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Re-Designing Curricula for Engineering Graduates: An Innovative 3-Dimensional Model Using Students' Perceptions, Teachers' Reflections, and Industry Demands

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Abstract:A scientifically designed curriculum is a key to achieving outcomes of any engineering education program. Engineering education has become a highly transformative field in the past few years; its conventional curriculum requires rigorous face-lifting and redesigning. The new age engineering program curriculum demands the inclusion of several transformative teaching-learning models and modern methods of assessment. These modern pedagogical practices have been well incorporated from time to time within the engineering education framework at various levels and stages. However, owing to the lack of explicit information on the modern curriculum attributes, the curriculum design has remained an area of exploration. This paper represents a systematic and scientific approach of designing the curriculums for undergraduate engineering programs. There are three important aspects of curriculum attributes namely knowledge, skills and experiential learning have been emphasized constructing the base of 3-dimensional model of curriculum designing. The paper discusses the current scenario for the engineering curriculum, the present needs and feedback from three important stakeholders namely students, teachers, and employers. The feedback revealed that students are looking forward to learning inter-disciplinary courses in their regular curriculum. The teachers require freedom of re-planning sessions unconventionally and the variations in the assessment models. The employers expect state-of-the-art knowledge, skills, and industry exposure from the students. The article finally extracts the significant attributes from the feedback analysis received from the stakeholders and suggests the micro-contents and attributes to be incorporated within the existing curriculum structure. The article provides one of the most effective ways to design the curriculum for the undergraduate engineering programs by achieving the desired outcomes and attainment levels.

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1. Introduction

The past few years for the engineering programs have remained highly transformative from the perspective of teaching-learning processes. Most of the premier

engineering institutions have made changes in their pedagogical practices to fulfill the requirements of modern industry and academic fields (Daun, M. et al., 2023). Engineering education has become more technology oriented, and use of modern teaching aids has become inevitable (Rehman, Z. U. 2023). The modern engineering education being referred to as 4.0 has presented several requirements in all attributes namely pedagogy, assessment and most importantly the curriculum design (Miranda, J. et al. 2021). Because of the progress of the industries, the requirements of employment have also changed. A graduating candidate is expected to have skills, awareness of technologies and capability to work on real-time challenges to meet the fast-evolving demands in nearly all sectors. The institutions have implemented modern methods namely experiential learning (Hernandez-de-Menendez, M. & Morales-Menendez, R. 2019), problem or project-based learning (Guo, P. et al., 2020; Wu, T. T. & Wu, Y. T. 2020), collaborative learning (Stites, N. A. et al. 2021), use of virtual tools and augmented reality platforms (Halabi, O. 2020) and so on and so forth to meet the field requirements.

However, it must be noticed that the mere implementation of modern methods of pedagogy may not fulfil the learning objectives of a program or course. It requires a grassroot level transformation starting from a new curriculum design approach (Coşkun, S. et al., 2019; Nancy, W. et al., 2020). The development of the sustainable curriculum is a key component and needs new design approaches for the engineering curricula (Hadgraft, R. G. & Kolmos, A. 2020). It is also expected that modern engineering graduates must be aware of the sustainable development goals that are not included in the current curricula (Gutierrez-Bucheli, L. Et al. 2022) in many engineering programs, because it requires modern pedagogies and reforms in the assessment also. The literature review of some of the most relevant works revealed a few missing links in the present curriculum design approaches also. Interestingly these links are not easy to identify by direct observations. They are the curriculum reformation, effective pedagogies, and their appropriate evaluation and finally the quantification of the attainment of the outcomes for a program or a course. Several attributes, including curriculum development, need attention to meet the modern requirements of academia and industry (Purzer, Ş. et al. 2022). It has been observed that the present academic curriculum and pedagogical models restrict and holistic competency of learners and thereby the system (Chan, C. K., & Luk, L. Y. 2022; Boelt, A. M. et al. 2022). Though there are modern approaches being utilized for characterization of nature of engineering (Barak, M. et al. 2022) to address the integration of domains namely science and engineering, through the methodologies, still there is need of curriculum design methodologies catering to the overall needs by the stakeholders. There are guidelines available for curriculum design from the national and international organizations and slowly being able to cater to the requirements of modern engineering education. However, the common or a generalized approach of curriculum design may not work for the needs of specific institute. The reason being that though the engineering program outcomes are nearly identical, the ways and approaches to achieving them vary along the organization. The vision and mission of the engineering program and institute may differ and therefore a specific curriculum based on the systematic and scientific approach is a need of the time.

