# Integration of Problem-Based (PBL) Learning in Data Structures Course to Engage Undergraduate Students in Higher-Order Learning

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*Abstract*—**Data Structures is 3-credit course offered to undergraduate students in the computer science and engineering program in India. Data structures are fundamental to computer science, impacting algorithm effectiveness and software systems. Careful selection of data structures leads to quicker problem-solving, reduced memory usage and improved scalability across domains like databases, networking, web development, and artificial intelligence. The traditional lecture-based instruction approach emphasizes on memorization and basic implementation of data structure concepts like linked lists, stacks, queues, etc. It allows students to understand concepts superficially which promotes recollecting information but they struggle to apply data structure concepts effectively with higher-order thinking skills to solve real-world or complex problems. This pedagogical approach does not adequately prepare students for the assessments they encounter which test the student's ability in higher-order thinking skills. In this study, we present a conceptual framework of how current challenges in the Data Structures course could be addressed through the adoption of problem-based learning.**

*Keyword*—**Collaborative Learning; Computing Education; Data Structures; Higher-order Learning; Problem-based learning;**

*JEET Category*—**Choose one: Research, Practice.**

## I. INTRODUCTION

Higher education in India is going through a transformational phase based the vision of NEP 2020 which focuses on higher-order learning and skilling for industry readiness (Kandakatla, R., Joshi, R., & Agrawal, A, 2024). The data structures course is considered one of the essential courses in undergraduate computer science curricula, as many real-world problems—from social networks and web search engines to financial systems and scientific computing—rely on sophisticated data structures. These data structures are fundamental tools for organizing, storing and manipulating data in software application development.

Data structures are classified into two categories: linear and nonlinear. Arrays, linked lists, stacks and queues store data sequentially known as linear data structures. Trees and graphs are nonlinear data structures which organizes data hierarchically or in interconnected networks. Both types are very important for designing algorithms that can be implemented in various programming languages to develop applications addressing real-world problems or scenarios (Abhar & Gatuam, 2019).

(Srihith et al., 2023) explored the critical role of data structures in the computing field, demonstrating how they support both simple applications for example a music player, and complex applications like Amazon online shopping, which manage large amounts of data.

(Mehta et al., 2019) described the implementation of graph data structures in real-world applications. Dijkstra's algorithm used to develop the Google Maps application provides real-time navigation updates by finding the minimum distance (shortest paths) between two points. These examples focus attention on the importance of mastering data structures for aspiring computer science professionals.

Mastery of data structures enables students to develop innovative solutions to real-world problems. Undergraduate computer science students must achieve higher-order learning in data structures to acquire more profound understanding of these concepts, which is crucial for their development as computer science professionals.

The data structures course is inherently problem-solving oriented. It's content is focusing on teaching students how to design, analyze, and implement algorithmic solutions to complex engineering real-world problems. Traditional lecture-based instruction concentrates on basic definitions, properties, and operations of data structures, providing a strong foundational understanding. However, this approach often falls short in encouraging students to apply their knowledge to real-world scenarios. And it fails to develop essential problem-solving skills, such as logical reasoning, analytical and critical thinking.

Relying heavily on rote memorization, limited coding practices on real-world problems can limit students' ability to engage in higher-order learning. Insufficient opportunities for collaborative learning may further limit their development of higher-order learning. This approach may hinder the development of critical problem-solving skills necessary for success in the field of computer science.

## II. BACKGROUND WORK / LITERATURE WORK

The current Data Structures course focuses on theoretical concepts rather than practical applications. A separate laboratory course for data structures is designed in line with the theory course, but the experiments are limited to the implementation of basic data structures like arrays and linked lists. These experiments are designed for practicing fundamental theoretical concepts, and their relevance to real-world problems is minimal.

The course outcomes of the Data Structures course focus on surface-level learning rather than deep learning due to more emphasize on memorization and the application of basic concepts. Students do not have adequate learning opportunities to think critically and engage in problem-solving, which would promote higher-order learning. Higher-order learning refers to cognitive processes that go beyond remembering and recalling facts and information. It involves critical thinking, analysis, and synthesis.

The concepts of data structures are often explained using worked (solved) examples. These examples are demonstrated using compilers in lecture-based learning, which can lead to difficulties in understanding multiple environments and increase the cognitive load required to construct meaningful knowledge (Mtaho & Mselle, 2024) (Cheah, 2020).

Higher-order thinking skills involve engaging in complex thought processes beyond memorization and recalling facts. These skills include the cognitive processes of analysis, evaluation, and the creation of solutions to problems (Billah et al., 2019). Possessing higher-order thinking skills is essential for any undergraduate in computer science and related fields.

