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PROBLEM BASED LEARNING THROUGH DESIGN THINKING TO STRENGTHEN EDUCATION IN SOUTH ASIA

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ABSTRACT
The practice of finding and solving 'wicked' problems, i.e., real-world, complex, and uncertain; creatively, so as to have a positive social impact has always been a designer-ly pursuit, and Problem based Learning (PBL) is a known to be an approach that enables real world problem solving, apart from other top skills for the future, as reported by the World Economic Forum (2016).
Based on the empirical findings, from several case studies and workshops, it was found that South Asian universities require resources that help in practical implementation of PBL approach in undergraduate engineering education, that is otherwise common practice in design discipline. Thus, a collated view of the PBL process, with stages, defined roles, and general guidelines for problem formulation is compiled for handy reference. This paper also presents a literature review on the historical development of PBL pedagogy; its definitions, characteristics and learning approaches; comparison with other approaches, such as, project-based and case-based, and its effectiveness in terms of measures and metrics; and discusses the classification of 'problems', its types and attributes, and the importance of identification and formulation of the 'right' problem to have the right impact with respect to Sustainable Development Goals. The key contribution of this paper is to showcase how Design Thinking has been used as a strategy to inculcate Problem-based Learning (PBL) into undergraduate engineering education and present the implementation of PBL and its impact on engineering education in South Asia .

Keywords: Problem based learning, design thinking, education

1 INTRODUCTION
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", in which students learn through "facilitated problem solving that centres on a complex problem that does not have a single correct answer"(Savery, 1999; Torp and Sage, 2002; Hmelo-Silver, 2004). Literature reports that it has profound implications on the motivations of the student to learn, and can be widely used to support several domains, as it is known to help develop various top skills, such as, critical thinking, complex problem- solving, self-learning, collaboration and communication skills (Duch, Groh and Allen, 2001) necessary for young graduates to be industry-ready and responsible innovators.
Technical education offered by South Asian Universities, particularly at undergraduate level, remains didactic, teacher-centric and contextually disconnected from the issues and challenges of the region, in turn, making the fresh graduates poor in skills needed to be industry-ready. In addition, the members of faculty too, struggle with inculcating real-world issues and problems into practical experiences for students due to course loads, lesson plans and lack of training in more appropriate pedagogical approaches (Acharya et al.., 2021). Problem based Learning (PBL) is one such approach, and has been reported to develop various top skills, as identified by the World Economic Forum (2016). The limitations reported in global context are applicable to the South Asian engineering education as well. The problems of students not being employable at the end of the course is a major issue as highlighted by various forums. Issues of rote learning, insufficient exposure to real-life problems, the development of soft-skills and the exposure to larger contexts is present in the South Asian context as well. Further,

the focus on examination and grades, rather than on learning, is a major concern for this part of the world. This is compounded by the fact that in countries like India, the majority of employers for engineering graduates are in IT and services sector across various streams of engineering, thus leading to the questions among students the usefulness of core engineering courses as compared to industry ready courses. The employability of students is a huge concern. This has led to a phenomenon in the industry where the companies recruit the graduates based on their general aptitude rather than industry ready skill sets and subject them to an extended training programme which span more than a year in some cases. This shows the lack of confidence of the industry in direct deployment of students in the industry without making them ready in such prolonged training exercises.
Through the Erasmus+ funded Capacity Building in Higher Education (CBHE) endeavour, a three pronged approach was taken : (i) development of a handy PBL best-practices quick guide compilation, (ii) hands-on inculcation of these best practices through case studies and workshops.

2 DEVELOPMENTS OF A HANDY PBL BEST PRACTICES QUICK GUIDE

Problem Based Learning (PBL) is an innovative teaching method, derived from the theory that, learning is a process in which the leaner actively construct knowledge (Gijselaers, 1996). PBL best practices were identified and contextually compiled, so as to enable the faculty in educating future problem solvers, with the below summarised topics.

2.1 Definitions, Characteristics and Learning Principles

Barrows (1996) identified six core characteristics of PBL, explained as follows: Learning is student-centred; Learning occurs in small student groups; Teachers are facilitators or guides; Problems form the organizing focus and stimulus for learning; Problems are a vehicle for the development of problem-solving skills; and New information is acquired through self-directed learning.
PBL is an approach to learning which is well matched with prescribed principles of cognitive and constructivist theories of learning. PBL process promotes the activation of prior knowledge and its elaboration. Also, discussion of a relevant problem in a small group facilitates processing of new information. This problem-oriented study allows mastery of principles and concepts such that that can be transferred to solve new problems. Solving problems via PBL method enhance integration of different subject/ domain knowledge. Also, PBL makes learning intrinsically interested and keep students self-engaged in learning. These propositions underlying PBL have been validated and have empirical basis (Schmidt et.al. 2011, Schmidt, 1993; Norman et.al., 1992).