This article addresses the challenges faced by the institutes and community in developing the modern curriculum for the undergraduate engineering programs and ways to design them with an innovative systematic approach by incorporating major attributes such as institutional vision, students' perceptions, teachers' concerns on implementation of modern pedagogies, assessment requirements and to an extent the employers' expectations from the candidates and institutions. The study includes analysis of students' feedback obtained in an online survey regarding their needs and expectations from their curriculum. Discussion on the teacher's feedback, employers' feedback, and ways to incorporate them in the curriculum via suggestions presented by the higher order academic bodies namely Board of Studies and the apex Leadership. The work has been presented based on the real time study carried out at one of the premier accredited institutes of India. However, the identity of the institute has not been revealed to maintain the publication ethics. The study revealed the demand of a highly systematic approach of design of the modern curricula for the undergraduate engineering learners. A model has been devised to cater to the program objectives, transformational pedagogies, and the assessment mechanism required evaluating the learning outcomes and attainments. The study suggested that implementing the innovative 3-dimensional approach of curriculum design may fulfill most of the requirements for an institution and for all the stakeholders.

2. Current Model of Engineering Curriculum

The present scenario of the curriculum of the engineering graduate programs primarily deals with the provisions of courses based on the varying cognitive

learning capacities of the learners. With the implementation of the model curriculum specified by the apex engineering educational authorities of the nation, several changes and inclusions have been implemented in the past three years. However, the industry and the research fields have been changing in many folds and faster than expected on the other hand. To briefly acknowledge the present salient feature of the engineering curriculum the following points may be enlisted.

- A four-year degree program consists of a semester structure of six months counting the total of eight, wherein total 160 to 180 credits are to be earned by the learners.
- The nature of courses in an engineering program have been divided into subcategories namely general science, engineering science, core engineering, open elective courses, core elective courses, audit courses, skill-based program specific courses, value education courses and domain specific courses for soft skills and professional ethics. However, the curriculum framework remains similar for nearly all courses.
- The mode of delivery of the contents includes conventional and modern methodologies though, the academic schedules, credit calculations of the academic activities, evaluation patterns namely internal and external exams, continuous evaluation, term work of assignments and tutorial along with the laboratory work are kept largely similar for most of the programs and their courses in for an institute.
- The assessment criteria have been revised and implemented in form of modern methods of project and problem-based assignments for a group of students, presentations on a given topic, model making and simulation-based assignments and evaluation, open book exams, take home assignments and a few more. However, the students learning capacity, attainment level of the objectives of a course or program remains a question or being achieved partially.
- The content revision for the course or program largely depends on the academic policies of the organizations and significantly varies from one to another institute. It is observed that the revision of the content is carried out over five years for most of the institutes and that also is not completely revised according to the need of the field applications. Herein, the outcome from an institute struggles to get absorbed in industry and research field.
- Very few institutes or universities offer inter-disciplinary courses, internship opportunities, Major and Minor specializations, exclusive training to the learners making them industry ready or research oriented.

