Problem Based Learning – An Effective way of teaching DSP course

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Abstract

The Digital Signal Processing (DSP) course is fundamental to many signal processing and communication applications. Since it is a mathematical intensive, faculty often face challenge in teaching and keeping students engaged for longer time. Students find it challenging to understand the core concepts and practical applications. The present work investigates Problem-Based Learning (PBL) approach to enhance the teaching of DSP by integrating real-world problems and active learning strategies. This new approach was offered to third-year students of the university, combining PBL with traditional lectures. The curriculum is redesigned according to constructive alignment. It included core DSP concepts as modules, PBL activities for each module and their assessment. The PBL was implemented in different phases focusing on orientation, problem identification, signal analysis, and system design. The new experience resulted in improved student engagement, concept understanding, and problem-solving skills in DSP, with positive feedback from students. The future plan is to focus on addressing the challenges faced during the initial implementation and to refine the PBL approach for the next batch of students.

***Keywords*— Digital signal processing (DSP); PBL; Real world problems, Reflection; Self-directed learning; Traditional teaching;**

***JEET Category*—Practice**

I. INTRODUCTION

Digital Signal Processing (DSP) is the fundamental course covering core concepts which find applications in various fields, including telecommunications, audio processing, image processing, biomedical engineering and other related programs. After completing the prerequisite course-Signals and Systems, students will continue to learn DSP. This course is also the basis of other subsequent courses such as Digital Audio Signal Processing, Image Processing and Communication systems. Traditionally, DSP courses have been taught using lecture-based methods, where instructors convey theoretical concepts to students in a linear manner. However, this approach often falls short in engaging students and thus deep understanding and practical application of DSP principles.

It is observed that many students find it hard and struggle to understand different DSP concepts such as Fourier transforms, convolution and filter design [1,2]. In traditional theoretical approach of teaching, not much focus is given on applications of these concepts to solve real world problems. This may lead to disconnection of theory and practical problem solving. Students may find other courses such as programming or hardware based projects more interesting where more hands-on activities are conducted. This demand for new pedagogical initiatives to bridge the gap in digital signal processing course to improve the concept understanding and ability to solve practical problems. The aim of the present work is to investigate an effective pedagogical approach for teaching the DSP course.

There are many articles exist in the literature on teaching learning reformation. The authors in [3] proposed a non-conventional pedagogical approach with innovative strategies that can foster an intuitive and engaging learning environment within Indian classrooms. To promote higher level thinking, problem solving ability, team work and time management, the authors of [4] have implemented project-based learning pedagogy for microcontroller theory course. A better teaching environment that facilitates learning and improve problem-solving skills is designed by authors of [5] which combine activity based and project-based learning pedagogy.

But we focus here only on DSP course related works. Few of the researchers proposed reforms to improve the teaching effectiveness by modifying the DSP curriculum and teaching methodology. The authors of [6] tried to find some solutions by means of combining online and offline mixed teaching practices. Cognition principles-based reforms are explored in [7]. Some of the educator researchers have employed experimental teaching by considering software or hardware-based experiments to improve the students' ability to solve DSP related problems [8-10]. To improve the student interaction and engagement, the authors of [11] have followed integrated teaching by giving simple problems and programming assignments or quizzes on DSP topics.

The above discussed methodologies have implemented different teaching learning methodologies but it is observed that the students are not exposed to real world problems where application of DSP concepts play important role. One of the effective ways to expose the students to such environment is the Problem-Based Learning (PBL) approach [12].

PBL has emerged as a promising pedagogical approach and investigated to address the challenges in DSP education [13]. PBL shifts the focus from passive listening to active engagement by presenting students with real-world problems or scenarios relevant to DSP. In this approach, students work collaboratively in small groups to analyze, discuss, and solve the problems, while the faculty serves as a facilitator and mentor.

This paper reports the results of a pilot study that combined PBL with few lecture-based instructional sessions to enhance the student learning. This new course named as DSP using PBL approach was offered for the first time to 320 students of 5th semester (third year) at the School of ECE, KLE Technological University. This course is a core course in the program and was taught in traditional mode for the previous batch students. In this new pedagogical initiative students were encouraged to formulate the problems on their own. The implementation methodology is discussed in detail in further sections.

