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Chapter 28
Problem-Based Learning (PBL) in Undergraduate Education: Design Thinking to Redesign Courses

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Abstract Problem-based learning (PBL) has profound implications on the motivations of the student to learn and is known to help develop critical thinking, complex problem-solving, self-learning, collaboration and communication skills, thereby enabling fresh graduates to be industry-ready. However, most institutes of higher education in South Asia offering undergraduate programmes have instructional and didactic pedagogical systems. The Erasmus + project, '***Strengthening***

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Problem-based Learning in South Asian Universities' (PBL South Asia) aims to build capacity of the South Asian partner institutes by collaboratively developing best practices in PBL for undergraduate education, bringing expertise and experience of peers from across Europe and India. Therefore, to gain benefits of the PBL approach, the redesign of existing courses was undertaken and the novel strategy of conducting a Design Thinking workshop to do so, was engaged. During the five-day workshop, faculties from the institutes in Nepal and Bhutan, who are most well aware of the challenges, shortcomings and strengths of their curriculum, were mentored step-by-step, by their Indian and European peers, who have more experience in delivering PBL courses. Backed by the strategy of Design Thinking, the complex problem-solving activity of course design was addressed systematically, and the five institutes proposed redesigned courses which are currently in the process of implementation.

28.1 Introduction

India, Nepal and Bhutan share a common history with respect to modern education practices and have a similar institutional and curricular construct for undergraduate, technical programmes. Graduate programmes are offered either on university campuses or in affiliated colleges, and a national-level body usually oversees curriculum development on technical education, such as All India Council for Technical Education (AICTE) in India and Nepal Engineering Council (NEC) in Nepal. Though the evaluation schemes may vary, the overall assessment is conducted as a common examination across all colleges affiliated to a university. A survey across South Asian universities revealed that the undergraduate curricula are predominantly instructional and not adequately hands-on due to several constraints, such as

- University-directed lesson plans with heavy syllabi to cover and restricted time for practical activities;
- A fewer number of co-instructors to guide in practical, real-world issues that can be addressed in courses;
- Dearth of motivation in students to self-learn and innovate during the stipulated practical hours within a course;
- Poor critical-thinking ability due to a general lack of awareness on sustainable development goals and their local implications in the students;
- Fewer collaborations in these courses and
- Poor communication skills.

Literature corroborates that in traditional engineering education [1]:

– Programs are content-driven instead of need-driven and do not provide sufficient design experiences to students.
– Students lack communication skills and teamwork experience, as well as awareness about social, environmental, economic and legal issues.

– Faculties lack practical experience and are not able to adequately relate theory to practice or provide design experiences, having outdated teaching and learning strategies.

Therefore, to address the above shortcomings and constraints, the introduction of problem-based learning (PBL) as a pedagogical approach is proposed as it is known to support the development of specific skills, such as critical thinking; complex problem solving, self-learning, due to increased motivation and engagement; collaboration and people management and communication [2] and can be implemented without altering the existing course content that is approved by the governing body or university.

This paper presents the unique proposition of using a 'Design Thinking' process to guide the redesign of existing courses into PBL courses.

28.2 Literature Review

28.2.1 Design Thinking

'Design Thinking', as a descriptive model of creative problem-solving, has its roots in architecture and industrial design practice [3]. It is defined as a cognitive process [4] of identifying and resolving 'wicked' or ill-defined problems through iterative stages and activities. Literature notes that this approach is viewed through various lenses, from being a process of reflective practice to being a systematic problem-solving methodology.

Stanford's d.school Design Thinking process [5] and IDEO human-centred design model [6] are among the most renowned, entailing five nonlinear activities, namely Empathize—Define—Ideate—Prototype—Test. These two models stem from human-centred design principles, whereas several other systematic design approaches, such as Cross [4], Pahl and Bietz [7], Hubka and Eder [8], Dieter and Schmidt [9], Eppinger and Ulrich [10] are prevalent in engineering practice. The latter models propose stage-wise progression from problem identification to concept selection, supported by several methods and tools. While each model has its relevance depending on the problem at hand, they may be broadly described by the following four steps [11]:

- ***Step 1: Identification of requirements*** generated and clarified against needs, through observations, interviews, role-play, stakeholder analysis and checklists;
- ***Step 2: Ideation of solutions*** through creative methods such as brainstorming and SCAMPER;
- ***Step 3: Consolidation of solutions into feasible solutions*** through for example TRIZ and morphological chart method and

- ***Step 4: Selection of the most promising solution*** as concept from among all other alternatives, upon evaluation by methods such as weighted objectives and concept selection methods.

