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Enhancing Engineering Education Through Pedagogical Change: "Application to Abstract

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***Abstract* –Students' understanding and capacity to apply and integrate principles from different units in each course are not being sufficed by the traditional teaching method, especially for the core courses. This research proposes a method, namely, "Application to Abstract" in which students learn the course by solving an application that draws on principles from various topics. The implementation of the same has been demonstrated with the help of a core course on Fluid Mechanics where a single problem statement with all the necessary information is defined and students work on the different aspect of the problem with the progress of the course. Compared to traditional method, more percentage of students showed interest in derivation of abstract principles (60%), the ability to apply the concepts (40%), ability to correlate with the basic principles and execute the project (50%). Their ability to comprehend and integrate the abstract concepts through the practical application has also enhanced their participation in laboratory classes.**

***Keywords*—Fluid Mechanics; Engineering applications; Project based learning; Rubrics design.**

***JEET Category*—Pedagogy of Teaching Learning Subcategory: Evolving Engineering Pedagogy for Implementing NEP 2020**

I. INTRODUCTION

Often, it is found that the learning ability of a student varies considerably depending on how the abstract principles are introduced. Conventionally, a course is introduced by deriving the 'formula' and then its applications are taught through some examples. Many students lose interest when abstract principles are taught first, especially in core courses like Fluid mechanics, Engineering mechanics, etc. Teachers resort to various other techniques for gaining students' interest. Several studies have been discussed with theoretical explanations that learning is highly specific(Ackerman, 1987; Kraiger & Salas, 1993). Different pedagogy and research have been conducted to improve the learning ability of the students, which is quite precise. Those studies have addressed mental practice, variability of practice, and task integration through the theories of identical elements (Singley & Anderson, 1989; Thornidke, 1906), encoding specificity (Tulving & Thomson, 1973), transfer suitable processing (Morris, Bransford, & Franks, 1977; Roediger, Weldon, & Challis, 1989), and procedural reinstatement (Healy, Wohldmann, & Bourne, 2005). Concerning engineering concepts, the engineers usually agree that the engineering process involves design and redesign. However, engineering design differs from trial-and-error "gadgeteering" (Weiss, 1964).An engineering design involves essential components such as identifying the problem, specifying the requirements of the solution, decomposing the system, generating a solution, testing the solution, sketching and visualizing the solution, modelling and analyzing the solution, evaluating alternative solutions as necessary, and optimizing the final design (Buede & Miller, 2016). These essential components can be categorized into three type-specific engineering concepts: basic science and math, domain-specific, and concepts common to most areas of engineering (Frei & Di Marzo (2011). The experience described by several universities, including United States and Europe (Lucena, Downey, Jesiek, & Elber, 2008), have suggested the important prerequisites for successful core engineering educational missions as follows:

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(a) A fundamental understanding of the physics principles, mathematical logic, and the philosophy of science is required, (b) Educational processes to be devised so as to eradicate the fear of mathematics, (c) When it comes to nature-based engineering, fundamentals of geophysics should also be taught; (d) Programming and analyzing skills for existing and emerging computing paradigms to be taught properly (Crawley, Malmqvist, Ostlund, Brodeur, & Edstrom, 2007). Despite substantial changes in teaching and learning theories and pedagogies, several programmes imparting core engineering education still rely heavily on deductive instructional strategies (Nair, Chandrasekaran, Nair &Pothiraj, 2020).In this situation, often, the learners are gradually detached by losing interest in abstract knowledge during the progression of the course, especially the slow learners of class groups. In this proposed practice, the authors have presented a teaching strategy where all Course Outcomes (COs) and anticipated course topics are inclusively planned in an overall scenario of a real-time practical application from the beginning of the course introduction. Further, this approach progresses from the application panorama to abstract knowledge transfer without compromising or diluting the understanding of complex topics by the learners. Inductive learning pedagogies have been incorporated with this approach with formative assessments. Based on the observation in multiple assessments and interpersonal communication with the teacher, the improvements in learning and ability of students were rated.

