



Program Assessment through Product Based Learning in Undergraduate Engineering Programmes in India

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Abstract

Engineering education is one of the key enablers for sustainable growth of a nation's economy. The exponential growth of engineering education in India has affected the quality of engineering graduates in terms of their employability. The National Board of Accreditation (NBA) accredits engineering programs using the Outcome-Based Education (OBE) framework. This framework has twelve graduate attributes of the 'Washington Accord' aligned with program outcomes. This paper proposes a systems approach which consists of input, transformation and output towards achieving employable skills in engineers. The program outcomes consisting of technical and professional skills are derived from the competencies required for the target roles in the industry and the graduates' attributes. Keeping this in mind, a structured outcome-based curriculum was established for a mechanical engineering program in association with the industry. The courses needed towards achieving the program outcomes were identified and course outcomes have been established. While the course outcomes were assessed using formative and summative assessments, the engineering institutions had no proven mechanism to assess the program outcomes explicitly. In an attempt to resolve this issue, a thematic approach called the Product and System Based Learning (PSBL) was adopted in the lines of Product Oriented Learning (POL) and Conceive-Design-Implement-Operate (CDIO) approach in three stages. The three stages include Implement-Operate (Skills), Design-Implement-Operate (Design), and eventually Conceive-Design-Implement-Operate (Innovation). Program learning outcomes were established for each stage as competencies and performance indicators were developed for assessment in the form of a rubric. On completion of the first stage, the performance of the students using the course assessment was compared with the performance assessment using the indicators aligned to competencies. The results showed a very high level of academic performance at the course level assessment, but this result was not reflected at the performance level assessment. This indicates that a direct assessment of program outcomes is important to develop employable engineering graduates for the industry. This paper demonstrates the need for a direct assessment of program outcomes which will ensure the readiness of hands on, industry ready engineering graduates from the academic system and proposes to resolve the gap through an integrated framework.

1. Background

Tertiary education, and in particular engineering education, is critical to India's aspiration of becoming a competitive player in the globalized world [1]. Post the economic reforms beginning in the early nineties, the enrolment to engineering education has increased from a meager 200 thousand in 1947 to 34 million in 2017-18 [2]. Engineering institutions have mushroomed without adequate infrastructure, effective governance and good faculty, resulting in poor quality of education [3]. Thus, the exponential growth of engineering education has significantly affected the quality of engineering graduates in India. The All India Council for Technical Education (AICTE), the apex statutory body for governance of the engineering institutions, reported that the employable engineering talent available is 47%, [4] whereas a testing and certification agency for engineering graduates in India, reports that less than 10% of the engineering graduates are employable [5]. Fair access and affordable participation to quality engineering education are critical to empower its people that allow individual potential to be fulfilled with opportunities for employment [1]. Most of the students who opt for engineering education are driven by parental aspirations or peer group influence than by their own desires or their innate abilities. Hence, they are not fully engaged during their studies, career and life [3]. These issues affect the employability of the engineering graduates.

2. Initiatives at macro level to improve the quality of engineering education

The National Board of Accreditation (NBA) was set up to assess the quality of programs offered by engineering institutions in India [2]. Outcome based education (OBE) [6] is targeted to achieve the desirable outcomes (in terms of knowledge, skills, attitudes, and behavior) [2]. NBA aligned its methodology to OBE using graduate attributes of the Washington Accord and started accrediting the engineering programs in India.

The graduate attributes are generic to the education of professional engineers in all the engineering disciplines. They are categorized into what graduates should know, the skills they should demonstrate and the attitudes they should possess [6]. While these standards are adopted at a macro level for governance by the accreditation bodies of India, the understanding and deployment at the institutional level needs significant improvement. The authors are engaged in understanding and deploying outcome-based curriculum for few programs in the last eight years. The primary and secondary school education system to a large extent in India is unfortunately rote based, in terms of memorizing the learning content

without an understanding of the concepts and context [3]. Engineering is about applied sciences and mathematics. Weak foundation in such subjects becomes a major constraint in learning engineering effectively. This needs to be addressed as this is a prerequisite to learn engineering.

3. Evolution of Outcome Based Education

Outcome Based Education (OBE) addresses the features such as outcomes as observable competencies, workplace relevance, assessments of outcomes as judgments of competence, improved skills recognition [7]. The graduate attributes of the Washington Accord are a set of assessable outcomes that are indicative of the graduate's potential and competence to practice at the appropriate level [8]. In addition, the institutions need to understand the job roles the students/graduates are expected to perform, and competencies required for such roles as an additional input for deciding the appropriate outcomes. This combined set of knowledge, skills, and attitudes is essential for strengthening productivity, entrepreneurship, and excellence in an environment that is increasingly based on technological complexity [9].

4. Systems thinking

The entire chain of education from schools to the university impacts the availability of employable talent for the industry. This chain is complex enough to consider leveraging the concept of systems thinking. Systems thinking is the discipline of seeing the whole and the patterns of change than the static snapshots. All the events are distant in time and space and yet all are connected within the same pattern [10]. A system can be represented as Input-Transformation-Output relationship as shown in Fig. 1.

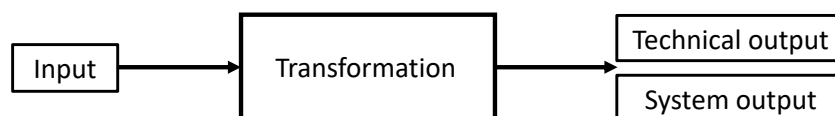


Fig. 1: Systems thinking model (Source: [11])

Systems thinkers must be able to integrate ideas, concepts, knowledge, and evidence across disciplinary boundaries [12]. The transformation between the inputs and outputs is the 'process' of the enterprise. The 'process' is frequently recognized through a set of measures of the process called macroscopic process variables. The output of the process can be classified as technical output and system output. Technical outputs are managed by those

who are internal to the process. System outputs are the outputs expected by the stakeholders external to the process [11].

5. A framework for Product and System Based Learning (PSBL)

PSBL framework was evolved by combining the concepts of Systems approach, OBE (Outcome Based Education), ADDIE (Analyze, Design, Develop, Implement, Evaluate) model of instructional design, POL (Product Oriented Learning) methodology and CDIO (Conceive, Design, Implement and Operate) to develop industry ready engineering graduates.