Higher-order thinking skills enable learners to construct conceptual knowledge of programming and data structures concepts. One who obtained these skills analyzes and evaluates different approaches, and make decisions about choosing an appropriate data structures and algorithms to solve real-world problems. Learners conduct analysis and provide specifications for problems by identifying the required number and types of variables, leading to the construction of general solutions called algorithms. This process exhibits their problem-solving skills through higher-order learning.

To achieve higher-order learning, students must become self-directed learners who are intrinsically motivated and can obtain and retain conceptual knowledge. Continuous practice is crucial for retaining the conceptual knowledge of data structures. Constructive learning theory promotes the retention of conceptual knowledge through collaborative learning.

Problem-based learning is an effective pedagogical approach that engages learners actively to achieve higher-order learning (Amashi et al., 2022). It is a student-centric approach that focuses on problem-solving through content learning, shifting the learning environment from content delivery to problem-solving (Asundi et al., 2021). It promotes collaborative learning and develops logical and analytical skills in solving real-world problems (Bhaumik et al., 2024). This approach not only improves theoretical comprehension but also makes practical visualization easier which helps students to develop critical thinking to solve real-world problems (Amashi et al., 2021). As a result students perform better on theoretical and practical tests to achieve academic success (Nayak et al., 2021).

In this study, we present a conceptual framework for addressing the current challenges in the Data Structures course through the adoption of Problem-Based Learning (PBL). These efforts are part of the pedagogical innovations being led by the Center for Engineering Education Development at KG Reddy College of Engineering and Technology (Tuti et al., 2016).

## III. METHODOLOGY

Problem-based learning (PBL) is a pedagogical approach that encourages students to learn and apply their knowledge and skills through active participation in the learning process. PBL can be effective in fostering higher-order learning among undergraduate students in the context of data structures courses. Faculty can create an interactive learning environment that enhances student engagement and fosters higher-order cognitive skills by integrating PBL into the data structures course when it is compared to the traditional lecture-based approach that focuses solely on theoretical aspects.

PBL can be implemented at the curriculum level, group level, and individual learner level. Problems and objectives are identical for all students at the curriculum level. At the group level, each group can have the same problem with different objectives, or different problems with the same objectives. Each student can be assigned a predetermined objective at the individual level.

In this study, the data structures course is part of the undergraduate computer science curriculum. And it is proposed to be re-designed with an integration of PBL to promote higher-order thinking skills among the undergraduate computer science engineering students. The learning outcomes and content of the data structures course, combined with the learning objectives of PBL, ensures higher-order learning through cohesive learning theories.

Learning outcomes of the data structures course are:

**CO1**: Select data structures that efficiently model the information in a problem.

**CO2**: Assess efficiency trade-offs among different data structure implementations or combinations.

**CO3**: Design programs using a variety of data structures, including hash tables, binary and general tree structures, search trees, tries, heaps, graphs, and AVL-trees.

**CO4**: Compare graph traversal methods.

**CO5**: Evaluate real-time applications using pattern matching algorithms.

Learning objectives of PBL include problem-solving skills, collaborative skills, and intrinsic motivation. These objectives are achieved through the learning outcomes and content of the data structures course, which ensures higher-order learning through the cohesive integration of learning theories and objectives.

TABLE I
MAPPING OF COURSE OUTCOME WITH BLOOMS TAXONOMY LEVELS

| Course Outcomes | Blooms Taxonomy Level |
|---|---|
| CO1 | Evaluate |
| CO2 | Evaluate |
| CO3 | Create |
| CO4 | Analyze |
| CO5 | Evaluate |

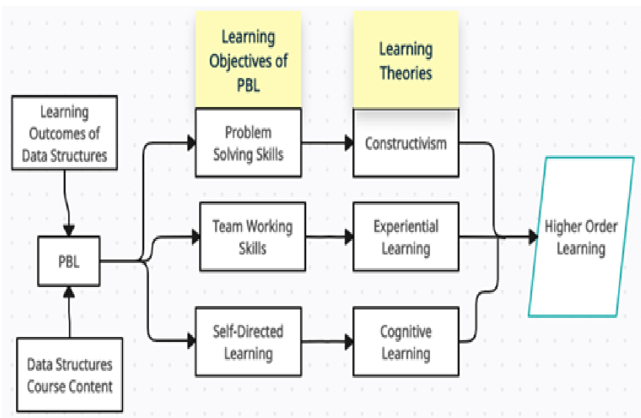


Fig.1 represents the relation among learning outcomes and learning objectives of PBL.

The constructivism learning theory promotes the knowledge construction through experimentation and by solving real world problem solving among the learners (Bada, S. O., & Olusegun, S., 2015). Through the collaborative teams the learners work in teams to solve real-world problems (Kumar & K. S., 2017). The learners analyze the problem and discuss among the team members and construct the knowledge to choose an appropriate data structure. This kind of process is demonstrated by Kolb experiential learning theory which consists of four stages such as concrete experience, reflective observation, abstract conceptualization and active experimentation (McCarthy, 2010) (Morris, 2019).