Above are only the attributed points of a present curriculum scenario in most engineering educational organizations. However, the objective of the observation is not to criticize or devalue the efforts, policies and notions of a system or framework, however a critical closer look on the above points led to the voids on several points mentioned as below and demands a re-design of the curricula:

- Except for a few, a well-defined mapping of the organizations and programs vision, mission with the objectives and outcomes of courses and contents are major weaknesses in the framework.
- A scientific approach of quantitative and qualitative analysis of attainment levels of a course, contents and program requires attention.
- A systematic assessment of the learners' capabilities using varying pedagogical practices requires modern and unconventional methods. The modern methods may be course specific, content specific or program specific and may not be followed monotonously throughout the tenure of the program.
- A little provision or in fact a very formal way of providing industrial experience and exposure to the learners. The curriculum mentioning compulsory internships largely lacks the appropriate evaluation framework which may confirm the learning outcomes and attainment level for the learners and for the organization.
- Sufficient exposure to the idea generation, innovations, entrepreneurship, professional leadership skills and capacities are largely not included in the regular curriculum.
- Implementation of more sophisticated teaching tools like MOOCs, Augmented reality and Virtual reality platforms have been included in

the curriculums; however, the learners' feedback, the effectiveness of these methods in cognitive enhancement of an individual is not getting satisfactorily analyzed.

- The overall frame of a curriculum is being followed nearly conventionally in the form of the assessment and grading systems. Such attributes must be revised with the inclusion of modern teaching tools, new course types, and changed industry standards and work culture.

Above points encourage to make necessary changes and carry out a new design for the modern curriculum for the undergraduate engineering programs. Especially when referring to the emerging engineering industry version 5.0, the present structure and framework of the engineering curriculum will require substantial reforms and changes. The modern engineering is becoming more accessible as highly integrated or rather nested platform for most of the programs and courses being taught in the institutes. The industry has started removing the barriers of streams and branches in employments to obtain a more skill based and capable workforce. There are a few skills like software awareness, coding capabilities, management and managerial skills, critical thinking, articulation of the conventional knowledge in real-time problem solving are being observed as the keys to successful employment. The experiential learnings through the entrepreneurship are also an emerging demand from the community and society to meet the demands of the sustainable development goals of the international organizations; those are rarely included and implemented in a regular curriculum of engineering graduate programs. All the above discussion raises a set of questions asking how to then re-design the curriculum for engineering graduates? This work represents an innovative approach of curriculum design without getting diverted from the primary guidelines of the national apex educational agencies but with an opportunity to incorporate the missing links mentioned in the discussion above.

Out of all stakeholders in an engineering educational ecosystem, the learners, teachers, and employers/industry play an important role in a successful implementation and attainment of the expected outcomes for a program or a course. The authors have presented three major hypotheses to be considered and critically cross examined by holding the feedback by each of these three communities. The feedback analysis has been utilized in developing an innovative 3-dimensional model design for the engineering programs and courses.

3. Hypotheses and Feedback

A. Hypotheses

A new design approach requires critical analysis of an existing system of framework to be revised. Therefore, before carrying out the re-designing process for the engineering curriculum, it was necessary to start with a set of hypotheses and obtaining similarity or differences from the stakeholders on various points. Three major hypotheses have been considered as shown in Fig.1 for three different stakeholders:

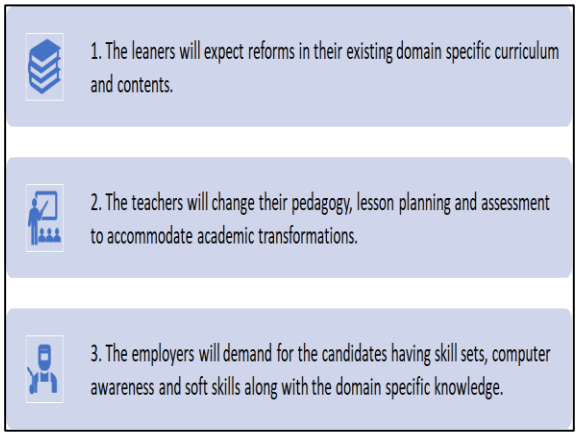

Figure1. Hypotheses for feedback by three stakeholders

Based on the above broad hypotheses for each category, the feedback forms were prepared and circulated to the respective communities. For each hypothesis a total of 32 feedback has been received anonymously via digital forms. Keeping the main aspect of the hypothesis, up to minimum five questions addressing subsets of the main idea were included in each survey form. The analysis and discussion for each hypothesis has been presented in the consecutive section. It is to be noted that the results of the analysis of the hypotheses have been utilized as a supporting tool for re-designing the process of the curriculum along with other attributes of the curriculum design.

