasks via the collaboration of team members from different departments. The project work concludes with students submitting comprehensive reports.

Role-based learning within student projects mimics real-world professional environments, providing valuable experiential learning opportunities [2]. In this project, students create roles and delegate tasks according to their position. In the project activity, RBL is seamlessly integrated as students apply their designated roles to tackle specific project tasks and challenges. This hands-on application of RBL ensures that students actively engage with their responsibilities, honing their practical skills and allowing them to witness firsthand the impact of effective role allocation on the project's success. Interdisciplinary design collaboration, with its diverse student range, fosters a dynamic and interactive learning environment, crucial for real-world interdisciplinary projects [9]. The interdisciplinary actions aim to develop general skills, fostering collective relationships that deepen students' understanding of the impact of their engineering projects [3].

3. Assessment

To achieve the learning objectives of the fluid mechanics subject, and since the content of the first 7 chapters is kept the same, the classwork and homework for the low-stakes and formative assessment, as well as the two midterms and the final exam for the high-stakes and summative assessment, will also be kept as is.

The semester-long project is structured into two key phases, in line with the outlined schedule in Table 1. The Initial Exploration and Research phase involves teams of 4-5 students exploring fluid mechanics applications, and defining learning objectives and project goals. An instructor meeting establishes objectives, defines roles, and creates a comprehensive project timeline. In the subsequent phase, In-depth Study or Design Development, teams delve deeper into chosen topics, submitting bi-weekly progress reports. The Design Review Presentation fosters a stakeholder-investor dynamic through recorded presentations and Canvas discussions. To conclude this phase, in the Finalization and Presentation, teams refine the project based on feedback, documenting their study or design process comprehensively. The Final Presentation emphasizes professionalism, allowing projects to showcase theoretical studies or design concepts, ensuring adaptability to the course's fluid mechanics focus. A detailed timeline is provided in Table 1 along with an example course schedule of the 2023 fall semester.

Table 1: Detailed Course Schedule with a Semester-Long Project

Date	Weekday	Topic	Semester-Long Project
8/21	M	1. Introduction, Big Idea	• Students form teams of 4-5 members. • Exploration of potential project topics while managing concurrent study commitments to fluid mechanics content. • Initial team meetings to discuss individual roles and responsibilities. • Develop fundamental knowledge of fluid mechanics. • First check in with the instructor at the 3-week mark.
8/23	W	1. Dimensions, Viscosity	
8/25	F	1. Viscosity, Surface Tension	
8/28	M	1. Surface Tension	
8/30	W	2. Fluid Statics Introduction, Pressure Equation, Manometry	
9/1	F	2. Hydrostatic Force on Plane Surface	
9/4	M	Labor Day	
9/6	W	2. Hydrostatic Force on Plane and Curved Surfaces	
9/8	F	2. Hydrostatic Force on Curved Surfaces and Buoyancy	
9/11	M	2. Buoyancy, Rigid Body Acceleration	• Teams narrow in on the exploration phase and have the project topics, expected outcomes and tasks. • Develop a deeper understanding of fluid mechanics and how it can relate to the project. • Second check-in to ensure students are on task at the 6-week mark.
9/13	W	3. Concepts regarding Bernoulli Equation	
9/15	F	3. Bernoulli Equation and Examples	
9/18	M	3. Bernoulli Equation and Stagnation Pressure	
9/20	W	3. Examples of Free Jet and Confined Flow	
9/22	F	3. Examples of Confined Flow and Flowmeter	
9/25	M	4. Kinematics, Material Derivative, RTT	
9/27	W	5. Finite CV, Momentum Flowrate	
9/29	F	Exam 1 (Ch1-3), and Informal Early Feedback	
10/2	M	5. Finite CV Examples	• Teams conclude the exploration phase and decide on the project topic, outcomes, and tasks. • Instructor meeting to establish objectives, define roles, and create a comprehensive project timeline. • Final meeting during week 9. • Incorporate any feedback during week 10.
10/4	W	5. Moving CV	
10/6	F	5. Energy Equation for CV	
10/9	M	6. Differential Analysis	
10/11	W	6. Continuity Equation	
10/13	F	6. Stream Function	
10/16	M	6. Velocity Potential, Irrotational Bernoulli Equation	
10/18	W	6. Navier-Stokes Equation, Viscous Flow in Slit	
10/20	F	6. Viscous Flow in Circular Pipe	
10/23	M	7. Dimensional Analysis and Buckingham Pi Theorem	
10/25	W	7. Similarity and Scale Models	
10/27	F	7. Common Dimensionless Groups and Dimensionless Equations	