The paper is organized as follows: Section II describes Application-centric learning and its teaching constituents, and Section III details the methodology adopted to implement the proposed strategy using an example of Fluid mechanics course in civil engineering. Section IV presents the comparison results of the type of skill improvements in learners'ability and interest using this approach and the benefits of the proposed method. Finally, Section V provides the conclusion and future scope of the presented strategy for improved learning of complex concepts in engineering courses

II. Literture Review

Introducing engineering concepts through real-world applications gives students a tangible context, making the theoretical content more relatable and engaging (Kruger, Wolff, & Cairncross, 2022). Rather than presenting abstract theories in isolation, educators can begin by showcasing how these concepts are employed to solve practical problems. The application approach can be exemplified through case studies, hands-on projects, and industry collaborations. Rio and Rodriguez (2022) introduced a project-based learning in a laboratory course for integration of knowledge and engineering design skills, offered for two different engineering courses, namely, mechanical, and chemical engineering. Rehman et al. (2023) analysed the impact of project-based learning on the students' learning ability in a math course of a Pakistani public school. They reported that the project-based learning had a positive impact on the students.

A. Relevance to Industry

Presenting applications that mirror real-world challenges helps students appreciate the importance of theoretical content (Talanquer & Pollard, 2010). For example, teaching the principles of thermodynamics could start with explaining their role in designing energy-efficient HVAC systems or high-performance engines.

B. Interdisciplinary Connections

Many engineering challenges require collaboration across various disciplines. Introducing applications at the outset encourages students to understand how different concepts interplay, fostering a holistic perspective (Tran, Phan, Le & Nguyen, 2020). For instance, teaching structural engineering could involve analyzing bridges for their mechanical strength and environmental impact (Chinowsky, Brown, Szajnman, & Realph, 2006).

C. Hands-On Experience

Incorporating practical projects early in the curriculum enables students to apply theoretical knowledge to hands-on tasks (Kim, Choi, Han, & So, 2012). It fosters a deeper cognition of concepts and improves problem-solving skills. For instance, learning about control systems becomes more effective when students build and program autonomous vehicles (Kim, Jung, & Lee, 2008).Conventional engineering education often starts with foundational theories and gradually progresses to practical applications. However, this linear approach can sometimes lead to detachment among students who resist seeing abstract concepts' relevance. Incorporating applications-centric learning in early commencement can spark students' interest and enhance their understanding of intricate subject matter. Core courses are being designed and taught in a manner that doesn't enhance the comprehension of the students and their ability to apply as well as integrate cross-disciplinary principles. Students study each unit in an isolated manner and are unable to comprehend the relationship between various concepts.

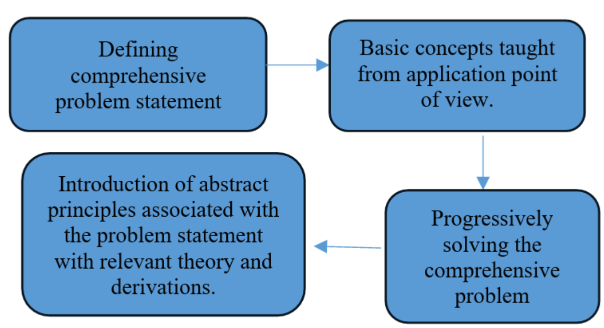

Fig. 1. Proposed strategy of "application to abstract"