B. Learner's feedback and analysis

A total of 32 students from varying engineering streams of semester 5 of their degree programs volunteered in the survey and provided feedback. The questionnaire consisted of short questions regarding the changes felt by the students regarding the curriculum being followed in their respective courses. The answer samples to the specific questions have been presented here in Fig.2, 3 and 4. It was necessary to know from the learners about the skill sets they have been developing during their study. They were asked to select any one of the most significant skills they were acquiring. Nearly 30% of

thestudents agreed on developing management skills, 12% site oriented problem-solving skills, and 12% design thinking skills. About 9% agreed to the problem-solving skills acquisition. Other minor responses were noticed on the different course specific skills less than 9%. The survey ensured that at least one skill was acquired via curriculum contents. The survey also revealed that the learners were struggling with administrative skills and analysis skills. Regarding their awareness of content consisting of the skill-based proportions, the answer was of a mixed response with agreement and maybe by 53% and 43% with 10% of complete disagreement. Moreover, to check their foresight about learning modern concepts, a question was asked as should your course consist of terms like "Internet of Things" and nearly 62% showed their agreement while 31% agreed partially. The feedback provided good bases regarding the positive response to the first hypothesis that the learners were on the opinion to have changes in their curriculum with respect to skills sets and receiving the state-of-the-art information imbibed within the contents. It is necessary that the learners feel that the contents and the curriculum being taught to them are meaningful and capable of providing required skills and updated or latest knowledge of the subject.