The authors have established a system for outcome-based education for an undergraduate program in Mechanical Engineering using system approach as shown in Fig. 2. This model is evolved using systems thinking with clearly defined inputs, technical and system outputs. Outcome based education is considered for transforming the input into output.

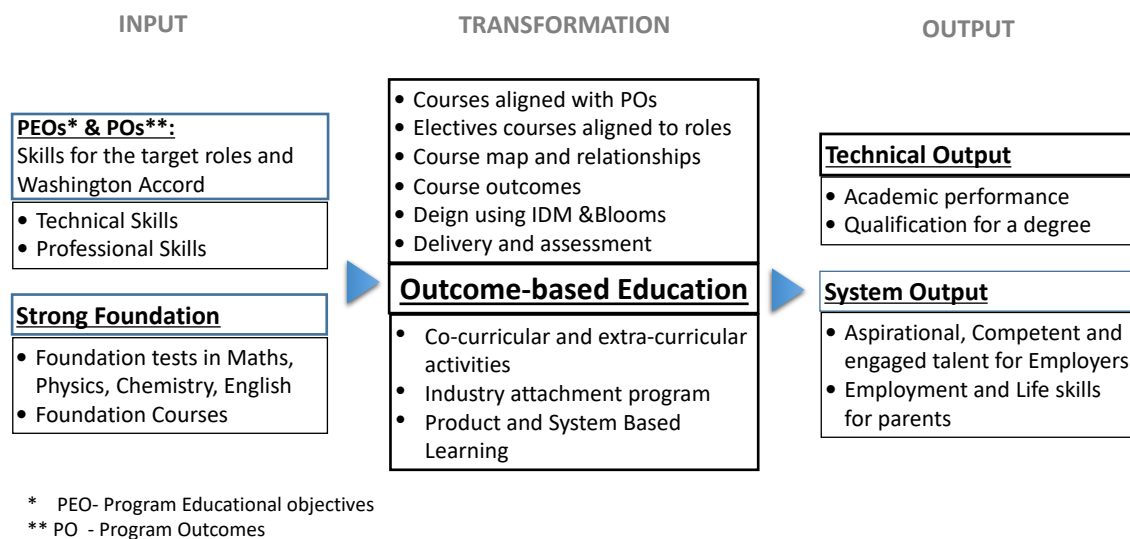


Fig. 2: Systems approach for education in engineering

5.1 Preparing inputs

The job roles that the engineers are expected to play were identified and competencies required for such roles were defined using a structured survey and job evaluation. Using these competencies and graduate attributes of the Washington Accord, the program educational objectives and program outcomes were articulated. The program outcomes were classified as technical and professional skills. Foundation tests were conducted for established higher order skills in English, Mathematics, Physics, and Chemistry for the first-year students. Even

those who obtained high scores in the school ended up getting low scores in the foundation tests. This proved that the students coming out of school lack higher order skills in these courses. Foundation courses were developed on those themes studied in their school which gets applied in engineering. Three modules of such foundation courses were developed and were delivered prior to the beginning of each semester for the first three semesters. This is further continually improved based on the analysis of technical and system output.

5.2 Defining the outputs

It is important to articulate the outputs expected out of the education process. As systems thinking model suggests, it is important to identify the technical output which are normally measured by those who are internal to or active participants in the process. Generally academic institutions measure academic performance of the students based on which they qualify for award of diploma or degree. It is important to understand what is considered to be academic performance; whether it is marks awarded by traditional, closed book examinations and few continual assessments during the academic year, or it is assessments that are tightly aligned to the outcomes. System outputs are the outputs that the stakeholders who benefit from the process or expect from the process. The key stakeholders for education in engineering include the parents who pay the fees for their wards, the students who physically spend years in the system, and employers who offer jobs and pay remuneration for their contribution. The parents and students expect the education to provide gainful employment and life skills. Employers look for aspirational, highly engaged, industry and role ready engineers and parents expect their wards to learn employable skills for gainful employment.

5.3 Outcome based education as a transformation process

Outcome based education is used to transform the given inputs into desired outputs. Fig. 3 shows the steps in the transformation process.

Courses required to realise the technical and professional skills stated in the program outcomes are identified and aligned in a matrix form. After this, a course map is established showing the interconnections between the courses indicating the order in which they need to be offered to the students. For each of the courses, outcomes are articulated in order to realise the program outcomes.

Course outcomes are deconstructed into specific learning outcomes. Appropriate content, teaching/learning methodologies, and assessment method for assessing the outcomes are developed based on the Knowledge dimensions and Cognitive dimensions. The program development and course development are carried out by a team of senior faculty members along with subject matter experts (SMEs) from the industry using the ADDIE methodology.

Fig. 3: Steps in the transformation process for outcome-based education

TABLE I: Assessment Framework of a Typical Course

5.4 Challenges in assessing program outcomes

While most institutions assess all the courses with the defined outcomes, not many have come up with a robust mechanism to assess the program outcomes during and at the end of the program directly. One of the authors has a lengthy experience in the automotive industry. In the automotive industry, thousands of parts are assembled together to get a passenger car or a motorcycle. There have been consistent efforts to improve the manufacturing processes that are used to produce several components over the years. Because of these efforts, the process capability of the manufacturing processes has been significantly improved as a result the defects are now measured at ppm (Parts Per Million) level which were measured at percentage level in the past. With more advanced machines and skilling of people, many automotive manufacturers have reached close to zero defect.

Despite this, the companies carry out rigorous tests on finished passenger cars or motorcycles at the end of the assembly line and they still do find issues on the finished vehicles. If we use this metaphor, students achieving all the course outcomes which are aligned to the program outcomes cannot guarantee achievement of program outcomes. This is a necessary condition and not a sufficient condition. It is necessary to evolve suitable mechanism to assess the program outcomes directly and objectively to qualify the students as engineers.

Product-oriented learning (POL) is one of the three essential elements of the entrepreneur-oriented education paradigm. This model emphasizes on the artifacts i.e. the end products or services which must meet the authentic need of an external audience, the customers who pays for it. In other words, the POL experiences are to help students create something others are willing to consume while learning the knowledge and skills that are essential to make the products of high quality and appealing to customers [13].

