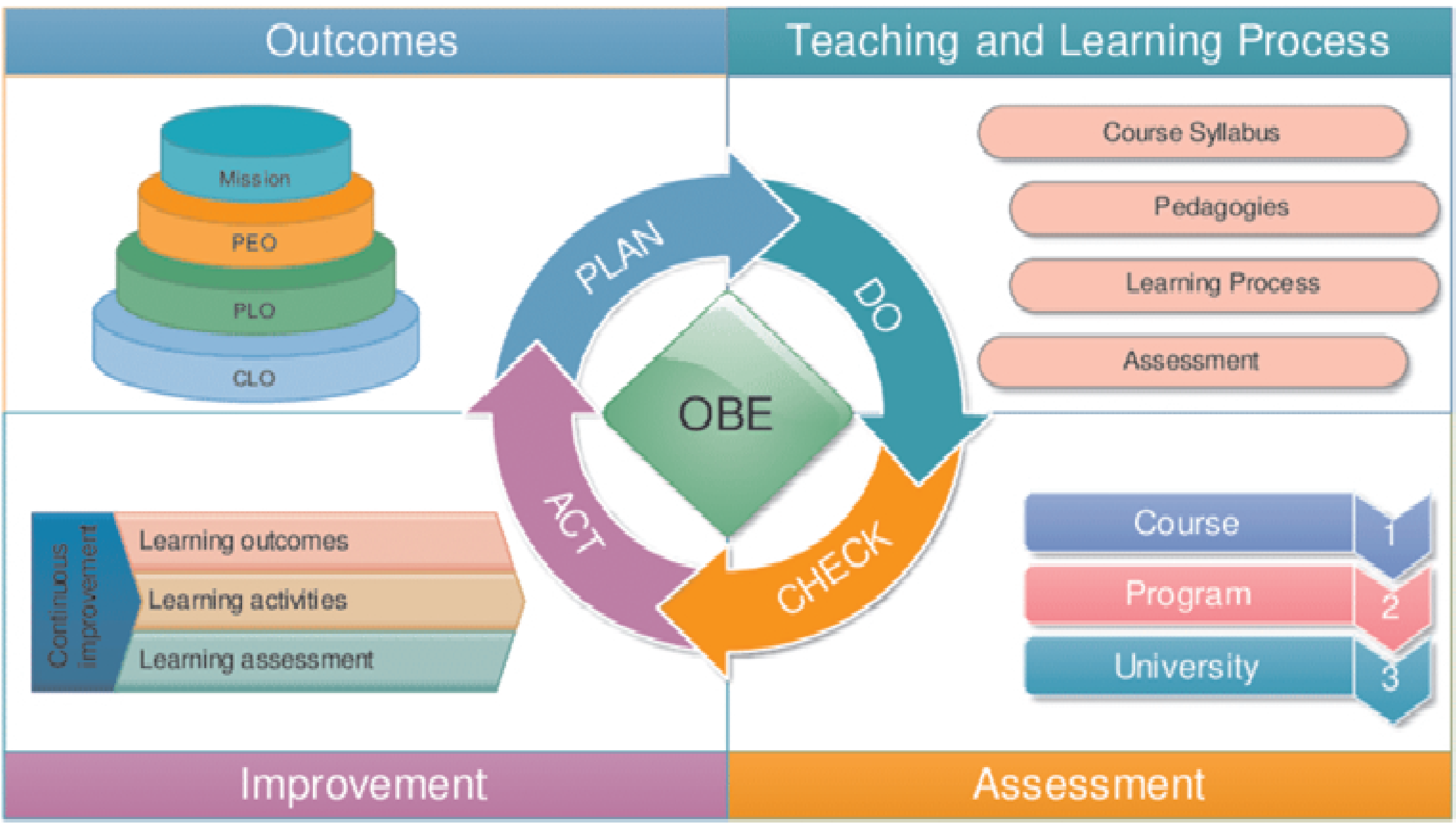
Understanding Outcome Based Education and Accreditation