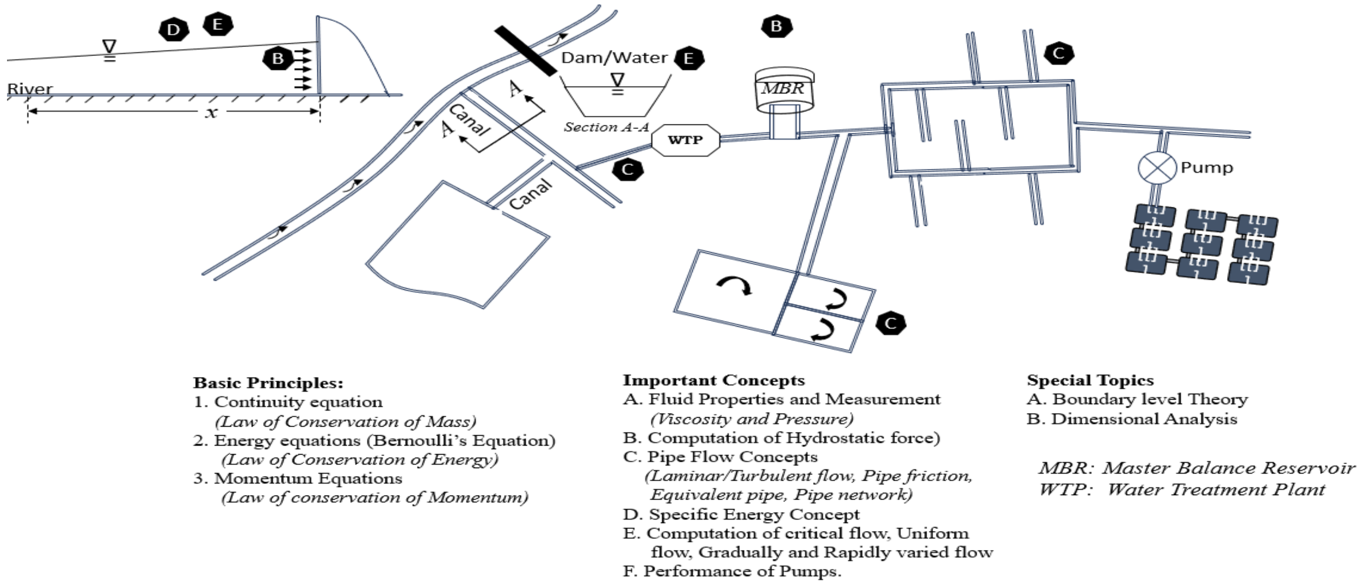

Fig.2. Illustrative demonstration of using application to abstract introduction concept in fluid mechanics to civil engineering UG students.

In this study, a strategy is being proposed where the students study the entire course through an application problem which encompasses concepts of all units. This automatically develops an interest in the students and thus makes engineering relevant for their life. The proposed strategy has been illustrated with a block diagram presented in Fig. 1.

III. Methodology

Primarily, the hypothesis of the proposed method lies in introducing an overall application scenario to a group of learners and emphasizing the situation to drag their attention and interest into it instead of directly beginning with teaching the laws or established mathematical principles for them to apply engineering concepts. In this case, the planning of the relevant application would require the utmost effort of the teacher where the course situation of application hidden segments of course outcome within. The introduction evolves learners' thinking and interest towards connecting the dots of required multiple engineering concepts. It is similar to providing connecting-dot worksheets in kindergarten practice that attract a learner's interest to try it but is not visible before joining them. The dot grid of the outer sketch given by the teacher gives broader context guidance. The emphasis is on providing an application statement and understanding the fundamentals as well as the inter-relationship of the various concepts involved in solving the real-time applications in contrast to the traditional method of teaching where development of deeper interest in the course takes place only with a small segment of students.

A. CO and Unit Integration:

The proposed innovative teaching strategy integrates all course outcomes in a single application scenario in a civil engineering course to improve students' learning interest in complex engineering concepts. The traditional segmented approach to teaching engineering courses often fails to provide

TABLE I Defined Course Outcomes of the Example course

Course Outcomes	CO Statement
CO 1	Apply principles of fluid mechanics in simple practical problems
CO 2	Analyse pipe flow problems,
CO 3	Analyse flow through pumps and perform dimensional analysis,
CO 4	Compute critical and uniform flow depths, and
CO 5	Analyse characteristics of varied flow.

students with holistic insights into understanding how concepts and theories are interrelated and collectively applied to real-world engineering needs. By implementing a comprehensive application scenario, students are encouraged to synthesize and apply their knowledge to solve a complex engineering problem, fostering a deeper understanding of the subject matter and enhancing their problem-solving and critical thinking skills. Fig.2 illustrates the proposed teaching strategy implemented in an example course, Fluid Mechanics, for the class group of undergraduate civil engineering students (Batch of 25 students from second year civil engineering). The illustrative problem in Fig.2 covers all the 5 units of the course through a single problem statement which helps the student to relate to the application of what they would be studying in each unit. Their problem-solving and critical thinking abilities are mapped through specially designed problems requiring critical thinking, which the students are encouraged to solve as a team.