TABLE II: Entrepreneur Oriented Education Paradigm

	Expected Outcome	Control	Setting
Academic Model	Academic content	Teacher-led	Primarily a single
Mixed model	Product within constraints of academic requirements	Teacher – student collaboration	Single or multiple classes, community
Entrepreneurship Model	Product	Student led	School and Community

TABLE II shows the features of entrepreneur-oriented education paradigm in comparison with other models [13]. POL distinguishes itself from project-based learning with these features: the entrepreneurial mindset, initiation by student, strength based, quality of the final product as the focus, and use of the final product. Project based learning helps connect the real world with learning. However, it has its own inherent disadvantages which include deficiencies in the assessments. If the products are used by self or commercially sold post the academic assessments, it can meet the criteria for Product Oriented Learning.

Over years, engineering programs moved from a practice-based curriculum to an engineering science-based model. The intended consequence of this change was to offer students a rigorous and scientific foundation that would equip them to address unknown future technical challenges [9]. But in reality, the engineering education moved too far from practice. The CDIO initiative meets this challenge by educating students with practice of ‘Conceive-Design-Implement- Operate (CDIO)’ on complex, value-added engineering products, processes, and systems in a modern, team-based environment [9]. TABLE III captures all the twelve standards of CDIO and features of the standards.

TABLE III: Key themes from Twelve Standards of CDIO Curriculum

#	Standard	Themes considered for OBE and PSBL
1	CDIO as Context	Adoption of the principle that product, process, and system lifecycle development and deployment -- Conceiving, Designing, Implementing and Operating -- are the context for engineering education
2	Learning Outcomes	Specific, detailed learning outcomes for personal and interpersonal skills, and product, process, and system building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholder
3	Integrated Curriculum	A curriculum designed with mutually supporting disciplinary courses, with an explicit plan to integrate personal and interpersonal skills, and product, process, and system building skills
4	Introduction to Engineering	An introductory course that provides the framework for engineering practice in product, process, and system building , and introduces essential personal and interpersonal skills
5	Design-Implement Experiences	A curriculum that includes two or more design-implement experiences , including one at a basic level and one at an advanced level
6	Engineering Workspaces	Engineering workspaces and laboratories that support and encourage hands-on learning of product, process, and system building, disciplinary knowledge, and social learning
7	Integrated Learning Experiences	Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal and interpersonal skills, and product, process, and system building skills
8	Active Learning	Teaching and learning based on active experiential learning methods
9	Enhancement of Faculty Competence	Actions that enhance faculty competence in personal and interpersonal skills, and product, process, and system building skills
10	Enhancement of Faculty Teaching Competence	Actions that enhance faculty competence in providing integrated learning experiences , in using active experiential learning methods, and in assessing student learning
11	Learning Assessment	Assessment of student learning in personal and interpersonal skills, and product, process, and system building skills, as well as in disciplinary knowledge
12	Program Evaluation:	A system that evaluates programs against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement

The key themes highlighted in the table are actively used by the authors to develop an integrated curriculum framework called Product and System Based Learning (PSBL) based on POL and CDIO.

5.5 Product and System Based Learning (PSBL) Phases

The scope of ‘Outcome Based Education’ initiated by the authors was expanded to cover PSBL. Three distinct phases were determined to cover product and systems orientation aligned to POL and CDIO standards. The three phases are shown in Fig. 4.

1. PSBL 1: Skills: Implement, Operate – Phase 1
2. PSBL 2: Design: Design, Implement, Operate – Phase 2
3. PSBL 3: Innovation: Conceive, Design, Implement, Operate – Phase 3

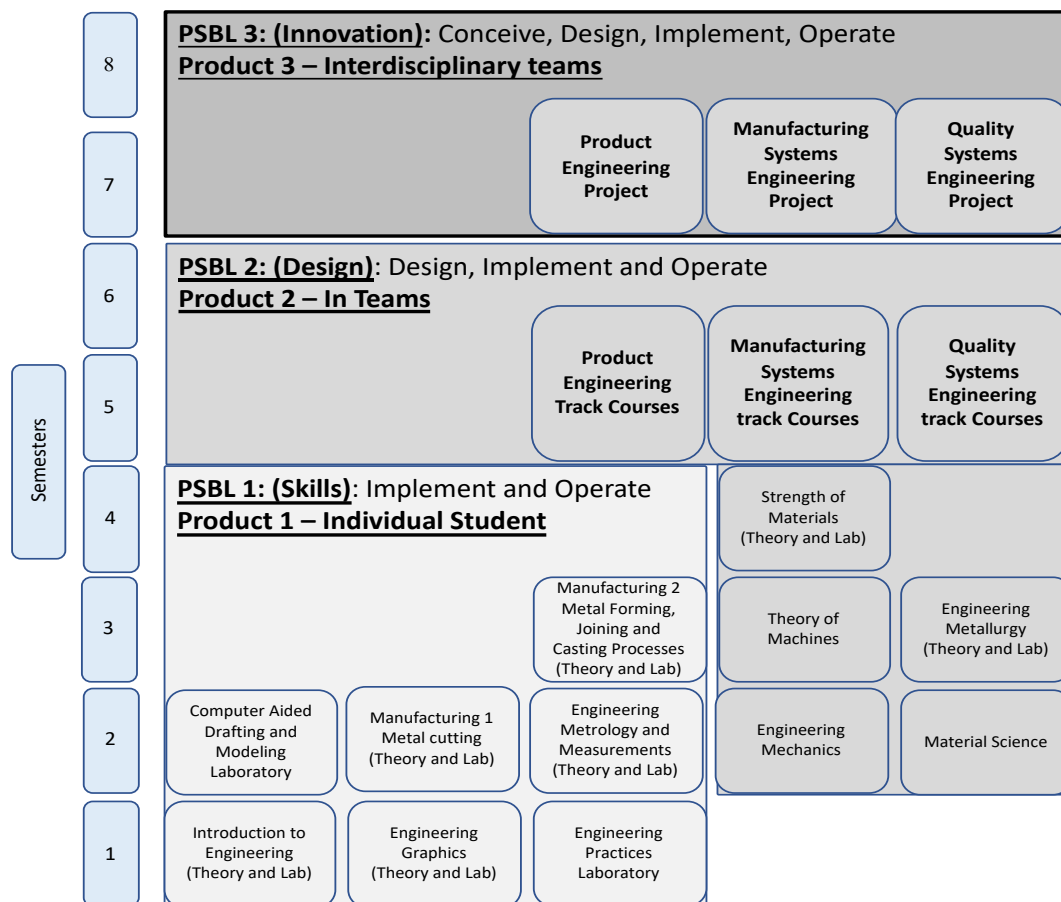


Fig. 4: Relevant courses and their arrangement in three phases of PSBL

5.5.1 PSBL 1: Skills: Implement and Operate

The first phase is for acquiring the basic skills for realizing a product with ‘Implement’ and ‘Operate’ tasks. During this phase, the design of the product was carried out by the faculty

and integrated with the courses during the first four semesters. Guidelines were established for choosing the products for PSBL 1 as follows:

1. The product is useful for day-to-day household activities in the student's family.
2. The product involves basic manufacturing processes such as casting, metal cutting, forming, and joining processes.
3. The components of the product are feasible for manufacturing with the facilities in the college and with companies nearby.
4. The product should be safe, reliable and easy to handle.