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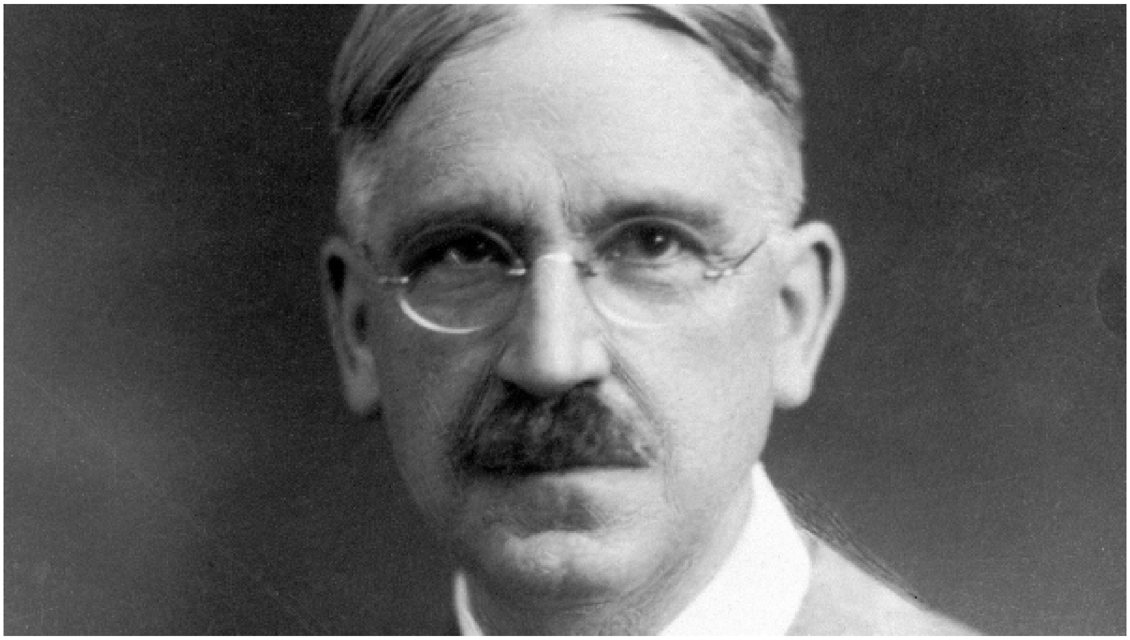
OUTCOME BASED EDUCATION AND ACCREDITATION



"The native and unspoiled attitude of childhood, marked by ardent curiosity, fertile imagination, and love of experimental inquiry, is near, very near, to the attitude of the scientific mind."

– John Dewey

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Attainment and Assessment of Program Outcomes through Product and System Based Learning in Engineering Education for Atmanirbhar Bharat

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Engineering education is one of the key enablers for sustainable growth of India. The exponential growth of engineering education affected the quality of engineering graduates in terms of their employability in a globalized business environment. National Board of Accreditation (NBA), a permanent signatory of "Washington Accord" ensures the portability and relevance of engineering degrees. NBA accredits engineering programs using the Outcome-Based Education (OBE) framework aligned to the twelve graduate attributes of the 'Washington Accord'. 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. The courses and their outcomes are derived from the program outcomes in undergraduate programs. While formative and summative assessment are carried out at the course level, there is no structured methodology followed for assessing the program outcomes directly. This monograph proposes a systems approach to assess the program outcomes directly using Product and System Based Learning (PSBL) methodology. This methodology was experimented on a mechanical engineering program in collaboration with the industry. PSBLmethodology adapts concepts from Product Oriented Learning (POL) and Conceive-Design-Implement-Operate (CDIO) approach. PSBL consists of three stages that include, Implement-Operate (Skills), Design-Implement-Operate (Design), and eventually Conceive-Design-Implement-Operate (Innovation). Program learning outcomes for each stage are established as competencies. Performance indicators to assess the program learning outcomes are developed benchmarking the examination reforms proposed by AICTE. A pilot of PSBL first stage and the performance of the students comparing the course and program learning outcome assessments is also reported. The results show a very high level of academic performance at the course level assessment, but the same level is not reflected at the program level assessment.

1. Background

Atmanirbhar Bharat requires contributions from all stakeholders, especially competent engineering fraternity. Higher education and in particular engineering education aimed at developing competent engineers is crucial for India's growth and development [1]. After the economic reforms, enrolment in engineering education has increased rapidly.There has been significant increase in the number of engineering institutions, programs and intake across the country. Many of these institutions lack quality infrastructure, faculty and governance, impacting the quality of engineering education [2]. All India Council for Technical Education (AICTE) has been reporting employability rates around 50% for the past several years [3]. A third party report indicates that every year less than 10% of the engineering graduates are employable [4].Access and affordability to quality engineering education are critical for empowering individuals and hence their suitable employment [1]. In most cases in the Indian context, aspiration to pursue engineering are driven by parental aspirations or peer influence than by desires or innate abilities. This results in limited engagement in studies, career and life [2], impacting quality of the engineers.