2.2 Effectiveness of PBL Approach : Measures and Metrices

Earlier studies revealed that the ‘level of knowledge tested’, as a learning outcome, was found to be equivalent to that of traditional approaches, however, students who experienced PBL showed; (i) improvement in problem-solving skills (Albanese and Mitchell, 1993; Vernon and Blake,1993) and (ii) increased engagement and motivation to learn, as they preferred PBL to the traditional methods of teaching (Denton, Adams, Blatt, & Lorish, 2000; Torp & Sage, 2002).
Dolomons et.al. (2016) study, across curriculum-wide PBL implementation and single-course PBL implementation, noted similar findings to the earlier studies, where PBL has 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, which gives them ownership over their learning”, and has capability to foster deep learning. Thus, the onus falls on the shoulders of the students as peer teacher (Caswell, 2017) to ensure the motivation of the team is maintained. Several studies in engineering provide empirical support that students learning gains for conceptual understanding is higher than traditional lectures (Yadav, 2011). PBL approach offers the opportunity for students to enhance their critical thinking and self-directed learning skills, and engages students in solving problems (Williams,1999). Students’ perceptions that the curriculum encouraged critical thinking significantly increased after PBL curriculum was conducted (Birgegard, 1998). Students’ critical thinking skills are fostered through their group discussions (Rideout and Carpio, 2001). s suggested that PBL encouraged them to share their opinions with others, analyse situations in different ways and think of more possibilities for solving problems.
Skills like Critical Thinking can be evaluated using California Critical Thinking Skills Test CCTST, Motivation and engagement of students can be evaluated using Motivated Strategies for Learning Questionnaire (MSLQ) Manual (Pintrich, 1991), effectiveness of group activities and interpersonal

skills, i.e., Collaboration, can be evaluated with Team Assessment Tool (Moore et.al. 2006), while Problem-solving and communication skills maybe assessed (summative) by peer, mentor and expert/jury across the duration of the course or curriculum.

2.3 PBL Process

There are many variants of PBL as it can be moulded according to institute traditions and individual course requirements, however, it is described in brief as follows; *The process starts with an ill-defined, real life problem formulated by tutor/ teacher. Students in a small group starts analysing the problem systematically. The terms and concepts are understood and clarified first. Students in a group have agreed opinion on meaning of the problem. Then, students construct a tentative theory explaining the phenomena or events described in the problem-at-hand in terms of its underlying principles or mechanisms. Students then identify the facts that they already know and what they require to know in order to solve the problem. Learning issues for individual study are formulated. These learning issues usually consist of questions arising from the discussion. Students search and evaluate resources which can be useful to learn problem domain. Students pursue learning 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 different aspects of it. Explore to what extent the students' understanding of the problem has developed and whether misconceptions remain that need to be addressed. Students self-evaluate and evaluate others in the group (peer evaluation).*

2.4 Role of Tutor /Mentor in PBL

Traditionally, teachers have been teaching the concepts as well as applications of the concept whereas PBL methodology asks teachers to be facilitator and help students to manage metacognitive activities. Thus, adopting PBL is difficult for teachers as they must transform the whole methodology that they have been following for years. Being a mentor, faculty has to keep in mind that learning is a constructive, not receptive process. They need to permit students to discuss issues. They need to ensure that learning issues are raised and discussed. Being a tutor, faculty should not stifle students' discussion by giving mini-lectures or factual information, asking stream of questions, giving answers or telling students whether they are right or wrong in their thinking, telling students what they ought to study or read, etc.

2.5 Importance of 'right' problem : Types and Attributes

Chi & Glaser (1985) defined problem as a situation in which one is trying to reach some goal and must find a means for getting there. In design domain, it is observed that problem-finding is as important at problem-solving and requirement identification, i.e., "right problem", is critical for seeking appropriate and satisfactory solution. However, in existing PBL approaches, a problem is defined, though ill and often complex; whilst leaving the activity of problem solving open-ended and the expected solution. This raises serious reservations on the 'self-learning' process of undergraduate students in technical schools across South Asia as course syllabus is heavy and didactic, which may inadvertently demotivate the students and they aren't naturally inclined to question. An exposure to design thinking; i.e., problem-finding and problem-solving, showed potential in imbibing reasoning, questioning, curiosity, and drive the students to pursue a valuable problem, with motivation and purpose and in turn, motivate the inculcation of PBL into engineering courses [1,2].