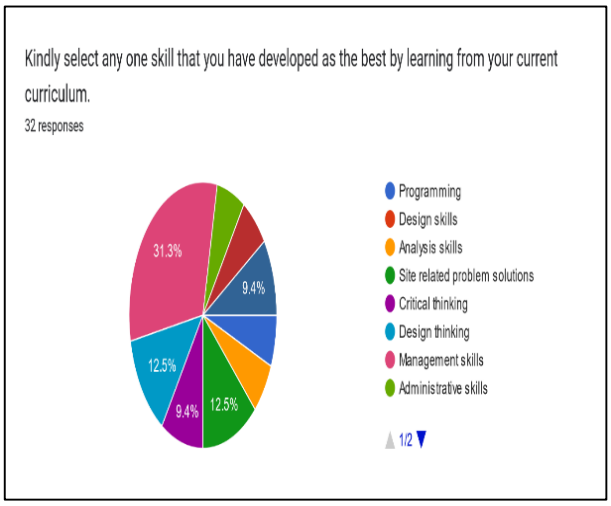

Figure 2. Learners' feedback on skill enhancement

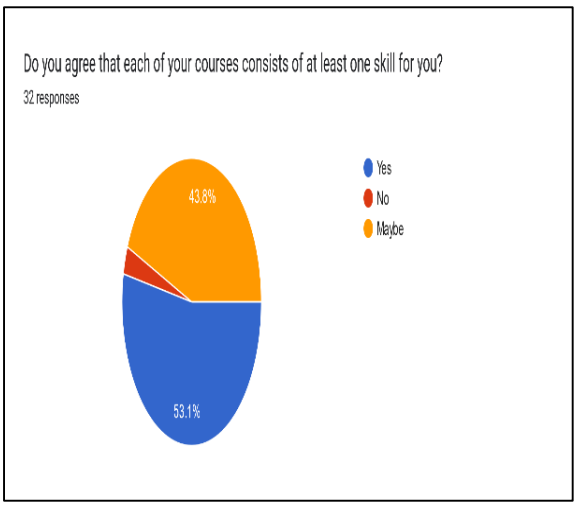

Figure 3. Learners' feedback on skill requirements from a course

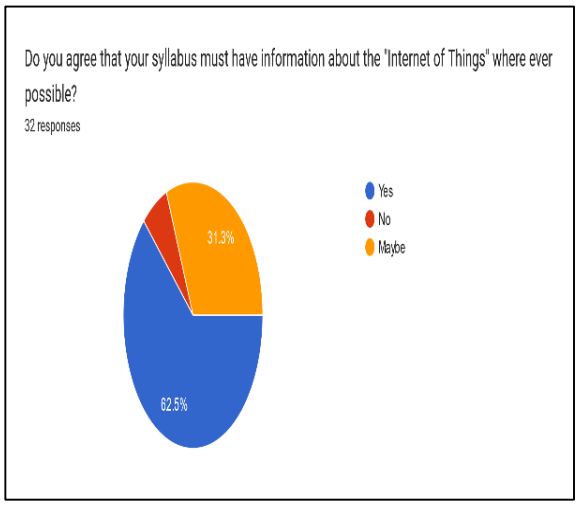

Figure 4. Learners' feedback on updated knowledge

C. Teachers' Reflections

The engineering teachers involved in university level teaching were requested to provide and share their insights on the current structure of the curriculum and requirements for the modifications. A total of 32 teachers were contacted teaching engineering undergraduate students for more than 6 years. The teachers were from different streams and designations however, care was taken that they all are well experienced and have observed at least one revision in the curriculum of the subjects they have been teaching.

Fig. 5 and 6 shows salient features of the feedback received from the teachers. Around 85% of teachers agreed that the inclusion of the modern methods of teaching requires re-planning or rescheduling of the academic sessions from the beginning. This means that

the curriculum should provide freedom or flexibility to an individual for selection of method and its planning. Teachers must generally follow the standardformat of 2 or 3 lectures and four or six sessions for the practical or tutorials. However, it is observed that conventional teaching many times need extra sessions. Hence while implementing transformative methods namely P2BL, collaborative learning, AR & VR sessions and similar others may not be justified within the conventional framework of curriculum.

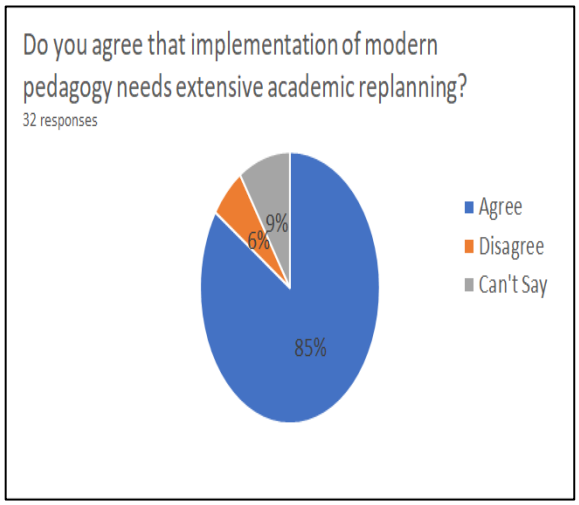

Figure 5. Teachers on the need of academic planning for new pedagogy

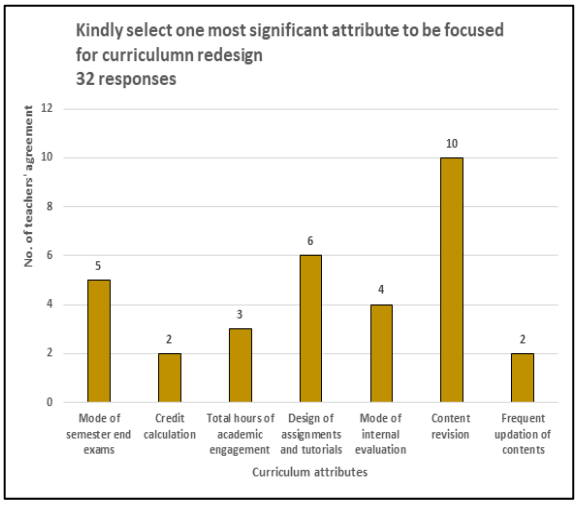

Figure 6. Curriculum attribute to be focused on for redesign.