The National Board of Accreditation (NBA) assesses the quality of engineering programs in India [5]. Outcome based education (OBE)aimed at achieving the program outcomes [5] articulated based on the graduate attributes of the Washington Accord [6] are assessed by NBA during accreditation. Around

2400 engineering programs had accreditation from NBA in 2020 (approximately 40% of the total number of engineering and technology programs in the country) [7] [8]. The rejection rate in the accreditation of engineering programs in 2019 was around 20% as reported in the annual report of 2019 by NBA [8].

The graduate attributes are a set of assessable outcomes that are indicative of the graduate's competence to practice engineering at the appropriate level [9]. They are categorized into knowledge, skills and attitudes that engineers have to demonstrate on successful completion of engineering programs [5]. Combined set of knowledge, skills, and attitudes is essential in the complex technological environment to improve productivity and promote entrepreneurship [10]. Outcome Based Education (OBE) addresses observable competencies, workplace relevance, assessments of outcomes as judgments of competence and recognition of skills [11], hence used in the engineering programs. In addition, to the graduate attributes of Washington Accord, institutions have to understand the current and future job roles in the industry, and the competencies required for such roles as an additional input for deciding the appropriate program outcomes.

2. Challenges in assessing program outcomes

Institutions that have adapted Outcome Based Education, conventionally practice a two tier system in assessing outcomes. Courses are mapped to the program outcomes and outcomes are established for each course. The outcomes of the courses within programs are assessed as part of continuous assessments in courses. The assessment of course outcomes is considered to fulfil the program outcome. This is akin to, stating that all the parts of an automobile have cleared quality checks hence, the automobile will meet the functional requirements without any further testing. In the automotive industry, thousands of parts are assembled to make an automobile (car/motorcycle/scooter). Automotive manufacturers have reached close to zero defect at the part level and product level with consistent and sustained quality initiatives. In-spite of parts which have the right quality being used in the assembly line there are rigorous tests on finished passenger cars or motorcycles at the end of the assembly line for functional and performance requirements. Companies still do find issues on the finished vehicles. If we use this metaphor, engineering education which has adapted OBE, mere achieving the course outcomes is no guarantee of achieving program outcomes. This is a necessary condition and not a sufficient condition. Hence it is necessary to evolve suitable mechanism to assess the program outcomes directly and objectively to qualify the students as engineers.

3. Assessment of program outcomes through PSBL methodology

Engineering programs must ensure the achievement of well-defined program outcomes which have to be checked using accurate, reliableand authentic assessments to ensure employable graduates. Program outcomes can be assessed directly by assessing the competencies to be developed and performance indicators for each of the competencies [12] as shown in Fig. 1.

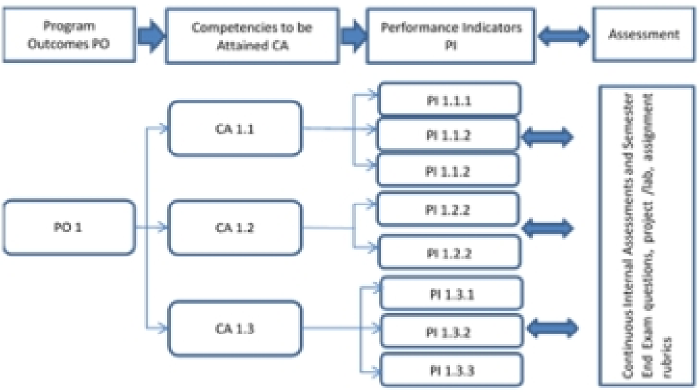

Figure 1: Assessment of Program outcomes through competencies and indicators

With the quality of examinations and assessments in India being questioned and what and how students learn depending on how they are assessed [12], assessments of performance indicators and competencies becomes challenging. Performance assessments are used to authentically measure knowledge, skills, and attitudes in terms of interest, and motivation to acquire competencies beyond marks or grades [13]. Assessment of outcomes corresponding to Bloom's cognitive levels such as apply, analyze, evaluate and create is not easy since they involve multiple responses. Hence such assessment cannot be carried out with answer keys. To deal with this challenge, a tool called rubrics is used, which defines the expected responses to the questions at different levels using criteria. Rubrics help multiple assessors to concur on assessment at higher-level conceptual knowledge, performance skills, and attitudes. Holistic rubrics are considered the best for evaluation of a performance, product, or process, to rate overall performance [14]. The steps that are followed in the development of rubrics [15] include:

a. Define the task(s).

b. Determine the key components to be assessed.

c. Chose the type of rubric.

d. Define the criteria for assessment.

e. Establish clear levels and standards of performance.

f. Develop a scoring scale.