Their performance is also measured through specially designed tests. Table 1 lists the Course Outcomes (COs) of the example course the student can learn. This core engineering programme course covers a wide range of topics, spanning five specific modules, including basic principles of fluid mechanics,

TABLE II Rubrics for student assessment to analyze the impact of the proposed teaching strategy

Parameter	Good (3 points)	Satisfactory (2 points)	Not Satisfactory (1 point)
Interest in derivation of the abstract principles	Consistently demonstrates a strong interest in and enthusiasm for understanding and deriving abstract principles.	Occasionally demonstrates interest in deriving abstract principles.	Displays no interest in deriving abstract principles.
Ability to apply the concepts	Consistently applies engineering concepts accurately and effectively in various contexts.	Inconsistently applies concepts with noticeable errors.	Cannot apply concepts effectively.
Ability to correlate the basic mathematics or physics principles	Demonstrates a strong ability to correlate basic mathematics or physics principles with engineering concepts consistently and accurately.	Inconsistently correlates principles with noticeable errors.	Cannot correlate principles effectively.
Ability to effectively execute course level mini project	Completes the mini project exceptionally well addressing typical engineering decision scenarios	Completes the mini project with some deficiencies and room for improvement.	Fails to complete the mini project.
Interest in laboratory classes	Demonstrates interest beyond regular laboratory experiments to extended experiments requiring research skills	Student occasionally demonstrates interest in laboratory classes.	Displays no interest in laboratory classes.

pipe flow analysis, hydraulic machines and dimensional analysis, critical and uniform flow in channels, and varied flow in channels.

B. Coverage of Engineering Principles, Concepts, and Special Topics:

In the application scenarios developed by the instructor, the understanding of basic engineering principles, including the continuity equation while figuring the Law of Conservation of Mass, the energy equations while estimating the Law of Conservation of Energy, and the momentum equations for finding the Law of conservation of Momentum have self-evolved in the progressive class work covering CO1. The important concepts of fluid properties and measurement to enumerate viscosity and pressure, hydrostatic force, and pipe flow concepts were used in the application scenario where laminar/turbulent flow, friction, equivalent pipe, and pipe network were adequately understood to cover CO2. Similarly, specific energy concepts computation of critical flow, uniform flow, and gradually and rapidly varied flow performance of pumps covered CO3, CO4, and CO5 of the course to cover the application segment shown in Fig.2. Moreover, the special topics adjoining the task imparted concept of boundary layer theory and dimensional analysis. In the broader sense, the application scenario has covered all the defined topics and course outcomes. As the learners are taken through each unit, they work either individually or as a group on the problem statement illustrated in Fig.2. In the conventional mode of teaching, the teachers refer to a standard textbook where for each topic in each unit, different problems are solved. This doesn't help the learners to get a full picture of its application in totality. The analysis of one part of the problem leading to a solution becomes an input to the next part of the problem. Thus, it invokes, retains and enhances the interest of the learners progressively. While taking the students through the topics of the units, emphasis is not placed on the derivation of the formula used. Rather, the emphasis is on informing the formula with underlying basic concepts and illustrating its application. In the second round, after all the five units are covered, the students developed a natural interest to know how the formula are derived with which they experimented to solve a typical real time problem. At this stage, the detailed derivation and abstract theoretical principles are discussed which fostered more interest in the abstract theories and derivations associated with the given formula and principle.

TABLE III Comparison of improvement in ability and developed interest

Parameter	Conventional	Proposed strategy
Interest in derivation of the abstract principles	10%	70%
Ability to apply the concepts	40%	80%
Ability to correlate the basic mathematics or physics principles	30%	80%
Ability to effectively execute course level mini project	50%	100%
Interest in laboratory classes	0%	50%

C. Parameters and Rubrics for Assessment of the Proposed Strategy:

A structured rubric was followed to assess and evaluate the student performance or work in the class to report the achievement of the proposed teaching strategy based on a specific predetermined set of parameters. The assessment of the entire teaching strategy is based on 5 parameters, including students' augmented interest in (1) derivation of abstract principles, (2) ability to apply concepts, (3) ability to correlate basic mathematics and/or physics principles, (4) ability to effectively execute course level mini project, and (5) Interest in laboratory classes. The rubrics with the assigned score to each parameter based on the student's performance are shown in Table 2, which was used to calculate the overall performance based on the score.