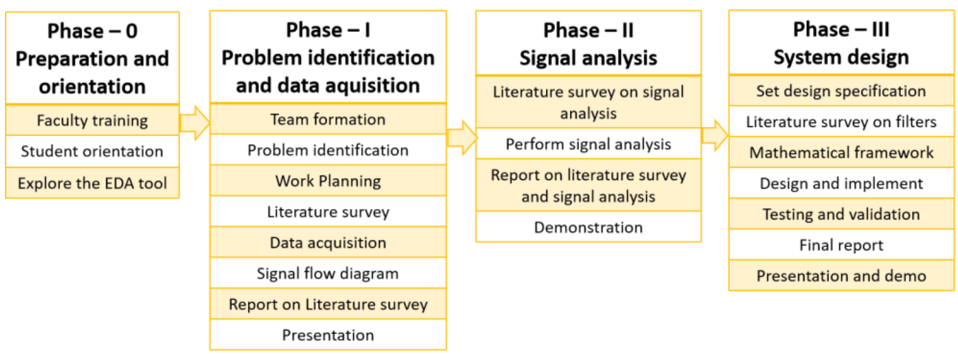

Fig. 1. PBL Implementation phases and activities planned in each phase

The remaining part of the paper is structured as: Section II describes the different phases of implementation of PBL approach along with curriculum design. Section III provides an overview of the delivery framework and Section IV discusses the conclusion and challenges faced during the first time offering of this new course format and outlines future action plan to further improve the outcome.

II. Methodology

The implementation of the Problem-Based Learning approach in the DSP course was carried out in several structured phases. This section describes the detailed methodology of integrating PBL with traditional lecture-based instruction, curriculum design, planning, delivery framework, and assessment strategies.

A. Curriculum design

The curriculum for the DSP course was redesigned considering constructive alignment to incorporate PBL principles while maintaining essential theoretical foundations. The key steps in the curriculum design included:

1) Identification of core concepts: Essential DSP topics such as Discrete Fourier Transforms (DFT), Fast Fourier Transforms (FFT), circular convolution, and filter design were identified as the core content to be covered. The topics were divided into three modules over a span of twelve weeks.

2) Module 1 focusing on DFT/IDFT and its properties, Module 2 on radix-2 decimation-in-time and decimation-in-frequency FFT, IFFT algorithms and Module 3 on IIR and FIR filter design techniques.

3) Integration of PBL activities: Many in-class activities such as online resource reading, watching LMS videos, implementation activities, group discussions, tests, presentations and demonstrations were included in the curriculum.

B. Planning

The implementation of the PBL approach was carried out in four phases as illustrated in Figure 1. The figure also presents the different activities planned in each phase which are described below in detail.

Phase 0: Preparation and Orientation

Faculty members were trained in PBL methodologies, including facilitation techniques and assessment methods. At the beginning of the course, students were oriented to the PBL approach, its benefits, and expectations. They were introduced to collaborative problem-solving techniques and the importance of self-directed learning. We had chosen MATLAB/Simulink as the platform for all the implementation activities and assessment tests. Hence students were asked to complete two self-paced online certification courses: MATLAB Onramp and SIMULINK Onramp from MathWorks before the start of semester.

Phase 1: Problem Identification and Data Acquisition

Students were given freedom to choose their team members and encouraged to choose the real-world problems in different themes/areas such as audio processing, vibration analysis, weather forecasting, image processing, and biomedical signal processing. For example, in the area biomedical signal processing, there is a need to develop an algorithm to identify and classify arrhythmia using Electrocardiogram (ECG) signals. The challenge lies in the need to enhance the quality of raw ECG signals through signal processing methods. These methods must effectively address issues such as noise and artifacts, ensuring that the resulting signals are of good quality with reduced distortions. Such problems helped the students apply theoretical concepts such as filter design to practical

scenarios of denoising applications.
The required guidance is provided by the faculty and ensured that the problems chosen were relevant, can be completed in the given time and aligned with the DSP concepts being taught.