3.1. Product and System Based Learning (PSBL) methodology

PSBL methodology combines the concepts of Systems approach, OBE (Outcome Based Education), ADDIE (Analyze, Design, Develop, Implement, Evaluate), POL (Product Oriented Learning) and CDIO (Conceive, Design, Implement and Operate) to develop employable engineers.

Product-oriented learning (POL) emphasizes on products or services that meet the authentic need of a potential customer willing to pay for it. By POL students develop a product or service which a potential customer is willing to consume, while the students learning the knowledge and skills [16].

The unique features of POL include the entrepreneurial mindset, student's initiative and product as the focus. In contrast to POL, project based learning helps the students to connect with real world. However, it has its own inherent disadvantage of disposing the product/non-functional (output of the project) at the end of the project. If the products at the end of the academic assessments are used by self or commercially sold it meets the criteria for Product Oriented Learning.

The CDIO (Conceive-Design-Implement-Operate) practice was evolved by a team of faculty members from MIT, USA, which has now evolved into a global community of practice of universities/academic institutions. CDIO involves a complex, value-added engineering products, processes, and systems in a modern, team-based environment [10]. TABLE I captures all the twelve standards of CDIO and features of the standards.The key themes highlighted in the table were used to develop an integrated curriculum framework called Product and System Based Learning (PSBL) based on POL and CDIO.

To begin with a structured approach was adapted for implementing outcome-based education for an undergraduate program as shown in Fig. 2. This model was evolved using systems thinking with well-defined inputs and outputs (technical and system). Outcome based education is a process for transforming the input into output.

TABLE I: Key themes from twelve standards of CDIO syllabus

Standard	***Themes considered in PSBL***
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*
Learning Outcomes	***Specific, detailed learning outcomes*** *for personal and interpersonal skill s, and product, process, and system building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholder*
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***
Introduction to Engineering	*An* ***introductory course that provides th e framework for engineering practice*** *in product, process, and system building, and introduces essential personal and interpersonal skills*
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*
Engineering Workspaces	*Engineering* ***workspaces and laboratories*** *that support and encourage hands -on learning of product, process, and system building, disciplinary knowledge, and social learning*
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*
Active Learning	*Teaching and learning based on* ***active experiential learning methods***
Enhancement of Faculty Competence	*Actions that* ***enhance faculty competence*** *in personal and interpersonal skills, and product, process, and system building skills*
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*
Learning Assessment	***Assessment of student learning*** *in personal and interpersonal skills, and product, process , and system building skills, as well as in disciplinary knowledge*
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***