PSBL 1 is carried out by every student, individually. The outcomes for PSBL 1 (Sl. No. 1 to 4 technical and 5 to 8 professional) is common for all students as shown in TABLE IV.

TABLE IV: PSBL 1 Outcomes

Sl. No.	Outcomes
1	Prepare part drawings of a given product independently based on functions with appropriate dimensions, tolerances, and fits.
2	Prepare process planning sheet independently by choosing the processes, sequence, tools, parameters, cycle time, among few other alternatives.
3	Manufacture the parts independently adhering to the process planning sheet and meet the required dimensions, tolerances and fits.
4	Check the functions of the assembled product and make corrections.
5	Maintain high energy level and mental alertness.
6	Plan and work to schedules.
7	Communicate effectively with stakeholders to get things done and report progress.
8	Practice ethical responsibility.

5.5.2 PSBL 2: Design: Design, Implement, and Operate

The second phase provides an opportunity to design, implement, and operate experience at an advanced level for a given concept of a product or system. The students are expected to develop alternative design options of a product or system and choose one of the concepts using a decision criterion. Then they design the product or system and components using functions, working environments and so on. The guidelines established to choose the product or system for PSBL 2 are:

The product or system shall be

1. Usable at the college or commercially salable in the market or industry
2. Designed and developed collaboratively in teams
3. Feasible to manufacture or build using the facility at the college or in the vicinity
4. Safe, reliable, and easy to handle

While the PSBL 1 is performed by every student individually, the PSBL 2 is expected to be performed by a team of students with three basic roles: Product Designer, Manufacturing System Designer, and Quality System Designer during fifth and sixth semesters. These roles are aligned to the industry roles keeping few potential employers in mind. Each role has a set of common courses and a set of electives courses aligned to the roles.

The distinct tasks expected to be performed in these three roles are expressed as PSBL 2 outcomes in TABLE V and TABLE VI.

Table V: PSBL 2 Outcomes (Technical) distinct for roles

Product Engineering	Manufacturing Systems Engineering	Quality Systems Engineering
Generate a Product design concept based on multiple benchmarks of similar functions for the given product that will comply with homologation requirement, legal requirement and environmental standards	Prepare process planning for the components/products by choosing the processes, sequence, tools and parameters & estimate the cycle time.	Evaluate the product / process design for Quality, Durability, Reliability and Serviceability during design stage.
Generate additional concepts if the process of manufacture is considerably different from benchmark product.	Manufacture the components/products conforming to the specifications, tolerances and fits following the process plans.	Prepare the inspection plan and inspect component, sub-assembly and product adhering to instruments and methods.
Prepare design layout to meet the design characteristics/Technical Specification. (Do analytical design calculations to arrive at final dimensions for standard components)	Generate alternative manufacturing cell design concepts and choose optimal concepts for the flow of Material, Information & Resource for minimum waste & maximum value.	Develop product/ process verification/validation plan for functional/ customer requirements.
Conduct simulation and analysis using CAE/IT tools for the critical parts and optimize the design.	Estimate the value adding ratio using value stream mapping and process design characteristics such as cycle time, lead time, takt time, inventory and space	Prepare the test procedures and design facilities to simulating the real life environment and customer use condition
Prepare the detailed prototype drawing for the part specifying the right fits and tolerances, Surface roughness, heat treatment, etc.	Optimize the manufacturing cell design using mathematical models and simulations for identified components/products.	Conduct test for functional/customer requirements.

Table VI: PSBL 2 Outcomes (Professional) common for all roles

Common outcomes for PSBL 2 for all the roles
Work effectively in teams and build/manage interpersonal relationships
Communicate effectively through oral, non-verbal, written and graphical means.
Articulate and engage in pursuit of career and life goals through continuous learning.
Apply management principles for executing projects in a multidisciplinary environment.
Practice Ethical and moral responsibility
Aware of the impact of engineering solutions in a global, environmental, and societal context
Maintain positive health (physical, mental and social)

Streams of courses were identified for each of the roles which can be offered as core and electives. Students are expected to work in teams during this phase. The teams work on the same product with three sub-teams of product engineering, manufacturing systems engineering and quality systems engineering. While the product is created by the team, the manufacturing and quality systems teams develop the concepts virtually and validate with subject matter experts. Fig. 5 shows the courses (core and elective) for the role of product engineering. Similarly, there are other courses identified for the other two roles.