10/30	M	8. Viscous Flow in Pipes: Flow Regime and Entrance Length	• Teams delve deeper into chosen topics. • Continued study of the last 3 chapters of the course material. • Bi-weekly progress reports submitted to the instructor.
11/1	W	8. Fully Developed Flow, Major Loss and Minor Loss	
11/3	F	Exam 2 (Ch4-7)	
11/6	M	8. Example: Non-circular Pipes, With and Without loss	
11/8	W	8. Example: Determine Flowrate with Iteration	
11/10	F	9. External Flow Key Ideas	
11/13	M	9. Examples: Lift and Drag	• Teams prepare for the Design Review Presentation. • Teams present their progress in the Design Review Presentation and record the presentation. • Student stakeholder-investors dynamic is emphasized through recorded presentations and Canvas discussions. • Feedback provided by the instructor and peers.
11/15	W	9. Boundary Layer Concept and Examples	
11/17	F	9. More Discussion on Boundary Layer	
11/20	M	Fall Break	
11/22	W	Fall Break	
11/24	F	Fall Break	
11/27	M	10. Open-Channel Flow: Wave Speed, Froude	• Teams refine the project based on feedback received. • Comprehensive documentation of the study or design process. • Preparation for the Final Presentation. • Bi-weekly progress reports submitted to the instructor.
11/29	W	10. Energy, Criticality, Multiple Possible States	
12/1	F	10. Uniform Flow, Manning Equation	
12/4	M	10. Nonuniform Flow, Hydraulic Jump	• Final Presentation of theoretical studies or design concepts.
12/6	W	Review	
12/11		Final Exam, Comprehensive	

Phase 1: Initial Exploration and Research
Phase 2: In-depth Study or Design Development

The instructor will assess students' performance in the semester-long project through a comprehensive grading approach. Criteria include the formation of effective and cohesive teams, thorough exploration of potential project topics, and the successful completion of milestones. Students are expected to demonstrate autonomy and accountability in their learning, aligning their education with career aspirations. The application of role-based learning and active engagement in interdisciplinary actions will be evaluated, along with the ability to balance project tasks and continued learning during a dedicated phase. Grading also considers the adherence to project frameworks, the clarity of documentation, and the professionalism of presentations. The adaptability of projects to the course's fluid mechanics focus is a key consideration. Instructors will communicate clear grading rubrics at the project's outset to ensure transparency and fairness throughout the evaluation process.

Discussion on the challenges of the redesigned lesson plan

There are quite a few challenges to the redesigned lesson plan after the integration of the activities for the objectives of interdisciplinary education. For instance, the instructor needs to learn the topics and curricula of interests of various departments to be prepared for the instruction of interdisciplinary projects. The instructor needs to help students set up the objectives and tasks of their projects with a reasonable degree of challenge so that the student teams can complete the projects as scheduled with reasonable effort. For the learning objectives regarding team management and communication for good collaboration, the instructor also needs to prepare the instruction on this aspect, besides the technical disciplines. Due to various interdisciplinary project topics of different teams and the semester-long process management, the workload of instruction will be high if the size of the class is large.

Summary

The redesigned lesson plan integrates interdisciplinary education into the fluid mechanics course through a semester-long team project. Learning objectives extend beyond fluid mechanics, emphasizing interdisciplinary problem-solving, systems thinking, and collaboration. Using Project-Based-Learning (PBL) and Role-Based Learning (RBL) pedagogies, the project spans the semester and enhances fluid mechanics knowledge while developing crucial interdisciplinary skills for real-world challenges. Assessment focuses on team dynamics, milestone achievement, and interdisciplinary skills. Continuous feedback ensures the plan's effectiveness and sustainability. Challenges involve mastering diverse topics, setting challenging project goals, and managing a high instructional workload in larger classes. The redesigned lesson plan aims to enhance fluid mechanics knowledge and cultivate essential interdisciplinary skills for real-world problem-solving. The authors plan to implement the redesigned lesson plan in class to check its effectiveness in the future.

Acknowledgements

The authors appreciate the support of the GATE grant of the Grainger College of Engineering and also the support of the Department of Mechanical Science and Engineering, the University of Illinois Urbana-Champaign.

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