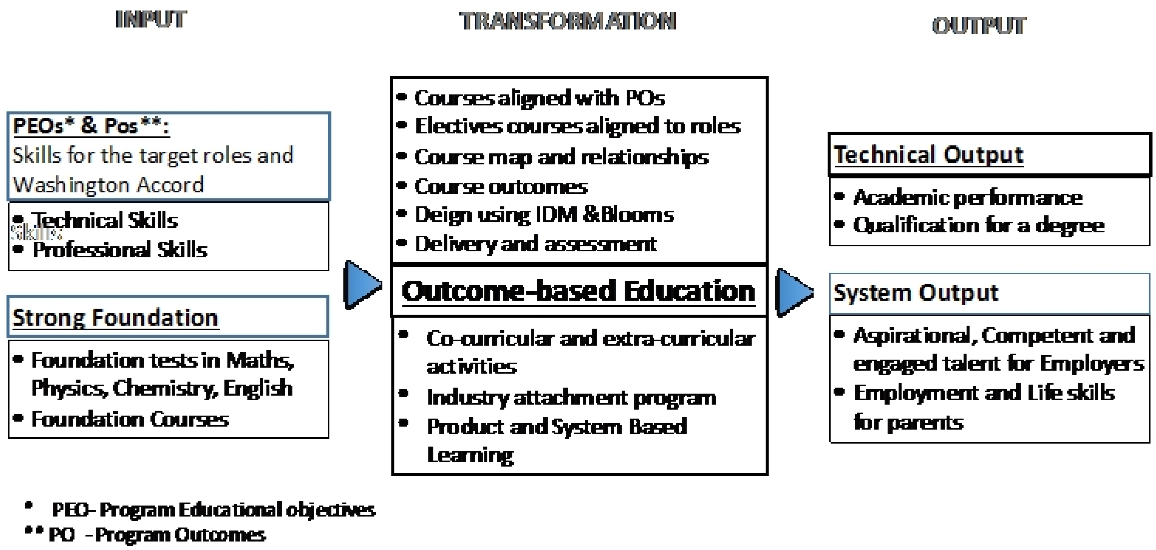

Figure 2: Systems approach for education in engineering

In this model for OBE, three stages of product and systems based learning were introduced to facilitate multiple assessments of program outcomes. At every stage few courses are pooled which provides necessary competencies to realize the product or system. While the product means an authentic product that needs to be realized, a system means a manufacturing or quality system that needs to be created along the product. As the products and systems are interdependent this methodology calls for collaborative effort by the students. The three stages are shown in Fig. 3.

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

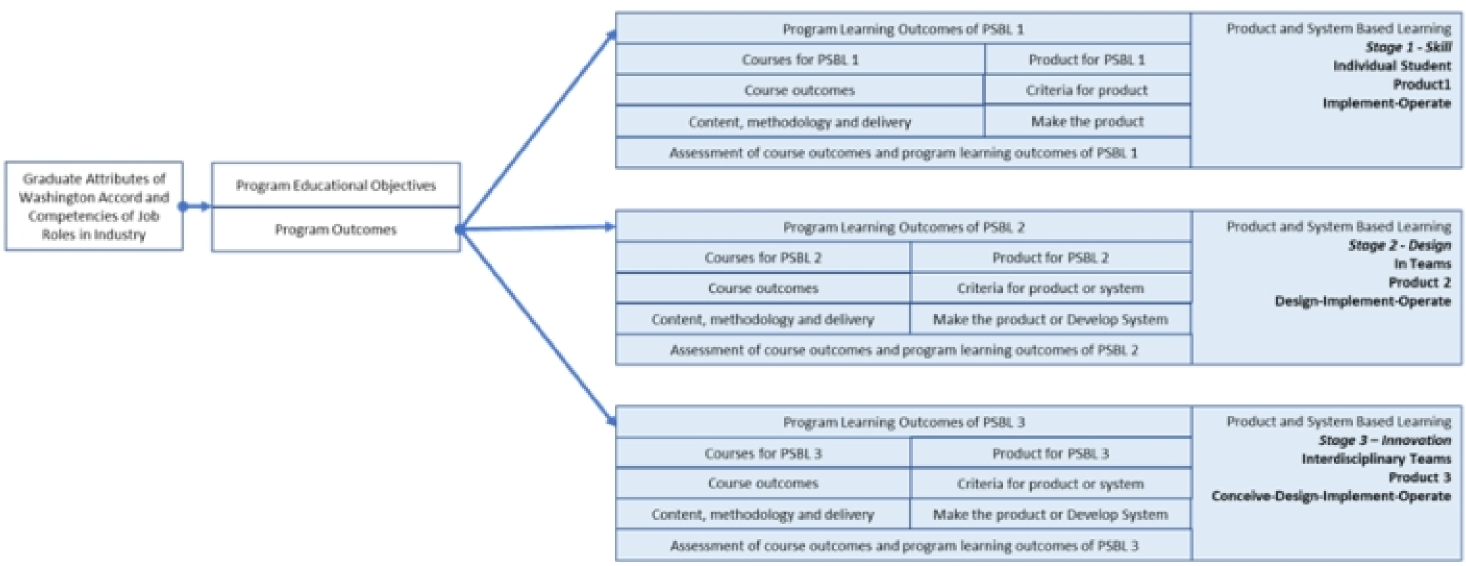

Figure 3: Framework for product and system based learningIn PSBL methodology, Program educational objectives and program outcomes (technical and professional skills) are derived from the twelve graduate attributes of Washington accord and the competencies of the target job roles in the industry. Program learning outcomes are derived from program outcomes for each stage as competencies to be demonstrated to realize a product or system. The courses required to achieve the program learning

outcomes for each stage are identified. The course outcomes for these courses are derived. The courses in the stages are aligned to products or systems in each stage. Assessment of course outcomes and program learning outcome are carried out. Assessment of program learning outcomes are carried out using rubrics. In order todevelop employable graduates aligned to specific job roles, streams of core courses and elective courses are identified.