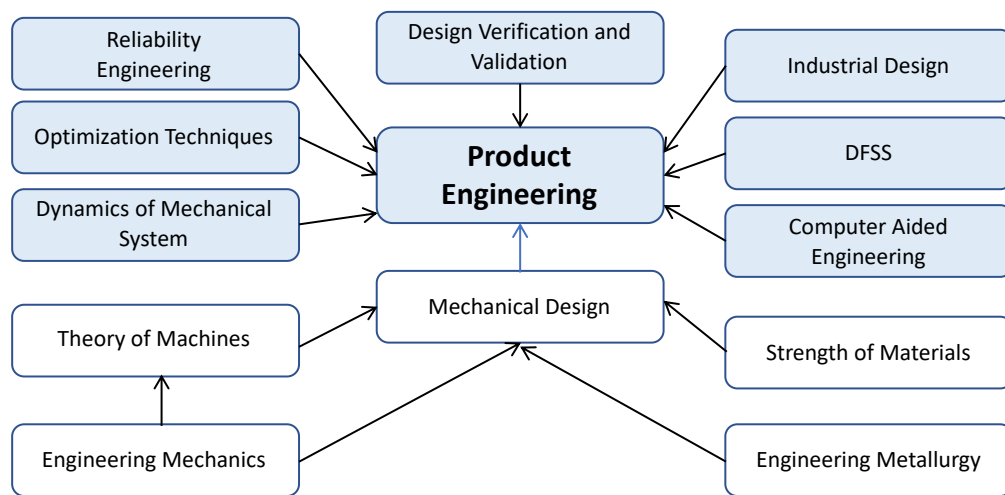


Fig. 5: Courses (core and elective) for the product engineer role

5.5.3 PSBL 3: Innovation: Conceive, Design, Implement, Operate

In the third phase, the teams are expected to visit the market, identify the customer needs including the latent needs, conceive a product concept, then design the product, as well as implement and operate. This is performed during last two semesters in an interdisciplinary manner where teams are constituted with members from different programs of engineering. The courses done in the first two phases are adequate to carry out this phase. A few additional elective courses will be added, including understanding customer requirements, language data processing, innovation, entrepreneurship etc. to support this phase. The outcomes for PSBL 3 are same as PSBL 2.

5.6 Assessment of program outcomes through PSBL outcomes

The academic quality of examinations in Indian engineering education system has been a matter of concern for a long time. What and how students learn depend to a major extent on how they are assessed [14]. Higher level skills such as systems thinking, procedural

knowledge, and attitude formation require more sophisticated measurement schemes [15]. Performance assessments measure the students' abilities to authentically demonstrate knowledge, skills, and processes in a way that provides value, interest, and motivation to students beyond the actual score or grade [16]. Performance assessment may lead to inconsistency among multiple assessors without a framework as they don't have one answer. Rubrics help multiple assessors to come to similar conclusions on higher-level conceptual knowledge, performance skills, and attitudes. Holistic rubrics are best suited for a summative evaluation of a performance, product, or process, so that the student receives their score based on overall performance [15]. The steps that are followed in the development of rubrics [17] include:

- a. Clearly define the assignment, i.e. the process to realise a product or a system
- b. Determine the key components that needs to be assessed
- c. Chose the type of rubric (holistic/general, holistic/task specific etc.) for the given purpose.
- d. Define the key components in detail for clear understanding
- e. Establish clear levels and standards of performance for each component
- f. Develop a scoring scale

An effective educational program needs to ensure the achievement of POs which need to be verified through accurate, reliable and authentic assessments. It is difficult to observe and measure POs at a course level. An effective method for assessing the program outcome directly involve identifying the competencies to be demonstrated and performance indicators for each of the competencies [14] as shown in Fig. 6.

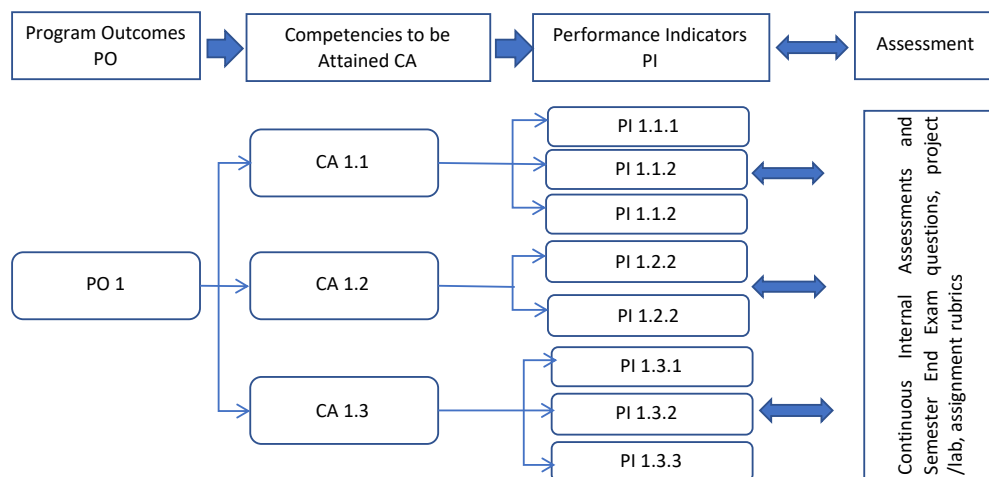


Fig. 6: Assessment of Program outcomes through competencies and indicators

Outcomes for PSBL are the competencies the students are expected to demonstrate during each phase. The rubrics describe the performance indicators that help to assess the competencies when the students undergo performance assessment while designing and building products. Rubrics for multiple competencies were developed and performances of students were assessed for PSBL. The demonstration of PSBL 1 outcomes/competencies through the tasks in making the product require the integration and accumulation of knowledge and skills learnt in various courses. A sample rubric used for the assessment of PSBL 1 is shown in TABLE VII.

TABLE VII: Rubrics used in the assessment of PSBL 1 – A sample

PSBL Outcome	Dimensions (What)	Level 4 (Competent)	Level 3 (Proficient)	Level 2 (Beginner)	Level 1 (Novice)
Prepare part drawings of a given product independently based on functions with appropriate dimensions, tolerances and fits	Part Drawing	The part drawing has dimensions, tolerances and fits specified for each part using standard notations and symbols	The part drawing has dimensions, tolerances and fits specified for each part, but standard notations and symbols are partially followed	The part drawing has dimensions, tolerances and fits specified for each part but standard notations and symbols are not followed	The part drawing is incomplete in dimensions, tolerances and fits. Standard notations and symbols are not used.
	Functions	Indicates all the features required for the specific functions of all the parts appropriately	Indicates almost all features required for the specific functions of all the parts	Indicates some features required for the specific functions of all the parts	Does not indicate features required for the specific functions of all the parts
	GD&T	GD&T are appropriately specified for all the parts	GD&T are appropriately specified for almost all the parts	GD&T are appropriately specified for some of the parts	GD&T are inappropriately specified for all the parts

For PSBL 1, the faculty decided on the rice noodles (a delicacy in the region where the college is located) making machine shown in Fig. 7 that can be used by students' mothers at home. The faculty made few alternative design concepts and shortlisted a version which is significantly better than the machine currently available in the market. The drawings of the components used for this product are prepared by the students as part of tutorials and lab exercises in the courses - Engineering Graphics, Computer Aided Drafting and Modeling. Process planning to manufacture the components were prepared by the students as part of tutorials and lab exercises, of Manufacturing processes 1 and 2 courses. The dimensions of components were measured using skills acquired in Engineering Metrology and Measurements course. The components of the rice noodles making machine were made during regular workshop practice sessions and special slots in the laboratories booked by the students. These components were inspected against the dimensions and tolerances and stored

until all the components are manufactured. Once all the components were manufactured, the students assembled them together to get the product. Then they checked for functional requirements of the product and then followed the testing by using rice batter.