Students formed teams of four members to work on the chosen problem. Each group was responsible for:

- Analyzing the assigned problem to understand its scope and requirements.
- Conducting a systematic literature review to identify the suitable approaches and methodologies for solving the problem using DSP concepts.
- Developing a detailed signal flow diagram outlining the process and steps involved in solving the problem.
- Exploring different publicly available datasets for the chosen problem.
- Preparing a short report on the literature survey, methodologies, and initial findings.
- Presentation of the work done at the end of Phase 1.

In this phase, faculty engaged the classes in Module 1 of the course, covering the concepts of Discrete Fourier Transforms (DFT), its properties, zero padding, linear and circular convolution. The in-class activity sessions involved students writing MATLAB programs to perform signal generation, DFT and IDFT computation, circular convolution both using time and frequency domain approach, and linear convolution using overlap save/ add method. This phase was spread for a duration of four weeks.

Phase 2: Signal Analysis

Students carried out a systematic literature survey to identify various signal analysis techniques and prepared a short report on their findings. Module 2 of the course was delivered during this phase, covering the concepts of Fast Fourier Transforms (FFT) using Decimation-in-time (DIT) and Decimation-in-frequency (DIF) FFT. In-class activity sessions involved students implementing FFT and IFFT by writing MATLAB programs on the acquired signal. Students have compared and analysed the performance of DFT and FFT. They have also implemented the chosen signal analysis algorithm and demonstrated their work at the end of this phase. This phase was spread for a duration of three weeks.

Phase 3: System Design

Students also conducted a systematic literature survey to identify the desired specifications and suitable filtering techniques observing the frequency spectra. Module 3 of the course was delivered in this phase, covering concepts on analog and digital IIR filters and FIR filters using windowing techniques. During in-class activity sessions students implemented involved students various digital IIR and FIR filters and compared their performance. Students implemented the relevant filters identified through the literature survey. At the end of this phase, they presented the detailed along with demonstration. This phase was spread for a duration of five weeks.

During the presentations, each group presented their work to the entire class. The presentation included - explanation of the problem, the approach, the DSP techniques used, specifications chosen, and the final solution. Group discussions were encouraged after presentation, where students exchanged thir queries, gave provided constructive feedback, and discussed alternative solutions. Reflection sessions were also conducted for students to evaluate their experience of PBL, difficulties faced, and the effectiveness of the new approach in understanding and implementing DSP concepts.

In all the four phases, the role of faculty was to act as facilitator and guide, throughout the problem-solving process. Faculties provided timely feedback, and also ensured that the correct DSP concepts were applied. To further evaluate the students' understanding and application of DSP concepts various assessment activities were conducted such as MATLAB Grader tests, presentations, and demonstrations.

C. Delivery framework

The combination of traditional lectures with PBL sessions ais included in the delivery framework as shown in Figure 2. Each session is of two hours and divided into different sub-sessions. The structure of this delivery framework is given below:

1) Traditional Lecture sessions: Every module started with a traditional lecture session focusing on theoretical cconcepts of DSP. These sessions provided the foundational knowledge required for the PBL activities and were conducted by our faculty in the classroom.

2) PBL sessions: Following the classroom lectures, there were in-class activities where students watched online resources, some prepared by our own faculty and others from the NPTEL and MathWorks. Implementation activities involved students applying the relevant algorithms using MATLAB. These sessions emphasized collaborative learning, critical thinking, and practical application of DSP techniques, with facilities for interacting with faculty, group discussions, and working on real-world problems.

3) Assessment and feedback: Continuous assessment was carried out through tests, reviews, presentations, and demonstrations. Feedback from faculty and peers was used to guide and improve student learning.