In PBL, the problems are solved by working together in teams in an educational format that promotes an authentic learning situation which strengthens the Self-directed learning which is closely related to self-regulatory learning as a cognitive ability.

These learning objectives are achieved through a seven step method and Aalborg PBL model (De Graaf & Kolmos, 2003).

The seven steps to be followed for implementation of PBL are:

1. Learning outcomes
2. Define problems that involve subject learning outcomes.
3. Analyze the problem
4. Explain how the problem is introduced, scheduled and supported.
5. Resource review
6. Documentation of guidelines of the process
7. Review and check the for the authenticity

1. ***Learning outcomes:*** the learning outcomes and content of data structures course introduced to the learners and also discuss about the learning objectives of PBL. i.e. the learners will be given an awareness of the problem solving process, how the teams will be formed and work and understand the strategies to be followed for learning concepts of data structures.

2. ***Meet the problem that involves subject learning outcomes:*** the learners will be introduced with problems which are of relevant to the real-world professional context. Learners will read, reflect and inquiry the problem individually and brainstorm the relevance of the problem with learning outcomes, content of the course to understand problem statements in an effective way.

**3.** ***Analyze the problem:*** the learners identify the learning issues individually and will go through the various resources such as text books, internet sources etc. and will come up with proper explanations and hypotheses to the issues identified.

**4.** ***Explain how the problem is introduced, scheduled and supported:*** In this step, the learners introduced their expected deliverables along with a detailed schedule, various supported methods and assessment process used in completion of the task.

**5.** ***Resource review:*** The teacher will identify the list of suitable resources required to ensure the students to achieve what they required through PBL in relevant to the course. The resources may include text books, online resources such as websites, journals and interactive virtual learning environment tools etc., these resources can be made available to the students by the teacher or students can also identify and use it to complete their tasks in the process.

**6.** ***Documentation of guidelines of the process:*** The teacher will prepare a detailed document which consists of a schedule of various stages of PBL, activities, deliverable and assessment criteria for the stages defined in the process. This document provides details and guidance to complete the tasks in the process.

**7.** ***Review and check for the authenticity:*** A teacher can check and review the total process and modify it according to the need wherever necessary to ensure the authenticity of learning outcomes through the PBL process before commencement of implementation of PBL process in the course of study.

The PBL process described above can be implemented in the data structures course in two different ways i.e. at full course level or at module level. The existing university course content of data structures consists of linear and non-linear data structures concepts which address specific learning goals or outcomes respectively different real-world problem scenarios. An easy or medium level complex problem may be solved by integrating few concepts whereas a difficult level complex problem can be solved with the help of both linear and non-linear data structures curriculum.

A teacher can define module wise simple or medium level problems or a difficult level complex problem covering all the modules of the data structures course content while implementing PBL with data structures course.

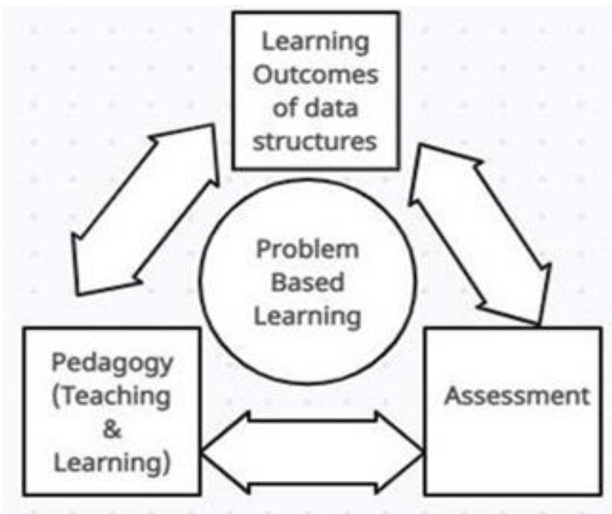


Fig.2: Integration of learning outcomes of a course, Pedagogy and Assessment in line with PBL.

One must focus on the components of constructive alignment (Kandakatla & Streveler, 2015) to achieve learning outcomes of the course in line with learning objectives of PBL as described in figure 2 (Rüütmann, T., 2023).

A module level or course level (part of curriculum) conceptual framework for PBL implementation process in data structures course is as follows:

***Introduction of Learning Outcomes:***

Introduce the learning outcomes of data structures and relevant topics to achieve these learning outcomes by aligning the PBL learning objectives such as problem solving, teamwork and self-directed learning.

***Introduction of Problem Statement:***

Identify the problem statements and introduce them to the learners which are open-ended and industry relevant real-world problems. A Teacher can introduce a problem statement to the learners to be solved. An example problem statement which can be announced to the students is mentioned as follows:

Problem Statement: A complex system is needed in a major health care center to handle patient records, secure access, and quick retrieval.