Fig. 7: Photo of rice noodles making machine made by faculty and all the students

The performance of students was assessed using three key steps - Prepare part drawings, prepare process plans, and manufacture the parts. Students were observed by the faculty members for the indicators of technical and professional competencies during the laboratory sessions while making the parts of the product and the faculty members gave a rating using the four level (Novice, Beginner, Proficient, Competent) rubric for the students on the technical and professional competencies of PSBL 1. A contest was also conducted to check the performance of the rice noodles making machines.

The experimental group for implementing PSBL consisted of 138 students of a Four-year undergraduate engineering program with specialization in Mechanical Engineering. The group consisted of 133 boys and 5 girls. The study was carried out over a period of two years during which the group completed the first four semesters of study out of the eight semesters in the Bachelor of Engineering (B.E.) in Mechanical Engineering program. The age group of the students undergoing this program is between 18 and 25. The team for the implementation of PSBL consisted of faculty members teaching the courses relevant to PSBL in the class rooms and faculty members assessing the outcomes in the theory and laboratory components. There were also technical assistants who were part of the instruction and assessments for the laboratory exercises. Specific faculty teaching competence and technical competence development measures were also implemented as part of PSBL to equip the faculty members sufficiently. The faculty team was all-along supported by subject matter experts from the

industry who were also adjunct faculty. The entire implementation was managed and reviewed periodically by the authors involving all the stakeholders.

5.7 Outcomes of assessment using rubrics

The assessments that were carried out for the experimental group is listed in this section.

- Course level assessment - Pass percentages and average marks in the courses
- PSBL outcomes assessment – Technical and professional competencies
- Product function assessment – Real life functioning of the product

5.7.1 Course level assessment

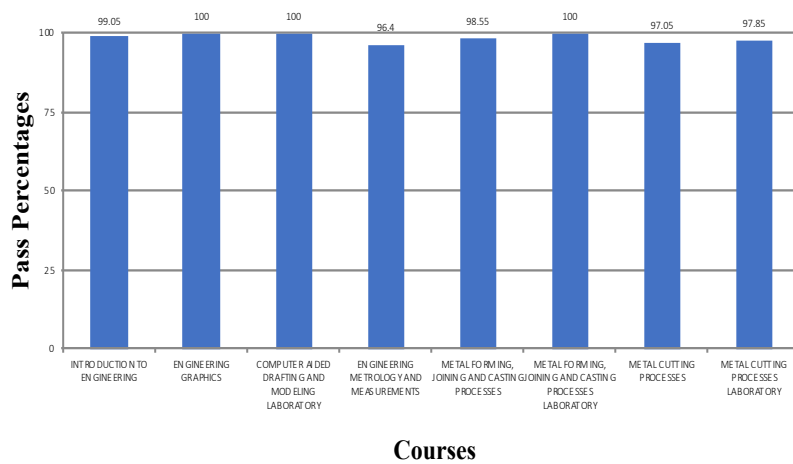


Fig. 8: Pass percentages in courses of PSBL 1

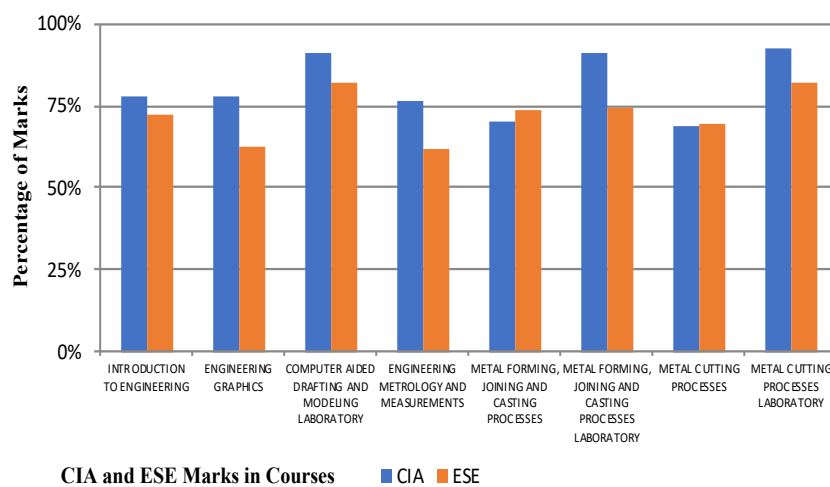


Fig. 9: Average marks expressed in percentage scored in courses in PSBL 1

Fig. 8 shows the pass percentages in the courses linked to the PSBL1 outcomes. This indicates that high percentage of the students have passed the course level assessment. The courses consisted of continuous internal assessments (CIA) and end semester examinations (ESE). The average scores in the courses are represented in Fig. 9. These indicate that most students have performed well above the threshold level for passing the examinations.

5.7.2 PSBL outcomes assessment: Technical and professional competencies

Fig. 10 and 11 show the distribution of rating of competencies assessed using rubrics while the students learnt the courses integrated with the product.

