Abstract: In this paper, an engineering design-centered project based learning (ED/PBL) model is presented. The ED/PBL model is used as a roadmap to develop Science, Technology, Engineering, and Mathematics (STEM) activities for K-12 students and teachers. The ED/PBL model incorporates principles of activity-based learning, problem-based learning, and project-based learning in a progressive manner. The ED/PBL model has been used as part of summer camps for kids, in-class activities by teachers, and semester-long projects for first year engineering students. Overall, ED/PBL is an effective approach for improving problem-solving skills of students. The model enables students and teachers to make connections between concepts, facts, and various skills by interaction with physical objects and each other instead of passively receiving information. Despite its great potential, creating such an active learning environment requires more work on the part of students and teachers compared to in-class lectures. During development and deployment of EB/PBL activities, we have observed a significant increase in students’ confidence in their problem solving and willingness to ask questions and further involve in deep discussion. Overall, we have seen that the ED/PBL approach stimulates curiosity and motivation, which are two essential ingredients for effective learning.

Key-Words: Project-Based Learning; Problem-Based Learning; Activity-Based Learning; Active Learning.

1 Introduction
Active learning has received considerable attention over the last several decades. Part of the “attention” is mixed with confusion in terms of how it differs from traditional learning. Literature on active learning includes various models, definitions, and implementation frameworks, which also contribute to the confusion due to overlapping boundaries among these concepts. Research in the cognitive sciences indicates that knowledge gained through activity is more useful than knowledge gained through memorisation.

In this paper, active learning is considered as any instructional method that engages students in an interactive manner in the learning process with frequent feedback loops by making them think about what they are doing, proactively ask questions, and steer the learning process as opposed to being on the “receiving end” of a traditional lecture as “passive listeners”.

Prince [1] provides a review of active learning approaches and classification of various forms of active learning. There are several comprehensive studies [2-4] carried out for meta-analysis of data on examination scores or failure rates when comparing student performance in undergraduate science, technology, engineering, and mathematics (STEM) courses under traditional lecturing versus active learning. While such studies highlight the impact of active learning on student learning and various positive outcomes [5], they also emphasize that active learning requires more effort for preparation, planning, execution, and assessment.

Within the scope of active learning topic, there are three broad categories that were utilized to develop the framework presented in this paper.
1. Activity-Based Learning (ABL) [6,7]
2. Problem-Based Learning (pBL) [8-10]
3. Project-Based Learning (PBL) [10-12]

ABL is simply about learning by doing; if learners are provided the opportunity to explore by their own and are provided an optimum learning
environment with proper feedback then they are motivated and learning becomes joyful and long-lasting. pBL and PBL are more specific approaches under the broader spectrum of ABL [13].

PBL concept goes back to the early 1900s. John Dewey (1859-1952) supported "learning by doing". PBL [13] is an individual or group activity that goes on over a period of time, resulting in a product (synthesis type activity). It typically has a timeline with milestones.

pBL is both a curriculum and a process. The curriculum consists of carefully selected and designed problems that demand from the learner acquisition of critical knowledge, problem solving proficiency, self-directed learning strategies, and team participation skills [8-10, 13]. The process replicates the commonly used systemic approach to solving problems (analysis type activity) without an “end product” as in the case of PBL.

2 Preparing for PBL

This paper advocates systematically blending of ABL, pBL, and PBL as shown in Figure 1. PBL requires learners to have higher level skills, such as synthesis and evaluation. Therefore, developing a PBL environment should start with “activities”, then “problems”, and then with all the skills acquired at these levels, a successful PBL program can be developed.

![Fig. 1. A Systematic Approach](image)

Activities facilitate building of personal and team confidence, which is essential to be engaged in active learning. Activities facilitate interaction and lead to team building. The instructor (or facilitator) can easily use activities to demonstrate the “fun side” of non-traditional learning.

Problems help build technical and communication skills. Learners start asking questions to explore the unknown and formulate problems. During problem solving, they acquire analysis skills and learn to listen, discuss, and make decisions. Problems have predictable outcomes without an end product or an artefact but they enable supervised progression through problem solving so that learners stay engaged without feeling lost. Problems layer in Figure 1 builds on the skills acquired at the Activities layer.