D. Assessment Strategies

The assessment strategies were designed to evaluate both theoretical understanding and practical application of DSP concepts. Around ten rubrics criteria were considered to effectively evaluate the performance. The criteria chosen were focused on Literature survey and report - summary of findings with clear understanding, data acquisition, applying transform techniques, understanding of signal characteristics, developing system block diagram, designing of filters, system analysis, simulation of results, validation of results, presentation and demonstration. These rubrics played an important role in

Timeline		Contents/Concepts/Topics covered	Activities	Assignment	Learning	Example application (Speech processing)	Assessment	Marks
Phase – I **Week – 1: Chapter 1:** Introduction to DFT/IDFT								
Day 2	15 mins	-	-	○ Numerical problems on Fourier series	-	-	Programming Test using MATLAB Grader ○ Signal generates and operations	5
	45 mins	○ Introduction to Fourier analysis	-		○ Mathematical perspective of Fourier Series ○ Time and frequency-domain (spectral) representation of a signal	-	-	-
	40 mins	-	Resources: Discrete Fourier Transform - MATLAB & Simulink Fourier Analysis - File Exchange - MATLAB Central (mathworks.com)			-	-	-
	20 mins	-	○ Problem Identification from the list of themes provided	-	-	○ Problem Identification	-	-

1. https://archive.nptel.ac.in/courses/108/104/108104100/ Week7- Week 11 (Prof. Aditya K. Jagannatham, IIT Kanpur)

Fig. 2 Sample delivery framework with teaching learning activities in a session

clarifying expectations and served as guide that help students understand the key areas where their performance will be evaluated.

The other key components of assessment included are:

1) Formative assessment: Tests using the MATLAB Grader tool were conducted to evaluate students' understanding of the concepts learned and their programming skills. Interim presentations and demonstrations also provided insights into students' grasp of the concepts and offered timely feedback.

2) Summative assessment: Final assessments included comprehensive presentations and demonstrations to evaluate the overall learning of DSP concepts and the ability to apply them to real-world problems.

3) Reflections: Two reflection sessions were conducted throughout the course. These reflection activities encouraged students to self-assess their learning progress and identify areas for improvement.

This structured approach aimed to bridge the gap between theory and practice in DSP education, enhance student engagement, and develop problem-solving skills essential for real-world applications. The results and challenges faced during the implementation of this new course format are discussed in the following sections.

III. RESULTS

After implementing the PBL approach for teaching DSP course to the third year (fifth semester) students, the experience of both faculty and students was very exciting. There were reflection sessions for students where they analysed, what they know, need to know and how to know. Reflection questions were prepared to cover the various aspects of their problem solving as shown in Figure 3. Students could relate the concepts studied- are applied to solve the problem. The demonstration and presentations scheduled at the end of each phase, to showcase the progress of the problem-solving process helped students to improve presentation skill and communication skill. The suggestions and comments given as feedback made the students to think, correct and confident of their solution. Since students were aware of the rubrics, it was observed that the learning, concept application and presentation became better after the first evaluation. The short reports prepared in the standard format for every presentation improved the technical writing skill. The MATLAB grader tests conducted frequently during the course helped them to improve programming skill also.

Elements	Questions	Response
Conceptual Understanding	Explain the fundamental concepts of frequency analysis and how it applies to audio/biomedical/speech/Image signals.	Frequency analysis of Image involves transforming the image from spatial to fourier domain spectrum, which highlights, edges and patterns in the image.
Data Interpretation	Analyse the frequency spectrum of the signal you obtained during the activity. What patterns or trends did you observe in the frequency analysis of the signal?	The spectrum puts the information into different frequency bins. On Analysing it is observed that, noise lies in the higher frequency, and vertical edges in spatial domain are horizontal lines in frequency. There is a DC component at 0

Fig. 3 Sample Reflection questions and response

Since this new initiative was implemented for the first time for this course, we could not compare the present results with previous experience. We considered this as a pilot study. Even the students' acceptance was also a factor as the cohort was quite big. Regarding the quantitative measurement of student engagement, we did not originally collect quantitative data, but we did observe increased student participation, which was reflected in class discussions, and presentations. Furthermore, informal feedback through continuous in-class interactions indicated improved involvement in the course. These activities also made the students to improve their problem solving skills. For future iterations of the course, we plan to implement formal surveys to quantify these observations. But we have collected the feedback where students were asked to opine on benefits of PBL approach as compared to traditional approach which they have experienced in other courses and in previous semesters.