28.2.2 Problem-Based Learning (PBL)

Problem-based learning (PBL) is an ‘instructional (and curricular) learner-centred approach that empowers learners to conduct research, integrate theory and practice and apply knowledge and skills to develop a viable solution to a defined problem’ [12]. This method was developed and implemented in McMaster University around 1965 and is based on the theory that learning is a process in which the learner actively constructs knowledge [13]. It is defined as a ‘focused, experiential learning organized around the investigation and resolution of messy, real-world problems’ [14] in which students learn through ‘facilitated problem-solving that centres on a complex problem that does not have a single correct answer’ [15].

Six core characteristics of PBL [16] are identified as follows:

1. Learning is student-centred: Students take responsibility for their own learning, identify the knowledge that is required to learn and determine the way/resources to get information by themselves.
2. Learning occurs in small student groups: A group generally consists of five to nine students who work together along with a tutor. Students share their knowledge and learn from others, and learning happens in collaboration.
3. Teachers are facilitators or guides: Tutor asks students typically questions to better understand and manage the problem.
4. Problems form the organizing focus and stimulus for learning: Problems represent the challenges students will face in real life and provide the relevance and motivation for learning. Students realize what they will need to learn in order to solve the problem.
5. Problems are a vehicle for the development of problem-solving skills: The problem format is in the same way that it occurs in the real world (ill-structured, complex) which allow students to inquire the problem deeper. The students do not restrict to a single subject; instead, they focus on integrating information from many disciplines.
6. New information is acquired through self-directed learning: The students are expected to learn from the world’s knowledge and accumulated expertise by virtue of their own study and research.

There are many variants of PBL as it can be modified according to domain or subject, individual course requirements or institute traditions, and can be implemented at a chapter level, course level or even curriculum level. Broadly, every variant has two phases, namely a collaborative-learning phase and a self-directed learning phase. A single phase alone has insufficient impact on learning in PBL [17]. An exemplary PBL structure is given below:

- The PBL process starts with an ill-defined, real-life problem formulated by tutor/teacher.
- Students in small groups start analysing the given problem systematically and try to reach a consensus on the meaning or implication of the problem based on the terms and concepts of the domain, subject or topic.
- Next, they construct a tentative theory explaining the phenomena or events described in the problem-at-hand in terms of its underlying principles or mechanisms and identify the facts that they already know and what they require to know in order to solve the problem. Thus, learning issues for individual study are formulated. These learning issues usually consist of questions arising from the discussions.
- Students search and evaluate resources which can be useful to learn problem domain and pursue these issues through individual, self-directed learning usually using a variety of resources: books, articles, movies and Internet sites, where tutor scaffolding takes place.
- Students return to their tutorial group, review and share what they have learned, propose the solution and elaborate on different aspects of it. Together they discuss and explore the extent to which the students understanding of the problem have developed and whether misconceptions remain that need to be addressed.
- Students self-evaluate and evaluate others in the group (peer evaluation).

Curriculum-wide PBL implementation and single-course PBL implementation show similar findings according to earlier studies [17, 18]. PBL has been found to have profound implications on the motivations of the student to learn, stating that ‘the freedom to select their (students) own resources to answer the learning issues gives them ownership over their learning’, [19] and the onus of ensuring retained motivation falls on the shoulders of the students as peer–teacher [20]. The role of the mentor is to assure the students and allow constructive discussion while not interfering with the process. The teacher or tutor may also be the mentor. However, the key responsibilities of the tutor are formulating a contextually appropriate problem and facilitating the learning by helping students manage metacognitive activities by providing ‘triggers’.

The key element driving PBL is the ‘problem’. It guides self-learning and problem-solving and, in turn, develops the other critical skills. Subject or topical problems and learning objectives for a domain maybe considered universal and are well-structured, less complex and domain-specific. However, ‘real-world’ problems are ill-structured, more complex and cover knowledge of multiple domains [21], and its context is subjectively unique to South Asia. Consequently, borrowing of existing courses and their defined problems from European curricula would not be appropriate. The revised literature also states that different cognitive skills are required to solve well-structured or classroom problems versus ill-structured or real-life problems [22], thereby reflecting that it is inadequate for students to merely be able to solve classroom problems as it has little to no bearing on their abilities for post-undergraduate studies.

The two critical attributes of a ‘problem’ are as follows [22]:

1. A problem must be an unknown entity in some situation (the difference between a goal state and a current state) varying from algorithmic math problems to complex societal problems, such as violence in the schools.
2. Finding or solving for the unknown must have some social, cultural or intellectual value, i.e. someone believes that it is worth finding the unknown.