From Fig.6 it may be observed that content revision and nature of assignments are two salient features related to the new designing of the curriculum. Nearly 31% of the 32 teachers supported the changes in the curriculum contents according to the demand of the modern curriculum. They also emphasized revisions in the assessment styles in all three exam modes, namely 19% suggested changing the assignment and tutorial structure, 16% suggested that the mode of end of semester exam should be revised with new methodology. About 13% of the teachers suggested changes in the internal assessment also. The opinions of the teachers were mapped with the hypothesis, and it was observed that most of them suggested changing the assessment style, rescheduling of lesson planning and content revision.

D. Employer's Feedback

The employers' feedback was one of the tough tasks to achieve as the professionals and officials are relatively more focused on their recruitment process continuously. However, the authors received the desired entries from the companies and organizations visiting the parent university to offer placement opportunities to the students on the regular basis. The heads of the departments and placement coordinators frequently discuss the performance of the students and receive input and suggestions from the employer to increase the placement ratio every time. Though the survey was conducted via online digital form, there were many important inputs obtained by the academicians from the employers during the conversations. Fig. 7 shows the employers' feedback on the most significant attribute of the placement expected from the students during the interview and placement processes.

Nearly 22% of the 32 employers emphasized post processing of the internships offered to the students as a part of their curriculum. This was important feedback. In fact, generally in the absence of adequate evaluation of the internship work carried out by the students, the chance of learning for the academic fraternity reduces. By offering professional or field experience to the graduates it is expected that they revert to the parent institute with their suggestions, and comments on the academic and other relevant aspects of curriculum it they to be modified. One more aspect of professional development of students was highlighted by the employers was inclusion of advanced topics in curriculum (16% of 32 feedback) and training for teamwork to the learners (13% of 32 feedbacks). These points again drew attention to the revision of the existing curriculum framework and by altering the content formation and mode of assessment. Along with the academic and assessment reforms, the employers suggested improving the soft skills and logic development and focusing on the development of the

culture of innovation within the students during the academics. The employers' feedback was found in good correlation with the hypothesis that the curriculum should offer skills, software awareness and advanced topics in the modern curriculum.

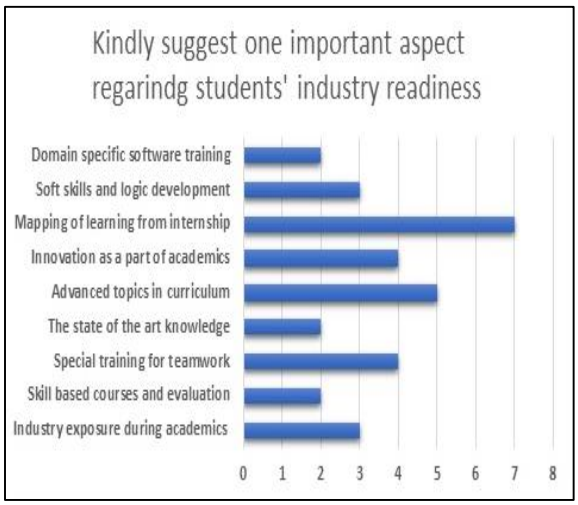

Figure 7. Employers' feedback on important aspect for students to placements

E. Summary and Remarks on the Areas of Improvement of Current Design of the Curriculum

A good correlation amongst all three stakeholders' feedback was observed. All three of them agreed that the redevelopment or redesigning of the existing engineering curriculum is a key to success in achieving the expected outcomes and attainment from a program and a course. From the feedback the authors retrieved that while revising the curriculum, the following points should be considered.

- Domain specific content revision with respect to the industry trends
- Innovative methods of assessment according to the nature of assignments
- Industry exposure, assessment of performance at the field and relevant changes in curriculum
- Flexibility in lesson planning and laboratory planning to the teachers
- Focusing on skill development in curriculum

The feedback and reflections were considered in proposing the model for curriculum design by the authors at the appropriate levels. The re-designing of curriculum has been suggested based on the guidelines proposed by the apex academic organizations of the country.