Finally, a Project can be introduced to carry out PBL with a timeline and milestones. PBL starts with a vague description of a “need”, which needs to be explored by teams of learners to obtain a clear formulation of the problem, which typically leads to an end product through a design (synthesis) activity. Learners add new skills, such as time management, project management, and conflict resolution or decision making in the presence of alternative solutions.

Due to its pyramid shape, Figure 1 suggests that a PBL program should have a “Project” founded on several “Problems”, which are founded on a higher number of “Activities”; all strategically blended into a curriculum so that technical skills and people skills are introduced at a reasonable pace to the learners.

The Activities/Problems/Projects pyramid in Figure 1 can be supplemented by the Active Learning Cycle (ALC) [14] as shown in Figure 2. Content (“① hear”) in curriculum should be supported by visual aids and demonstrations (“② observe”). Learners should be provided hands-on applications to interact with (“③ interact”). Then problem solving step is introduced (“④ analyze”), and finally an open-ended project is given with a realistic timeline (“⑤ synthesize”).

![Fig. 2. Active Learning Cycle](image)
3 Execution of PBL

A PBL program requires learners to have acquired analysis and synthesis skills and become familiar with PBL. Learners in a PBL environment must be supervised and monitored in terms of their progress at milestones and pace in order to ensure timely completion of the overall PBL process. As shown in Figure 3, a successful “project” must be founded on accurate problem formulation. On this foundation, there will be three pillars of skills: Technical, Communication, and Time Management. Together with the foundation and pillars, a project effort will lead successfully to an end product and a long-lasting learning experience.

![Fig. 3. PBL House](image)

start with a strong problem formulation. program should be Problems help build technical and communication skills. Learners start asking questions to explore the unknown and formulate problems. During

Lecturing is obviously effective for transmitting information where the learner is in a passive, receiving mode. The ultimate goal is not transmitting information but developing higher level thinking skills, problem solving abilities, and lifelong learning skills, which requires a student-centered approach. The concepts depicted in Figures 1-3 are focused on these goals. However, it involves a change in the role of the teacher from presenting information to learners to facilitating and guiding learning at a reasonable pace.

The realization of this type of learning environment depends to a large extent on the skill of the teacher to lead and facilitate group discussion. For inexperienced teachers and learners, who are not familiar with active learning, attempting to implement PBL becomes extremely difficult. Creating a positive experience and a success story out of PBL, requires (1) the teacher to focus on the design and development of the learning experience and less on transmission of content, and (2) the learners to set their expectation at a different level than traditional classroom type lectures. Due to Internet, abundance of information, and related applications, learners of today have an attention deficit and are not patient. Therefore, it becomes even more challenging to keep such a group focused on a topic for a longer time. PBL has potential to achieve this goal if executed properly.

When learners are given open-ended projects that require a longer time to use their analysis and synthesis skills, as opposed to “answering multiple choice questions” and finding out the answers in a short time, it becomes essential (1) to communicate a timeline for the project and the nature of the expected “end product”, and (2) to provide milestones along the timeline that enforces stopping points along the timeline for discussions and feedback. For this purpose, which is to set the right pace for a project, the framework presented in this paper follows an Engineering Design process, as shown in Figure 4.

![Fig. 4. Engineering Design Process](image)

As an example, a semester-long project is divided up into sequential phases of problem formulation, concept design, configuration design, parametric design, and detail design along a timeline. The teacher communicates expectations in terms of outcomes of each phase. While there will
be class time to discuss project progress, this approach requires comprehensive discussions at the end of each phase, along with a short report. The goal of this “pause” along the project timeline is to provide concrete feedback to the project group for their direction and decisions made so far. Teacher may intervene to change the direction or ask the group to consider other aspects or even sometimes to simplify certain aspects of the project. This approach does two adjustments: (1) Groups and teacher feel more confident in terms of effort and outcomes, and (2) Teacher has an opportunity to adjust and influence the amount of effort and scope of project across all project groups so that nobody is left behind since the goal is to create learning experiences during the PBL process with all the learners onboard without solely attributing the end products to the group success.