Jonnassen (2000) classified the problems into various types (i.e., logical problems, algorithms, story problems, rule-using problem, decision-making problems, troubleshooting problems, diagnosis-solution problems, strategic performance, situated case analysis problems, design problems, dilemmas). On one hand, story problems and algorithms are typical classroom problems that are well structured, procedural and predictable in nature. On the other hand, design problems and situated case analysis problems are real-world, ill-structured problems. Shin et al (2003) discovered that solving well-structured and ill-structured problem needs different mental skills. This shows that the performance of classroom problem-solving skills is independent and learning of which does not necessarily help to solve practical real-life problems. Real-life problems are ill-structured and complex. 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 (Funke, 1991).

Delisle (1997) prescribed the general guidelines for problem statement formulation in the form of checklist. Marchais (1999) identified criteria for constructing problem and subsequently evaluating them. (e.g., Stimulating thinking, analysis, and reasoning, assuring self-directed learning, using previous basic knowledge, proposing a realistic context, leading to the discovery of learning objectives, arousing curiosity etc.). Gijselaers (1996) identified the features of problem that make PBL ineffective, (i.e., description of problem has questions which are substituted for students generated learning issues, title of problem is same as title of the book chapter, problem is too simple (well- structured/ having only one acceptable solutions) which can be completely resolved during initial analytic process).

2.6 Defining the 'right' problem

Halfin (1973) identified total 17 mental process used by practitioners, as follows ; defining the problem or opportunity operationally, observing, analysing, visualizing, computing, communicating, measuring, predicting, questioning and hypothesizing, interpreting data, constructing model and prototypes, experimenting, testing, designing, modelling, creating and managing. Here Haflin refers to 'designing' as an activity or task, while latter literature clarifies that, "*Design is a type of problem solving in which the problem solver views the problem or acts as though there is some ill-defined-ness in the goals, initial conditions or allowable transformations*" (Thomas and Carroll, 1978). Cross (2001) describes designing as, 'finding' appropriate problems, as well as 'solving' them, and stressed that it includes substantial activity in problem structuring and formulating, rather than merely accepting the 'problem as given', and further adds that, designers' behavior is characterized by their treating the given problems as 'ill-defined', for example, through exploration where goals and constraints are changed even when they could have been treated as well-defined problems.

Awang and Ramly (2008) used creative thinking approach, a sub-set of Design Thinking with focus only on 'problem-solving', for implementing PBL in the classroom and found that the combination of both enhanced creative skills and technical abilities. Thereby suggesting complementarity between the PBL methodology and the methods of design practitioners, i.e., Design Thinking.

Williams & Williams (1994) reported the similarities between PBL and design process, i.e., large no. of stages, identification of problem as an opening phase, require motivation, organization skills and capability to initiate things, open-endedness to outcomes, group work and collaboration. While PBL is an instructional, curricular approach where the problem is defined and given with the intent to stimulate learning, Design is a cognitive process of 'finding' an appropriate, 'ill-defined' problem. Thus, supporting students to identify contextually grounded 'real life problems' and accordingly seek solutions, enables them to go beyond Remember-Understand - Apply, towards Analyse-Evaluate-Create, hierarchically identified by Bloom's Taxonomy (1956) as key learning objectives, and further enhances their ability to contribute to society.

3 IMPLEMENTATION AND IMPACT

3.1 Implementation

The two key modalities for implementation and dissemination were ;

(i) Case-study based workshop, with 70 case participants undertaking PBL through real world cases [2]. The case participants consisted of students from European and Indian universities who largely had prior exposure to PBL based curriculum, and faculty from Nepal and Bhutan, in mixed teams so that the knowledge transfer to the South Asian HEIs would happen at faculty as well as student levels. 7 cases were identified with expert-mentors, and each team comprised of 6-8 members with diversified backgrounds in terms of its composition: across ages, skill sets, hierarchies, roles in their home institution and also project, disciplines, cultures and so on, to imbibe multi-disciplinary mindset. Teams went through an extensive series of lectures and workshops primarily focused on design thinking and PBL methods and worked for two weeks to discover socially acceptable and sustainable solutions to problems they identified with the help of given brief. During this journey, they were facilitated to interact with the social communities, formal organizations and NGOs for having a broad understanding about the problem and various stakeholders involved. In the concluding session of the workshop, each team presented the solutions developed by them, and took a self-assessment on the learning outcomes and experiences.