4.Dimensions for Re-Designing of Engineering Curricula

By mentioning the 3-dimensional approach, the overall 18 aspects of the curriculum design have been considered and utilized for creating the framework of the curriculum. All such aspects are shown in Fig.8.

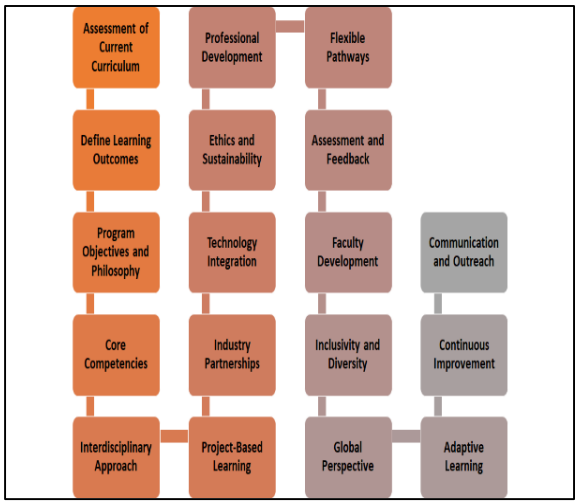

Figure 8. Important aspects of curriculum design

The aspects of curriculum design have been divided into three broad categories namely a) Knowledge domain, b) Skill domain, and c) Experiential learning domain. It is to be noted that by mentioning domain, the authors are not targeting any specific engineering branch or stream. Rather, the approach is highly generalized which may be incorporated by any engineering stream.

A 3-dimensional approach for designing an engineering curriculum refers to a framework that considers three key dimensions or aspects when developing a curriculum. These dimensions help ensure that the curriculum is comprehensive, effective, and aligned with the goals of engineering education. Here are the three dimensions:

1. **Knowledge Domain Dimension:** This dimension focuses on the content and subject matter that students will learn. It includes the technical knowledge, theories, principles, and concepts that are fundamental to the engineering discipline. Within this dimension, you can consider the following:

   a. **Core Engineering Disciplines:** Identify the core engineering disciplines that the curriculum will cover, such as mechanical engineering, electrical engineering, civil engineering, etc.

   b. **Interdisciplinary Knowledge:** Determine areas where interdisciplinary knowledge is essential, such as materials science, data analytics, and environmental sustainability.

c. **Emerging Technologies:** Stay up to date with emerging technologies and trends in engineering to incorporate relevant topics into the curriculum.

d. **Foundational Sciences:** Include foundational sciences like mathematics, physics, and chemistry that provide the basis for engineering principles.

2. **Skills and Competency Dimension:** This dimension focuses on the skills, competencies, and abilities that students should develop during their engineering education. It goes beyond theoretical knowledge and encompasses practical and soft skills. Within this dimension, consider the following:

a. **Technical Skills:** Include hands-on technical skills and laboratory work relevant to the chosen engineering discipline.

b. **Problem-Solving:** Emphasize problem-solving skills, critical thinking, and the ability to apply engineering principles to real-world challenges.

c. **Communication Skills:** Develop students' abilities to communicate technical information effectively, both in writing and verbally.

d. **Teamwork and Collaboration:** Encourage teamwork and collaboration skills, as engineering projects often require working in multidisciplinary teams.

e. **Ethics and Professionalism:**Instil a strong sense of ethics, professionalism, and social responsibility in engineering practice.

f. **Leadership and Project Management:** Provide opportunities for students to develop leadership and project management skills.

3. **Experiential and Contextual Dimension:** This dimension focuses on the application of knowledge and skills in real-world contexts. It emphasizes hands-on learning experiences and practical exposure to engineering challenges. Within this dimension, consider the following:

a. **Internships and Co-op Programs:** Facilitate internships, co-op programs, and industry partnerships to provide students with practical work experience.

b. **Capstone Projects:** Implement capstone projects that allow students to apply their knowledge and skills to solve complex engineering problems.

c.**Research Opportunities:** Offer research opportunities for students to engage in cutting-edge research within their chosen discipline.

d.**Field Work and Site Visits:** Organize field trips and site visits to industrial facilities, construction sites, or research labs to expose students to real-world engineering environments.

e. **Entrepreneurship and Innovation:** Encourage entrepreneurial thinking and innovation through coursework and extracurricular activities.

f. **Global and Cultural Awareness:** Promote global perspectives by offering study abroad programs or projects with international partners.