PSBL 1 is carried out by every student, individually. It develops basic skills for realizing a product with 'Implement' and 'Operate' tasks. At this stage, the design of the product is carried out by the faculty and integrated with the pool of courses in the first four semesters.

PSBL 2 is carried out by teams of students. It provides an opportunity to design, implement, and operate at an advanced level for a given concept of a product or system. The students are expected to develop alternative options for a product or system, and choose one of the options using a decision matrix. It is followed by design and manufacture of the product or system and the parts meeting the functions and reliability. PSBL 2 is expected to be carried out by a team of students with specific roles. These roles are decided based on the roles offered by potential employers. As an example, roles identified for early experimentation include engineers for product engineering, manufacturing systems engineering and quality systems engineering. PSBL 3 is further extension of PSBL 2, where the teams are interdisciplinary dealing with products and systems requiring contributions from several disciplines. Products for all the stages are identified using the guidelines developed by a team of faculty members in consultation with experts from industry.

The program learning outcomes linked to program outcomes are assessed multiple times with increasing complexity (three in this case), hence providing scope for improvement in each stage. In each stage the assessment of course outcomes are carried out using formative and summative assessments. The program learning outcomes are assessed using rubrics specifically designed for them. These rubrics are used in integration with the course related activities. Quite often these pertain to specific tasks performed by students as part of the courses and not only responding to the formative and summative assessments. The product made in each stage is also tested for function and reliability using suitable methods such as contests. Product function and reliability testing is also carried out using rubrics.

A pilot was carried out to demonstrate PSBL methodology in B.E. Mechanical Engineering. The application of PSBL methodology in stage 1 to the program and its findings are reported below.

3.2. Application of PSBL methodology

Seven program learning outcomes were derived for PSBL 1 from program outcomes. It consisted of 4 technical skills outcomes and 3 professional skills outcomes. Table II shows the program learning outcomes of PSBL 1 derived from the program outcomes for the course.

TABLE II: Program Learning Outcomes for PSBL 1

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.

For PSBL 2, eleven program learning outcomes were derived for the three roles (product engineering, manufacturing systems engineering and quality systems engineering) identified. 5 technical skills outcomes were unique to the roles identified and 7 professional skills outcomes were common to all the three roles. Program learning outcomes of PSBL 2 are listed in Tables III and IV respectively. The PSBL methodology aligning to all the eight semesters of the program with three stages, with the pool of courses in PSBL1 and role-based PSBL 2, 3 are shown Fig. 4.As a sample, pool of courses identified for product engineering track is shown Fig. 5.Similarly pools of courses were identified for manufacturing systems engineering and quality systems engineering.

Table III: Program Learning Outcomes (Technical) for PSBL 2 – 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 IV: Program Learning Outcomes (Professional) for PSBL 2 – common for 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)