(ii) Curriculum design workshop, where capacity building of 30 South Asian faculty members is undertaken through re-designing existing engineering courses, under mentorship [1]. Its main objective was to apply ‘design thinking’ strategies to collaboratively design the curricula suitable for each of the beneficiary HEIs, across disciplines, in Nepal and Bhutan. The European and Indian institutions presented on their know-how in the area of PBL, and faculty and research associates mentored sessions to co-create courses, while considering the contextual and practical issues of affiliation, evaluation, etc.

3.2 Findings and Insights

The key findings from (i) are ;

- **Faculty from being teacher in a course to a mentor in a PBL based curriculum -** The transformation of faculty from teachers to mentors was appreciated as the most significant factor in terms of shifting to a PBL based curriculum. As discussed in the earlier sections, the mentor’s role is quite different from that of a teacher. The hands-off approach where the students are allowed to freely discuss the issues with minimal intervention and direction by the mentor is the key to self-learning. However, it is a difficult role as the mentor still has to balance the learning objectives of course while allowing students to explore freely and define their problems/spheres of work.
- **Upfront uncertainty in goal setting may not be comfortable to students -** The faculty from Nepal and Bhutan, who transformed themselves as students for this workshop, faced uncertainty in the early stages of the case-study where the goals are not defined, and the problem is ill-structured. The mentors’ major role is to keep the morale and motivation of the team going so as to meaningfully achieve the learning objectives and still expose students to the uncertain nature of the problem definition in real world. Tools to get constant feedback from the students, especially like a mood meter, is essential to understand the team spirit to create quality problems.
- **Appreciation of learning objectives is a natural outcome of PBL process -** The students (including the teachers from Nepal and Bhutan) acknowledged the effectiveness in PBL based methodology in appreciation of the learning outcomes. The case studies made the teams contact local communities and interact with NGOs and various other entities on the field, which led to sometimes a drastic change in objectives. The interactions also helped dispel some of the initial notions and biases that existed in the team. The teams were naturally passionate about their solutions by the end of the case study exercises and owned their work.

Some key points raised and addressed during the (ii) are ;

- PBL is best suited for courses with a practical or project component, which are usually at the end of the programme in fourth year projects for undergraduate students.
- PBL has been adopted with some success in core engineering courses as well. Some experience in this regard was shared by a few partnering HEIs.
- The scoring schemes should reflect the work done throughout the project and have weightage for even failed prototypes etc.
- PBL is excellent method especially if the course involves teams working on inter-disciplinary areas.
- The number of students registered should not have a bearing on the pedagogy. PBL has been shown to be adopted on class sizes of more than 100 as well. However, as the class size increases, there is a need for specific mentors for teams which are usually about 5-6 students strong. Thus, there is a need for strong mentors as day-to-day facilitators and an overall course instructor who guides the philosophy of the course. For smaller number of students, the faculty can double as mentors for the teams.
- A lot of discussion on the course evaluation is necessary to capture the assessment in line with course objectives. Usually, a combination of continuous evaluation throughout the course study with a final assessment based on one or a combination of presentations, peer evaluations, prototype fairs and presentations to the community would be warranted in the case of a PBL based course.
- A template was designed for the HEIs to structure their new course adoption under the PBL mode. The template is given later in this document.

4 CONCLUSIONS

Newly initiated PBL practitioners, as seen in South Asian universities, require theoretical and practical hand holding in the early implementation of PBL courses which are known to imbibe industry-ready skills into engineering and technical curriculum. As a result, a handy reference guide of ‘best practices’ as pedagogical aid, along with workshops and multi-disciplinary groups immersed in PBL case studies was found to be a successful strategy to inculcate Problem-based Learning (PBL) into undergraduate educational practices and content. Following these efforts, the beneficiary universities have been in turn, practicing PBL cases in their regular engineering courses, that were developed during the workshops and have been referring to the handy guide, stating that it is of great value and usefulness. Future works entail the evaluation of its effectiveness in inculcating PBL into Engineering education.

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