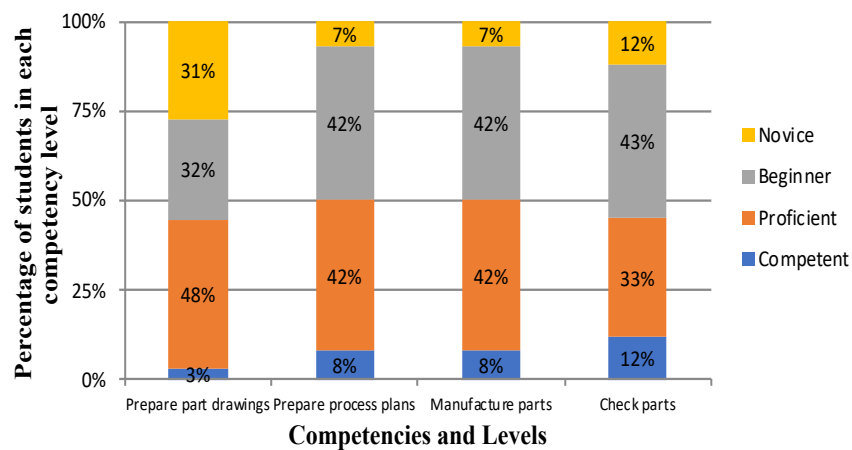


Fig. 10: Technical competency assessment

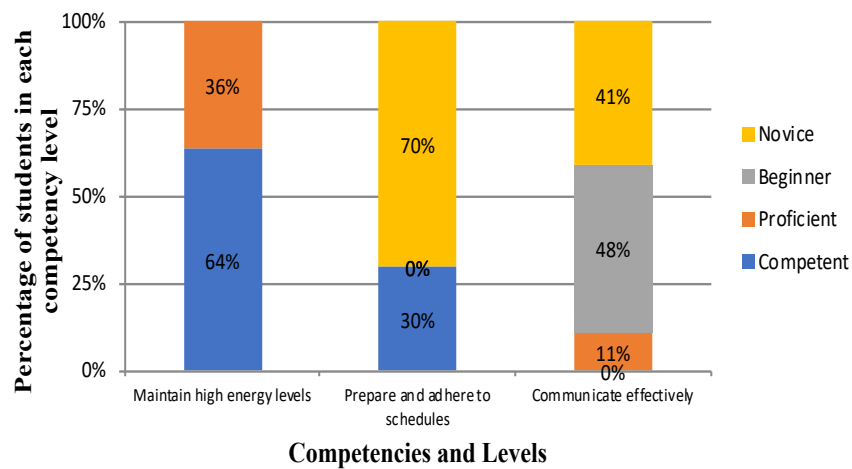


Fig. 11: Professional competency assessment

While pursuing the courses, product part drawings, process plans, part manufacturing, energy levels and alertness, schedule management, and communication were assessed using rubrics as well as knowledge and skill components as part of the laboratory exercises in the courses. It is observed from Fig. 10 and 11 that while 45% of the students qualify for the technical skills, only 11% of the students qualify for professional skills. The percentage significantly dropped when competencies are assessed in comparison to course outcomes.

5.7.3 Product function assessment

138 students of the program participated in the PSBL 1 and made a rice noodle making machine using the components manufactured in four semesters. On completion, 113 students had participated in a contest over two days. The contest consisted of three stages – inspection of parts, testing for product functioning without rice batter, and testing for product functioning with rice batter. Faculty members and SMEs trained in using rubrics for assessment, assessed the students during the contest. For the first two stages, one assessor was assigned for 10 students. However, for the third stage, every student (participating in testing with the hot rice batter using the machine made by them) was assigned an assessor.

A demo was given by the faculty on the rice noodles making process using the machine. Subsequently each student was given two trial runs to familiarize themselves with the extruding (rice noodle making) process. The objective for the third and final stage of the contest was to extrude 3 rice batter shots (approximately 100 grams each) into noodles in 3 minutes. The objective was set based on the experience of faculty members in making rice noodles from the prototype machines which they made considering allowance for first time users.

This was the first opportunity for students to showcase their product in public, in a real-life environment. Also, this was the first time the faculty members assessed the performance of students using an authentic product. The students were excited to try their machines in real life. The Fig. 12 shows the product function assessment in stages 1 (inspection of parts), 2 (without batter) and 3 (with batter) respectively. This assessment and its rating carried out using rubrics and multiple criteria is the most critical since it is the reflection of all the other competencies coming together for a performance assessment.

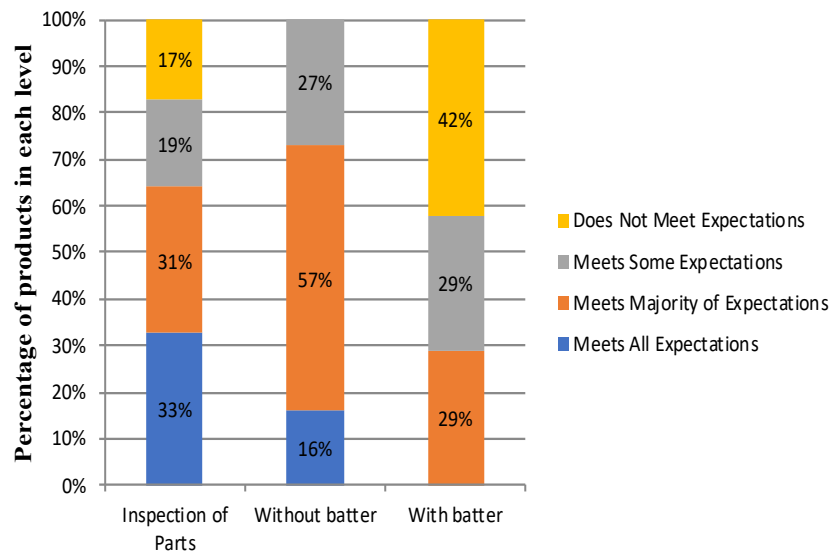


Fig. 12: Product function assessment

To the surprise of the students and faculty, only 29% of the machines functioned satisfactorily and produced rice noodles. The rest of the machines could not produce noodles as the pinion kept slipping from the rack. Even though the students measured the dimensions, there was not enough attention to tolerances and analysis. Both the students and the faculty understood the importance of the tolerances to achieve the fit and functions. The rest of the students are in the process of reworking on the components that have deviation. The relative performance of the students in multiple assessments is summarised in TABLE VIII. This proves that the professional skills and product performance are areas for significant development. These are essential parts of employable skills.

TABLE VIII: Relative performance in multiple assessments

Parameter	%	Remarks
Students passing all the courses in PSBL 1	96	Course Outcome Attainment
Students in Proficient and Comptent Levels in all Technical Skills in PSBL 1	45	Programme Outcome Attainment - Technical
Students in Proficient and Comptent Levels in all Professional Skills in PSBL 1	11	Programme Outcome Attainment - Professional
PSBL 1 products meeting majority and above expectations without batter	73	Product functioning without load
PSBL 1 products meeting majority and above expectations with batter	29	Product functioning with load

An analysis was carried out on the gaps in carrying out the manufacturing and measurements by the students for the next cycle. The following are improvement actions proposed for the next batch:

1. Increase the rigor of assessments in the courses.
2. Introduce stringent compliance on dimensions, tolerances, and fits.
3. Compile the outputs of each of the stages in making the product as a PSBL portfolio, which will enable students to realize the significance of each stage in making a product.