IV. Results and Discussion

Preliminary findings suggest that integrating all course outcomes in a single application scenario positively impacts student learning of complex engineering concepts. Students reported that the integrated approach allowed them to see how different topics and theories relate and gave them a deeper understanding of the subject matter. A significant inclination in student engagement and motivation was observed in the early days, and students demonstrated improved problem-solving skills and critical thinking abilities in the multiple assignments and assessments. To assess engineering students based on these parameters shown in Table 3, one can use these rubrics to evaluate their performance. Assign a score to each parameter based on the student's performance and calculate an overall score for the course based on these assessments. Providing constructive feedback along with the scores can help students understand their strengths and areas for improvement. The students' learning outcomes assessed through their performance in written examinations, conduction of laboratory experiments and involvement in a course-level mini project is compared for the two different batch of students, namely the previous batch, which went through the conventional mode of teaching and the next batch in which the proposed mode of teaching is implemented (Batch of 25 students of second year civil engineering). The comparison indicating a significant improvement in the learner's ability is given in the graph shown in Fig. 3 that clearly demonstrates the impact of the proposed method. The percentage of improvement of the theory course was calculated based on their performance in the class tests and the feedback received from them. Similarly, for the laboratory courses, the ability of the students in assessing the inference from the experimental results and conduction of extended experiments were adopted for the evaluation of their improvement.

A. *Benefits of the Approach*

The proposed Application to the Abstract approach offers many advantages when compared to its traditional counterpart namely the Abstract to Application approach:

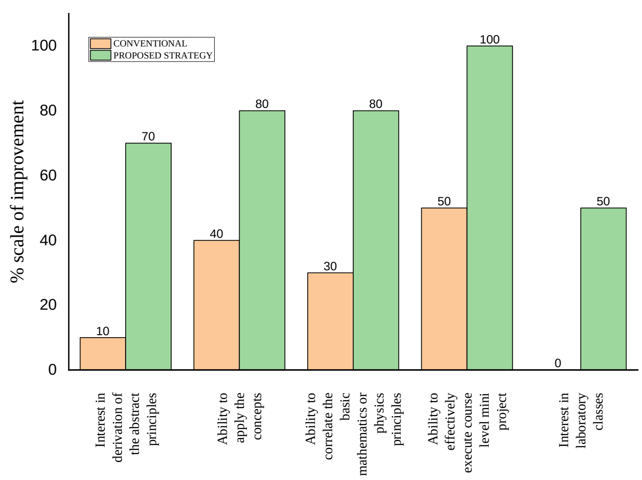

Fig.3. Assessment of improvement parameters using application-to abstract introduction teaching strategy based on the student's reflection.

(a) Contextual Understanding: Real-world examples provide a tangible context for theoretical concepts, making them more relatable and understandable,

(b) Motivation and Engagement: Students are more motivated to learn when they can see the immediate applications of their studies,

(c) Critical Thinking: Real-time applications require students to analyze, troubleshoot, and apply theoretical knowledge creatively, fostering critical thinking skills, and

(d) Holistic Learning: This approach encourages a holistic comprehension of engineering by blending theory with hands-on experience.

The learners showed a lot of interest in doing the mini project associated with the project. The course also has a laboratory component associated with it, and the students could more easily relate to why they are doing these experiments and its connection to what they are studying. To the teacher's surprise, many students came forward to carry out extended experiments using the same experimental set-up, demonstrating the inculcation of research skills.

V. CONCLUSION

There is a need for an integrated teaching strategy, particularly for core engineering education, where the students are expected to apply their knowledge to solve complex problems catering to multiple domains. They are also required to understand the interconnectedness of various engineering concepts. The study employs a novel strategy known as "Application to Abstract" where an application statement is issued to the students at the commencement of the course and the students are taught the art of integrating the abstract principles involved. The qualitative component involves observing classroom activities, collecting student reflections, and conducting semi-structured interviews with instructors and students to gather their perceptions and experiences of the application-centric introduction to abstraction strategy. The quantitative component includes pre-and post-assessments to measure students' knowledge and understanding of changes before and after implementing the comprehensive application scenario. The results highlight the benefits of integrating all course outcomes in a single application scenario in a core engineering course as an innovative teaching strategy. Compared to traditional methods of teaching, this strategy has enhanced the interest in derivation of abstract principles by 60%, the ability to apply the concepts by 40%, ability to correlate with the basic principles and execute the project by 50%. This approach has enabled the students can enhance their problem-solving skills, critical thinking skills and overall comprehension of complex engineering concepts by achieving a holistic understanding of how different concepts and theories are applied in real-world engineering projects. The findings of this study can contribute to the ongoing efforts to improve engineering education and provide students with a comprehensive education that prepares them for real-world engineering practice. Further research could explore the long-term effects of this teaching strategy on students' career readiness and professional development.

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