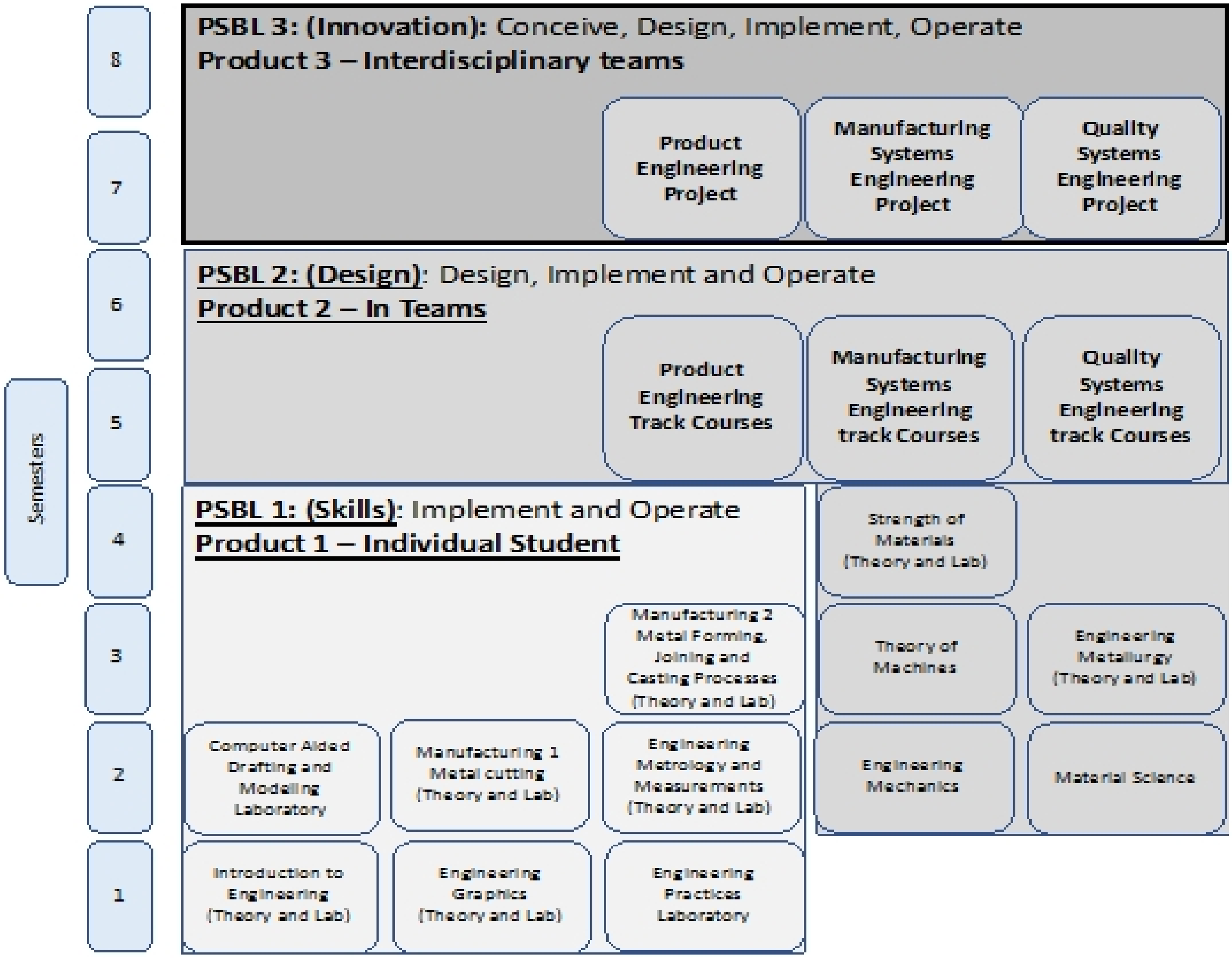

Figure 4: Arrangement of stages and pool of courses in a B.E. Mechanical Engineering program