Problem complexity is defined by the number of issues, functions or variables involved in the problem; the degree of connectivity among those properties; the type of functional relationships among those properties and the stability among the properties of the problem over time [23]. Problem statement may be formulated with respect to general guidelines in the form of a checklist [24] or criteria identified for constructing problem [25]. Therefore, formulating contextually appropriate problems for South Asian undergraduate students is important.

28.3 Descriptive Study—Redesigning Courses with Design Thinking

A five-day workshop was conducted at the Indian Institute of Science (IISc), Bangalore, with the intent to redesign existing courses into PBL courses, to be implemented in the partnering universities of Nepal and Bhutan for the final year undergraduate students.

28.3.1 Methodology

The workshop had 24 participants comprising 12 faculties from the five South Asian partner universities in Nepal and Bhutan as the key course designers, supported by 12 faculty and research associates from the Indian and European Universities.

Four teams were devised (Table 28.1), based on two factors—(1) status of institute: (S1) autonomous or (S2) affiliated; and (i2) intervention sought: (i1) process and PBL methodology focus; (i2) domain and technical focus and (i3) Soft skill focus. While the status of the institute reflects the ability of the institute to implement the proposed redesigned PBL course, the three broad areas of focus for course development were clarified from previous surveys and need assessments. The four teams were as follows.

Table 28.1 Team composition

	(i1) Process and Methodology focus	(i2) Domain and Technical focus	(i3) Soft skill focus
(S1) Autonomous	Team 1	Team 3	
(S2) Affiliated	Team 2		Team 4

The workshop was planned, such that each day would emulate a stage of the design process, as elucidated by the Design Thinking steps discussed above and, in turn, had (1) tutoring sessions, where the specific design stage and its methods were taught to support the course redesigning task, as well as for further dissemination during the course; (2) collaborative-learning sessions, where each team consisting of the 'course designers' and mentors co-created the solution. Apart from this, expert practitioners of PBL presented cases and examples of PBL course or curricula implementation in India and Europe. At the same time, self-learning sessions were encouraged prior to or during the off hours of the workshop.

The program for the workshop was as follows:

Day 1—Team building

Day 2—Identification/exploration

Day 3—Conceptualisation/ideation

Day 4—Consolidation/discussion

Day 5—Selection/reflection and presentation.

The teams were provided with a template for 'proposal of a new course/PBL course adaptation'. It provided an overall guideline for development and implementation of each proposed course and highlighted the essential elements that need to be addressed, apart from the individual requirement of each course and syllabus.

28.3.2 Results

On the final day of the workshop, the teams presented their proposed 'solutions' for each of the focus areas and drew discussions, reflections and insights to conceptualize institute-specific, redesign of their course with adoption of the PBL approach. An example of such a proposal, detailed with respect to the provided template, is given below.

28.3.2.1 Current Course Description and Justification for Change

This course will teach additional practical skills related to integrated circuit building (including the prototyping of the printed circuit board and integrated circuit) and knowledge of scale integration that are currently missing in the existing course. These missing skills, along with the recent course, will be taught by using PBL methods.

28.3.2.2 Problem Identification

Overview of the Intervention needed is as Follows

Aim: To change the conventional passive learning into active, problem-based learning.

1. Course to be redesigned: Integrated Digital Electronics (Credits: 3) Level: B.Eng., 3rd Year, 1st Sem
2. Course Objective: To impart knowledge different types of Logic Gates, Memory and Switching Systems and apply the same through PBL approach.
3. Duration: One Semester, 15 weeks
4. Learning Outcomes: *On course completion, students should be able to:*
   (a) Develop different digital logic gates using semi-conductor components.
   (b) Analyse, design, simulate and implement digital logic circuits.
   (c) Classify and compare different gates in terms of operation and performance.
   (d) Classify different semiconductor memories.
   (e) Acquire the knowledge to address real-life applications of digital logic gates.
5. Learning Objectives: *Students must be capable of:*
   (a) Independently managing a project;
   (b) Solving real-life problems using digital logic gates/electronics;
   (c) Critically thinking to identify and assess complex problems;
   (d) Working in teams collaboratively, manage projects and people, show leadership; and
   (e) Communicating one's ideas and concepts with clarity.

The Formulated List of Requirements Are Below

1. Course must have the following PBL course elements and ensure that the time is adequately planned:
   (a) Lecture (L) delivery time
   (b) Tutorial (T) time for mentoring/facilitating time
   (c) Students' group/self-learning time
   (d) Students' collaboration time
   (e) Communication time—presentations (Pr)
2. Course must imbibe PBL through several 'triggers' and 'methods' that aid the process.
3. Course Plan must have the stipulated minimum number of hours per week, as per University:
   (a) 3 h/week—Lectures (L) or Tutorials (T)

(b) 1 h/week—Presentation (Pr)
(c) 1 h/week—Lab for prototyping (*P*), or Field visit (*F*)

4. Internal Evaluation Scheme is required, with the consultation of the department, as final exam will be conducted as per University.
5. Availability and access to dedicated Team workspace/prototyping space.