By considering these three dimensions (Knowledge Domain, Skills, and Competency, and Experiential and Contextual) in the design of an engineering curriculum, you can create a well-rounded and effective educational program that prepares students for success in their engineering careers while staying responsive to industry needs and technological advancements. It's essential to continuously evaluate and update the curriculum to ensure its relevance and effectiveness in a rapidly changing world.

5. Results and Discussion

The survey analysis of three important stakeholders and the model presented in the discussion are to be correlated with each other to obtain useful information and way of re-designing of the curriculum as shown in Fig.9.

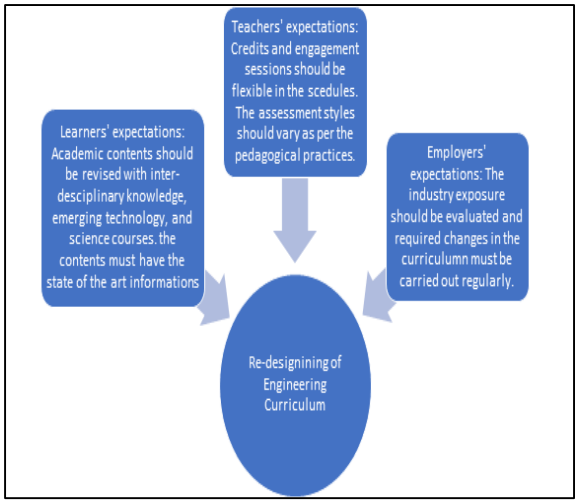

Figure 9. Extract of the stakeholder's feedback

The 3-dimensional model should be connected to all the extracts of the feedback. Especially, from the employers' perspective, the curriculum should be revised on regular basis and the contents must be changed as per the industry expectations and exposures of the students. This is one of the most important aspects of our current curriculum system, where the learners' reflections are rarely given attention. The apex academic bodies like Board of Studies should be reported with the valued input of the learners so that the framework of a consecutive curriculum may be modified.

Secondly, the skill-based courses should be incorporated within the existing curriculum and contents and may be given adequate credits to reflect their importance to the learners. The inter-disciplinary work may be included in the projects and assignments where the learners must form a team of students from different streams working together for a common purpose.

The faculty should be empowered to decide the pedagogical model to be used in the teaching-learning process. The assessment should get decentralized as fast as possible and may be done by the respective departments rather than the central process. This is necessary because, in such cases, the faculty will be able to evaluate learners' attainment levels. Apart from the conventional classroom teaching styles, each transformative method requires a unique scale of assessment, and that freedom should be with the faculty those are deeply involved in the process from the planning stage to the end by assessing the learners' outcomes.

6. Conclusions and Recommendations

The aspects discussed in the present article encourage us to retrieve the following important concluding remarks.

- The re-designing of the curriculum should be done using real-time feedback from the stakeholders. The syllabus should be revised or updated in the line of the suggested points by the stakeholders.
- The micro-structuring of the contents may be carried out by keeping three major aspects namely the knowledge, skills, and experiential learning. These three dimensions support the formation of the base of the curriculum apart from the credits, hours of engagement, and mode of assessment.
- The revised curriculum must demonstrate clear inclusion of the skill-based courses and the state-of-the-art knowledge on the subject to the learners.
- The teachers and instructors should contribute to the new assessment methodology where the transformative pedagogical practices are being introduced. The internal and external assessment structure may be redefined and as a rubric it should be presented to the learners for transparent evaluation.
- The learners should get more industry exposure by internships and training by the industry persons. The performance of the learners at the industry should be evaluated and measured with the course and subject outcomes for the given curriculum.

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