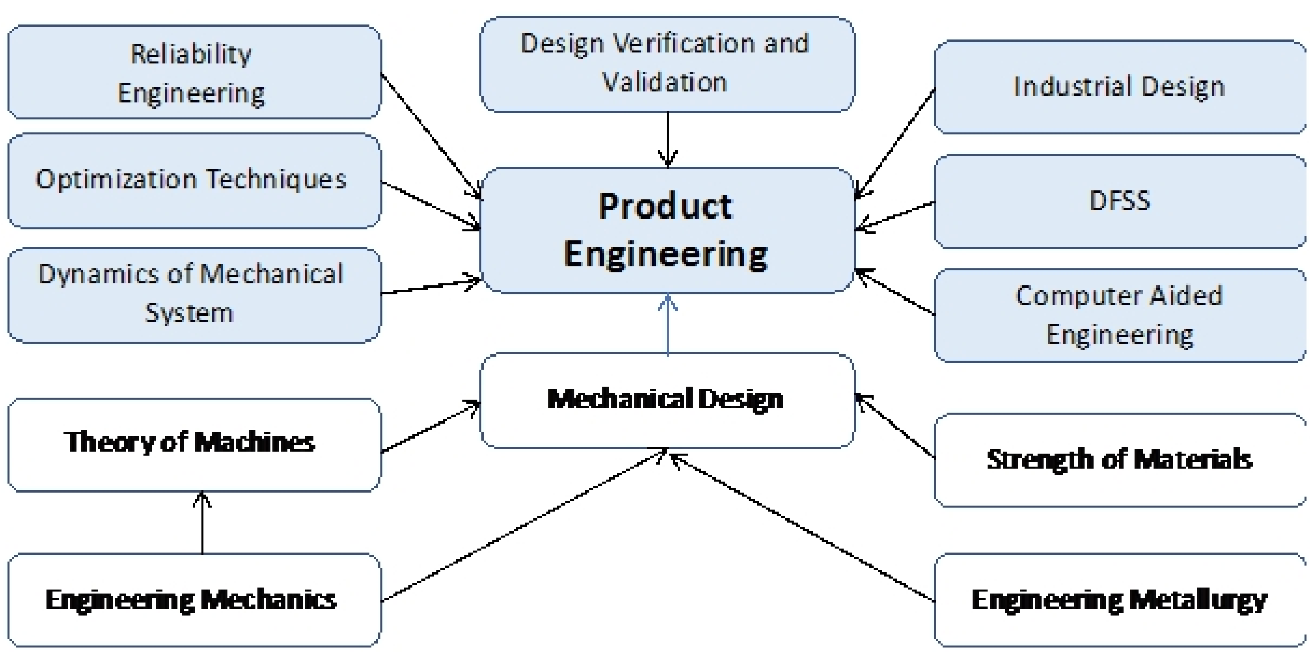

Figure 5: Courses (core and elective) for the product engineer role

Program learning outcomes of PSBL1 were assessed through the tasks in making the product. A sample rubric used for the assessment "Prepare part drawing of a given product independently based on functions with appropriate dimensions, tolerances and fits" of PSBL 1 is shown in Table V.

TABLE V: 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 indicates 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

Rice noodle making machine was chosen as the product to be made by each individual student as part of PSBL 1. Design of the machine was made by faculty members and given to students. Course related tasks of the first four semesters were planned and managed optimally so that each student could manufacture a machine at the end of four semesters. The tasks commenced from the very first semester and culminated in the product in the fourth semester. The course related assessments and the task, product related assessments were carried out by faculty members and support staff using formative, summative assessments and rubrics respectively.

Assessment of course outcomes, program learning outcomes and product functions were carried for all the students. The course level assessment was based on the pass percentage, average marks in formative and summative assessments. The program learning outcomes assessment were carried out using rubrics for the technical and professional skills based on tasks. The product function assessment was also carried out using a contest involving testing the product in situ.

The course level assessments in all the seven courses of PSBL 1 (shown in Fig. 4) indicated percentage of students passing was above 96%. The averages in the formative assessments and summative assessments ranged from around 60% to 80%. These numbers indicated high levels of course achievements by the students.

The program learning outcomes were assessed at four levels using rubrics. The levels of learners were classified as novice, beginner, proficient and competent. The target levels fixed were competent and proficient. There were only 45% of the students reaching the target in all the 4 technical program learning outcomes. In the professional program learning outcomes only 11% reached the target.

The products made by all the students as part of PSBL 1 were tested in a contest. To the surprise of the students and faculty, only 29% of the machines functioned satisfactorily and produced rice noodles.

The performance summary of the students in multiple assessments is summarised in TABLE VI, which clearly indicates that professional skills and product performance are areas of concern. These are essential parts of employable skills, which are not captured and reflected in the course assessments.

TABLE VI: 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

4. Conclusion

This experiment indicates that assessments of course outcomes using formative and summative assessments is a necessary condition to develop employable graduates. However, it not a sufficient condition, as applying the engineering practice to realize a product or system is an essential element to realize employability. This experiment provides a framework to assess the program outcomes directly using program learning outcomes as competency and rubrics as performance indicators as recommended by AICTE examination reforms.

In the industry engineers are deployed in multiple job roles. The choice of electives or the choice-based credit system must be carefully designed to align to the specific job roles in the industry to improve employability.

Organizing the pool of courses in each stage needs to be sequenced based on the prerequisites for the advanced level courses required to realize the product or system.

Selection of the appropriate product or system that provides an opportunity to utilize the technical and professional skills learnt through respective courses. Even though five of the twelve graduate attributes of Washington accord relate to professional skills, very negligible share of credits allotted for courses for professional skills. This needs to be significantly increased.

Development of product and system-based learning methodology requires considerable time and efforts, and it is essential to involve industry experts at all stages. Also, it is necessary to assign fulltime team to implement outcome-based education and product and system based learning.

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