In other ways, the learners can come up with their own problem statements and can present it to the peers and teacher.

The teacher will form the teams and inform the learners and analyze the problems statements.

***Analyze the problem statements:***

The learners analyze the problem statements individually and record the learning issues and brainstorm them in the teams. This kind of activity promotes analytical thinking skills through analysis of one’s own knowledge with team member’s feedback or knowledge sharing. Through this process learners will construct knowledge about a problem statement.

***Detailed Schedule:***

The learners present their problem statements which were brainstormed and finalized in their teams to the entire class. Both the teacher and learners (Teams) confirm their problem statements and plan for implementation of problem statements through the course content. In this stage, a detailed schedule is prepared and shared with learners by the teacher. The schedule contains a timeline for completion of task along with aligned pedagogy, resources and assessment.

***Resources Review:***

The teacher will provide resources which are required for the course content, problem solving such as textbooks, online materials and simulation tool. A learner also can search for various resources other than resources provided by the teacher for additional information which will help them to provide solutions for the chosen problem statement.

***Guidelines Document:***

A teacher will provide detailed information on the content, pedagogy, resources, assessment and timeline to complete the task. This also contains the roles and responsibilities of teacher, learner roles in the process of PBL implementation. It is the teacher’s responsibility to provide a detailed plan of various stages of process in the document like, identification, formulation, designing a solution and implementation of solution using the course content, rubrics for evaluation of presented solution.

***Review and Finalization:***

The teacher reviews all the problem statements presented by the learners (teams) or teacher provided statements relevant to the course of study and modifies accordingly if any for relevance and confirms for process implementation.

A high-level correlation of course content, pedagogy, assessment and higher order thinking skills in the implementation of PBL process in the data structures is presented in the following figure and table.

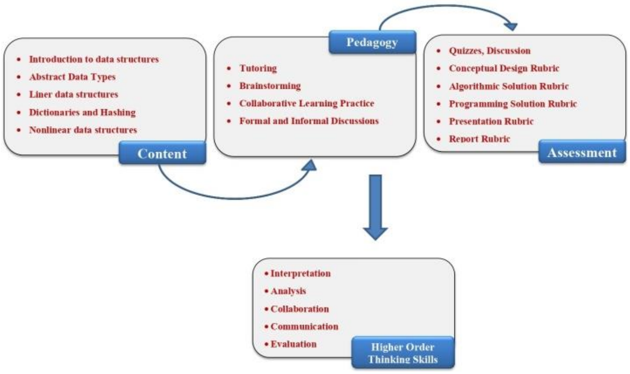


Fig.3: Alignment of content, pedagogy and assessment to achieve higher order thinking skills in the implementation of PBL in data structures course.

TABLE II
ALIGNMENT OF CONTENT, PEDAGOGY AND ASSESSMENT TO ACHIEVE HIGHER ORDER THINKING SKILLS IN IMPLEMENTATION OF PBL IN DATA STRUCTURES COURSE

| Course Content | Pedagogy | Assessment | Higher order thinking skills |
|---|---|---|---|
| Introduction to Data Structures, abstract data types, Linear list (Arrays, Linked list, Stack and Queues), Dictionaries, Hash Table representation, Trees (BST, B-Tees, B+ Trees, AVL Trees etc), Graphs and Graph Traversal Methods, Sorting Techniques, Pattern Matching and Tries | Tutoring<br>Brainstorming<br>Collaborative Learning Practice<br>Formal and Informal Discussions | Quizzes<br>Discussion<br>Conceptual Design Rubric<br>Algorithmic Solution Rubric<br>Programming Solution Rubric<br>Presentation Rubric<br>Report Rubric<br>Peer Evaluation | Interpretation<br>Analysis<br>Collaboration<br>Communication<br>Evaluation |

## IV. RESULTS (WORK IN PROGRESS)

The proposed conceptual framework presented in this study sheds light on the various issues in the current format of the Data Structures course and indicates barriers to enabling students to engage in higher-order learning. The issues and barriers discussed are grounded in educational learning theories to provide a foundational understanding of why they exist. The conceptual framework then presents the changes to be done with the content, assessment, and pedagogy of the Data Structures course with the intended learning outcomes and learning objectives of PBL focused on higher-order learning.

## V. CONCLUSIONS

Problem-based learning is an effective pedagogical strategy alternative to traditional lecture-based instruction in the data structure course by situating learning within the context of complex, real-world problems. The observation from this study is that problem-based learning approaches through constructive alignment of the course have the potential to enhance students' deeper understanding through the application of complex concepts of data structure courses to solve real-world problems. Future work of this study will focus on the implementation of a redesigned Data Structures course by following 7-step of PBL and Aalborg PBL model and experimentations of students' enhanced learning outcomes.

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