5.8 Learnings from PSBL

An online feedback survey was conducted with the students. The survey consisted of 15 questions, which included self-assessment rating by the students against the PSBL 1 outcomes. The students self-rated themselves in the four levels aligning with the rubrics. Also all the students gave an open ended written feedback about PSBL. Some students even shot videos about the experience of designing and building a product.

This experiment showed that even though the course outcomes were achieved by the students at a satisfactory level with their formal examinations, the PSBL 1 outcomes in terms of professional skills and product and system skills needed significant improvement. This is equivalent to the quality of the components of a motorcycle or passenger car meeting the requirements but the performance of the motorcycle or passenger car not meeting the requirements. Industry and role readiness can be confirmed with assessment of the program outcomes directly through PSBL outcomes as competencies, with rubrics as performance indicators.

But this requires rigour in planning two or three cycles of PSBL in line with CDIO framework, training the faculty members and orienting the students. These constraints listed below were experienced during this experiment:

1. The capacity of facilities for manufacturing components by a large number of students is required. This is also due to limited working hours of these labs. This requires capacity planning and improvement in the utilisation with extended working hours and adding additional capacity.
2. The students were used to carrying out their workshop exercises for only one cycle for each component. If there are deviations found on components that will affect the

functioning of the product, the students must be given feedback for rework or repeating the jobs immediately.

3. Rigorous training of the tutors and technicians in the lab is very important to make sure the students are trained and guided to implement the manufacturing of the components to the level of acceptable quality.

5.9 An integrated framework for PSBL

Based on this experiment, an integrated framework is established by the authors as shown in Fig. 13. Program educational objectives and program outcomes (technical and professional skills) are derived from the competencies along with job roles in the industry and the students' attributes of the Washington Accord. From these, three phases are established for product and systems-based learning in the programme. The courses in the programme are aligned with these three phases(PSBL 1 to 3). The courses are aligned to roles in PSBL 2 and PSBL 3.

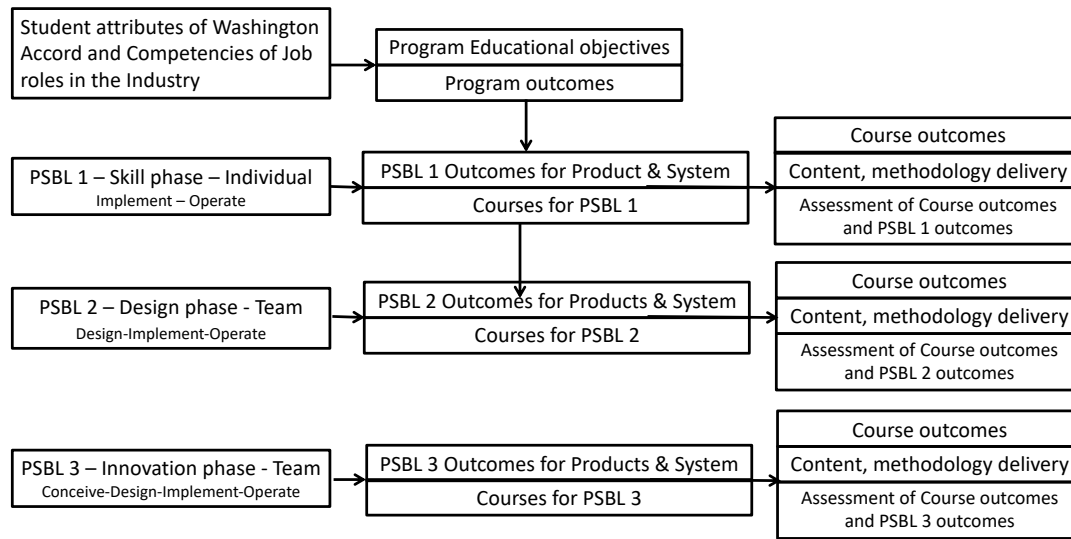


Fig. 13: Integrated framework for Product and System based Learning

For each phase of PSBL, a matrix is prepared, as shown in the TABLE IX to establish the relationship of PSBL outcomes as competencies with program outcomes.

TABLE: IX: Relationship matrix between Program outcomes and PSBL outcomes

		Apply scientific principles and concepts in design and development of products and manufacturing processes.	Identify, formulate, and analyze engineering problems using scientific principles and concepts	Design products, manufacturing processes and facilities that deliver the requirements of the target customers and desired quality	Conduct experiments, analyze and interpret data to provide solutions for	Implement appropriate tools and techniques to solve engineering problems.	Develop and maintain positive health (physical, mental and social wellbeing) to face societal, health & safety, legal and cultural challenges with rigor and emotional stability.	Aware of the impact of engineering solutions in a global, environmental, and societal context and demonstrate the knowledge of need for sustainable	Practice Ethical and moral responsibility	Work effectively in teams and build/manage interpersonal relationships.	Communicate effectively through oral, non-verbal, written and graphical means.	Apply management principles to manage individual and team work for executing projects in a multidisciplinary environment	Articulate and engage in pursuit of career and life goals through continuous learning.
1	Prepare part drawings of a given product independently based on functions with appropriate dimensions, tolerances and fits	XX	X	XX	X	XX							
2	Prepare process planning sheet independently by choosing the processes, sequence, tools, parameters, cycle time, among few other alternatives.	XX		XX	X	XX							
3	Manufacture the parts independently adhering to the process planning sheet and meet the required dimensions, tolerances and fits.				XX	X	X	X	X				
6	Plan and work to schedules.											XX	X
7	Communicate effectively with stakeholders to get things done and report progress.										XX		

5.10 Conclusion

This experiment was useful to confirm the need for a direct assessment of program outcomes which will ensure the readiness of hands on, industry ready engineering graduates within the academic system. Using this assessment, it is possible to improve the rigour of the course deployment and the assessment of course outcomes. This is new in the academic system in India which requires a major mind-set change and commitment for hard work and perseverance in the next four to five years. This also requires re-orienting the students to become flexible in planning their time and booking their slots for the laboratory work. Our experience with PSBL 1 provided confidence to the team to take on PSBL 2 and PSBL 3.

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