The feedback was collected by sharing the google form containing questionnaire on different aspects of PBL experience they underwent during the course. The total number of students who have completed the feedback is 256. The quantitative details of the feedback along with feedback questions and the response of students in shown in Table 1. The feedback questionnaire was collected on a 5-point scale (1 = Strongly disagree, 5 = Strongly agree). The response received was exciting with 88% of the students (225 out of 256) gave feedback that PBL method helped them to learn DSP concepts better, usage of software tools and various practical applications where DSP plays a vital role. They also expressed the benefits of self-directed learning and appreciated the guidance given by the mentors at various stages of problem solving. This indicates that the new pedagogy has a significant impact on student learning.

TABLE 1.
FEEDBACK RESPONSE OF PBL APPROACH

Sl.No.	Feedback Questionnaire	Feedback %				
		5	4	3	2	1
1	Overall experience: Overall experience with PBL approach in DSP course?	35.4	33.1	22.3	7.7	1.5
2	Engagement and collaboration: How did you find the level of engagement and collaboration among team members during PBL sessions compaired to traditional classroom setting?	42.3	28.5	19.2	8.5	1.5
3	Understanding concepts: Did the PBL approach helped you in better understanding the key concepts of DSp compared to traditional teaching methods?	34.6	30	21.5	10	3.8
4	Self-directed learning: To what extent the PBL approach encourage self directed learning and independent research in comparison to traditional teaching methods?	38.5	29.2	20	9.2	3.1
5	Problem solving skills: To what extenet do you think PBL improved your problem solving skills in real-world scenarios related to DSP when compared to traditional teaching methods?	33.8	32.3	24.6	6.9	2.3
6	Application of knowledge: Did the PBL approach enhance your ability to apply theoretical knowledge to real-world problems in the field of DSP as compared to traditional teaching methods?	35.4	31.5	21.5	9.2	2.3
7	Real-world relevance: How well do you think the PBL approach helped bridge the gap between theorotical knowledge and real-world applications of DSP as compared to traditional teaching methoods?	33.1	36.2	19.2	9.2	2.3
8	Facilitators role: How effective do you fel the facilitators were in guiding your learning process and providing support during PBL sessions?	43.1	22.3	20.8	9.2	4.6
9	Preference: Given the choice, would you prefer future courses in DSP to be taught using the PBL approach, traditional teaching or both?	42.3	26.2	19.2	10	2.3

IV. CONCLUSION

Problem-Based Learning offers a promising approach for teaching mathematical oriented courses such as Digital Signal Processing. Students were given freedom to choose their team members and the problem from their area of interest. The mentors helped them to refine and reviewed by giving feedback. The students were directed to learn few concepts on their own as and when required for problem solving. By engaging students in active learning, promoting critical thinking skills, and real-world application of DSP principles, PBL approach was found effective in better student learning as compared to traditional learning. Though it was very exciting experience for both students and faculties, it was more challenging for the faculty to engage huge number of students around 320. The faculty workload was increased due to the extra hours spent for preparation and regular reviews across multiple student batches. To address this in future iterations, we plan to implement the following strategies: (i) Peer Review Mechanism where students provide feedback on each other's progress at certain checkpoints. This will help reduce the frequency of formal faculty reviews and encourage collaborative learning. (ii) Teaching Assistants (TAs) will be trained to provide initial feedback on student progress, allowing faculty to focus on higher-level guidance and final reviews (iii) Digital tools for progress tracking such as automated submission portals and real-time dashboards could allow faculty to monitor team progress more efficiently without needing frequent in-person reviews (iv) To integrate more reflections from the students in the form of quotes or testimonials to make the impact of the PBL approach stronger and relatable.

As educators, we continue to explore PBL to enhance its effectiveness and equip students with the advanced knowledge and skills required to excel in signal processing application areas.

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