A “project” starts with a “needs statement”. In Problem Formulation phase, the goal is to convert “need” into a problem definition and validate “end product” as a concept. For example, below is a needs statement:

Child-proof pill bottles are too difficult for people with arthritis to open.

The project then becomes designing a “gadget” so that people with arthritis can open child-proof bottles. Here are a few examples for “problem formulation”:
- design a child-proof pill bottle that is easier to open
- design a child-proof pill container that is easier to open
- design a child-proof pill system for dispensing pills
- design a child-proof system for dispensing medication

The complexity of “formulation”, as listed in the examples above, ranges from a simple bottle to container to system. Problem Formulation phase sets the boundaries for project requirements, including the performance metrics for the end product; therefore, the teacher must carefully examine the implications of a project statement so that project teams, across the class, tackle problems at a similar complexity level.

In Concept Design, project teams develop alternative concepts to meet the “need” and synthesize and validate working principles. Each alternative identified at a phase in the Engineering Design Process (Figure 4) is moved forward to the next phase unless there is an obvious flaw with the alternative. In this way, alternatives are not weeded out in a myopic fashion but they are evaluated until the last phase.

In Configuration Design, components and sub-components for each alternative concept from the earlier phase are identified, analyzed, and evaluated. The promising alternative configurations, along with their components and sub-components, are further analyzed in the Parametric Design phase. In this phase, uncontrollable (constraints) and controllable (design parameters) parameters are identified for each alternative configuration. An analysis of value of design parameters versus performance is carried out.

In the Detail Design, manufacturability and prototyping issues are determined for each alternative design. After a comparison and ranking of alternative designs, the best design is moved forward for prototyping and development.

The overall engineering design-centered project based learning (ED/PBL) model is shown in Figure 5.

**Fig. 5. Engineering design-centered project based learning (ED/PBL) model**

## 4 Conclusions

The ED/PBL model has been used in developing PBL programs for K-12 students, freshman level engineering students, and teachers (train-the-trainer programs) at the University of Texas at San Antonio.

As instructors of PBL programs, we have seen that converting the classroom into a student-
centered learning environment enables students to voice their opinions freely and allows for effective articulation of viewpoints and concerns. Group activities, ranging from short team building activities to group problem solving to semester-long projects, reinforce accountability; students feel responsible for “learning to learn”, carrying out tasks that are a part of the group work, and being an integral part of the overall learning process.

In conclusion, PBL is a joyful process for both teacher and learners if it is planned, prepared, and executed properly. There are “7 E’s” to consider when developing a PBL program:

1. **Exciting**: Activities, problems, and projects must be exciting, creating and satisfying the curiosity of students.
2. **Empowering**: Activities, problems, and projects must provide autonomy at personal and team levels, while building competence and confidence.
3. **Enabling**: Activities, problems, and projects must be relevant to real-life so that students feel connected and see future opportunities in their careers.
4. **Engaging**: Activities, problems, and projects must be engaging mentally and physically. The Internet generation has a problem of focusing and staying focused on “things” for a long time. This is the most critical part of a PBL program.
5. **Effective**: Activities, problems, and projects must provide timely feedback relevant to the progress of the group as well as the end product expected out of PBL. Lack of effective feedback is a recipe for learners to get lost in the process and to remember PBL as a “disaster”.
6. **Easy**: Activities, problems, and projects must be convenient for space, budget, technical capability, timelines, and expected end product. Similar to item#5 above, complicated and unrealistic activities, problems, and projects cause student to lose interest, put stress on the teachers, and turn the PBL process into a nightmare.
7. **Efficient**: Activities, problems, and projects must be sustainable over time. One time “big efforts” are not helpful in creating a PBL program. One should plan and prepare PBL activities, problems, and projects at a pace where it will be possible to repeat the program every semester and gradually make improvements.

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**References:**