28.3.2.3 Ideation and Solution Consolidation

Teams used several ideation techniques to generate various sub-solutions with respect to the requirements identified earlier and consolidated the same into solution variants (Tables 28.2 and 28.3).

Table 28.2 Activities and skills for each PBL course elements

Course elements				
L: Lecture	*T*: Tutorial	*P*: Practical	*F*: Fieldwork	Pr: Presentation
Lecture delivery	Assignment mentorship	Simulation	Industry visit	Presentation/communication
Question answer session	Analytical thinking and self-learning	Testing	Survey Data collection	Report writing/collaboration
Group discussion/ collaboration	Problem finding/ identification	Prototyping	Problem reformulation	Evaluation (by instructor)
	problem-solving/ideation		Solution validation	Feedback (from instructor, mentor, peer)
			Feedback	

Table 28.3 Mapping of PBL course elements to each chapter/unit of course

Chapter/Unit	Topic/Course details	*L*	*T*	*P*	*F*	Pr
1	Review of BJT and MOS	✔	✔	✔		
2	Resistor–transistor logic (RTL) and integrated–injection logic (IIL)	✔	✔	✔	✔	✔
3	Diode–transistor logic (DTL)	✔	✔	✔		✔
4	Transistor–transistor logic (TTL)	✔	✔		✔	✔
5	Emitter–couple logic (ECL)	✔	✔	✔	✔	✔
6	NMOS and CMOS logic	✔				✔
7	Comparison of logic families		✔			✔
8	Memories	✔			✔	✔
9	Switches					

L stands for 'lecture', for *T* stands for 'tutorial', *P* stands for 'practical', *F* stands for 'fieldwork', and Pr stands for 'presentation'

Table 28.4 Proposal for internal evaluation scheme

Attendance	Scheduled test	Laboratory test	Presentation	Report	Prototyping/	Total
5	10	5	10	5 + 5	10	50

28.3.2.4 Concept: Selection of the Most Promising Solution

Teams evaluated the solution variants and selected the most promising as 'concept' to further detail, as described in Tables 28.4 and 28.5.

Table 28.5 Week-wise course plan

Week	PBL tasks	Roles and responsibility	Notes
1	Course introduction, orientation of teaching methodology, timeline, evaluation criteria	Instructor	Introducing PBL
2–4	Lecture delivery, laboratory work, problem identification and analysis	Instructor and supporting laboratory staff	Classroom and laboratory activities
5–6	Case preparation/field visit followed by presentation and preliminary report submission	Instructor, mentor and supporting staff	Group formation, literature review, domain identification, field visit
7–9	Problem-solving assignments, group discussion, lectures, laboratory works and mentoring	Instructor, mentor and supporting laboratory staff	Brainstorming, classroom and laboratory activities
9	Mid-term presentation /assignment evaluation	Instructor, mentor	Group discussion, feedback collection
10	Incorporating the feedback and generating final outcome	Students	Modification, prototyping
11	Deliverables	Students	Prototyping, assignment submission
12	Deliverables	Students	Final presentation and report submission
13–14	Preparation week	Student	
15	Final assessment, university examination	Student	

28.3.3 Discussions

The proposed courses were conceptualized through a systematic approach and mitigated the conflicts between current practice, university demands and the unorthodox approach of PBL. The resulting course plans and evaluation schemes mapped onto the PBL methodology elements were selected upon extensive discussion and evaluation with the mentors/ course co-creators from the other partner universities, from India and Europe, with expertise and experience in PBL.

28.4 Summary, Conclusions and Discussions

Problem-based learning is a pedagogical approach where students pursue self-learning of a subject or domain, driven by real-world problems. This approach is reported to be effective in inculcating hard and soft skills needed to be industry-ready. However, present undergraduate programs in South Asia are instructional and content-heavy, thereby requiring redesign to incorporate PBL methodology. Design Thinking, a creative approach towards problem finding and solving, is employed during a five-day workshop to guide the redesign process and develop a course proposal for each of the participating institutes of Nepal and Bhutan, mentored by Indian and European partner universities. The use of Design Thinking allowed the faculty course designers to identify several issues from different perspectives, ideate large number of solutions, consolidate them into viable solutions and select the most promising one to further detail. At present, these proposals are being implemented at the home institutes and gathering feedback is in progress.

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