Engineering Exploration : A Collaborative Experience of Designing and Evolving a Freshman Course

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***Abstract*—Designing innovative freshman courses has attracted engineering educators world over. "Engineering Exploration" course is the outcome of one such effort and it focuses on engineering problem solving, multi-disciplinary engineering skills, engineering design process, team work and collaboration. Ethics and sustainability are also essential part of this course. The course is characterized by a number of unique features: 1. It promotes students' learning through exploration and learning by doing. 2. It is codesigned by a team of faculty members from diverse engineering disciplines 3. Learning is facilitated by a group of teachers engaged in team teaching 4. It follows PBL pedagogy with focus on both engineering design process and the product. Over the past three years the course is acting as a test best for a number of experiments in engineering education resulting in several reforms not only in this course but also influencing several other courses in the subsequent years of undergraduate engineering degree programs. The course is today recognized by India Electronics and Semiconductor Association (IESA) as a foundation course for its National ESDM skills Training & Research Academy (NETRA). Through this initiative 17 institutions in India have adopted "Engineering Exploration" course in their curriculum. This paper discusses the evolution of the course (*Abstract*)**

Keywords—Engineering Problem Solving, Freshman Engineering Course, Engineering Design, PBL, Engineering Ethics and Sustainability

I. Introduction

Designing freshman engineering curriculum has remained the focus area for engineering educators and several efforts can be seen in this area [1-9]. Several reasons can be listed for this with the major ones being: i) Changes in the nature of problems being solved by engineers ii) Rapid changes in the engineering and technology, engineering practices and skills and iii) Change in characteristics of 21st century learners.

In this paper, the authors have shared their experiences of collaborative approach at various stages of the course evolution, the need for it, the methodologies used and their benefits. While the paper describes the current version of the delivery, the section on Course Evolution traces the maturation of the course since the first delivery.

II. Engineering Exploration Course Design

The traditional freshman curriculum that focused on application of basic engineering knowledge is offered through a set of engineering courses at elementary level. This approach suffers from what is termed as "elementitis" and "aboutitis" [10]. This approach is plagued by the following limitations: i) It does not give the holistic view of engineering for freshmen that is required for engineering problem solving ii) Lacks emphasis on multi-disciplinary skills required for engineering problem solving iii) Students need to wait for long to experience engineering problem solving.

A study of alternate approaches to design of freshman engineering curriculum was required which was facilitated by Indo-Universal Collaboration for Engineering Education (IUCEE) through a visit to Virginia Tech. Engineering problem solving, multi-disciplinary skills required for engineering problem solving, engineering design, data acquisition and analysis, ethics, sustainability along with teamwork and collaboration formed the core of the course. The course "Engineering Exploration" was thus born with the following course outcomes:

At the end of the course the student should be able to:

1. Explain the role of an Engineer as a problem solver.
2. Apply multi-disciplinary skills to solve complex engineering problems.
3. Demonstrate data acquisition and analysis skills.
4. Build engineering systems using engineering design process.
5. Use basics of project management in doing projects.
6. Analyze engineering solutions from ethical perspectives.
7. Analyse engineering solutions from sustainability perspectives.

Course content includes modules on Engineering Design, Platform Based Development (Arduino), Mechanisms, Project Management, Data Acquisition and Analysis, Project Management, Ethics and Sustainability. The course content design and delivery necessitates collaboration between team of instructors from multiple disciplines. Courses with a similar mandate have been studied extensively and their benefits range from giving an understanding of the engineering profession, honing creativity supported by a positive learning environment, initiating students on a lifelong learning trajectory, helping freshmen gain cognisance of the ill-defined nature of engineering problem solving, exposing freshmen to the dynamics of teamwork and instil the belief that engineers are communicators either through text or graphics [11].

III. Assessment of learning outcomes

In this course, assessment of learning outcomes has two components: In semester assessment (ISA) and end semester assessment (ESA) the details of which follow:-

1. ISA is accorded 80% weight and is carried out in multiple intervals focusing on learning in various modules constituting the course content. Since the course follows PBL pedagogy, intermediate reviews of the course project are also included as part of ISA.
2. ESA is accorded 20% weight and focuses on the course project delivery.

Assessment planning begins with formulation of the rubrics for assessment activities that are aligned to the module and course outcomes. The success of the assessments depends on how adept the multi-disciplinary team of faculty members are in interpreting the rubrics for usage and in communicating the expectations to the students. Hence, mentoring the faculty members to achieve a proficient level is achieved via short trainings on assessment conduction.

A practice of communicating the assessment rubrics to students before commencement of assessment activity is followed throughout the course. This has benefitted in terms of both improved students performance and earning their confidence and trust in the assessment system. Self assessment and peer assessment practices are also followed in a few occasions.

The practise of team review is followed in all course project reviews. This practice has evidenced significant benefits in terms of:- i) instructors getting an opportunity to acquire knowledge from their colleagues belonging to different engineering disciplines and ii) students receiving feedback from multi-disciplinary perspectives that has led to improvements in their course projects.

IV. Engineering Exploration course delivery

To be able to cater to the overarching course outcomes required a paradigm shift in the dimensions of course design, delivery and creation of learning spaces. Across all three dimensions, the challenges faced, solutions adopted and the collaborative effort in the deliberations are discussed in this section.

A Building instructors team

This course required multi-disciplinary skills in the delivery team of instructors which was difficult to find among the members of a single faculty. Thus, building a team of course instructors with different disciplinary background was chosen as a strategy. Team composition had mandatory representation from mechanical, computer science, electrical and electronics engineering disciplines. However, this approach had the following challenges:

i) Team members brought disciplinary knowledge to the team, however, none of the team members had all the competencies and skills required to deliver the course.
ii) Faculty members needed common understanding of few of the engineering concepts.

To address the challenges, a workshop on “Course Design” is conducted for the team of instructors identified for this course. This workshop is led by the University’s Academic team which shares the system’s aspirations. Accordingly, course outcomes, content, pedagogy, assessment planning are collaboratively discussed and finalized in this workshop. Since the course follows PBL pedagogy, course project planning and scheduling is a pivotal part of this workshop. This includes tasks like identification of need statements to planning infrastructural resources. The first such workshop had learning and inputs from the experiences of Virginia Tech [12]. Today, this workshop is an annual practice and is conducted during summer vacation before the commencement of the academic year.

B Pedagogies of engagement and instructors collaboration

Choice of appropriate pedagogy forms an important part of creating the learning environment centered on students. Pedagogies of engagement [13], active and collaborative learning pedagogies practiced by a team of instructors are chosen as the means to engage with students in this course. The approach of team teaching is seen not only as a means for providing students with the skills they need, but it also was discovered as a way to enhance the teacher’s own professional development [14].

C Creating Learning Spaces

1. Engineering Exploration Learning Studio: The course practices active, collaborative and PBL pedagogies. Therefore, there was a need to create learning studios that promote active and collaborative learning [15]. Since the course is resource-intensive, an additional space was carved for stocking and arranging these resources.
2. Thinkering Lab – the prototyping facility: Engineering Exploration course follows PBL pedagogy and the students collaboratively design and build mechatronics systems (prototypes) following engineering design process. Thinkering Lab houses the tools, equipment and provides services required for building and fabricating mechatronics prototypes. This facility designed to be a freshman friendly environment incorporating adequate safety and security aspects. There is a conscious effort put to move students from “quick hack mindset” to “engineering mindset” through insisting on following appropriate procedures, use of proper tools and equipment.

V. Student Support Systems:

Need for establishing students’ support system was observed during the course delivery because of the following reasons:

1. Freshman students are new to campus and not yet identified with their degree-granting department, need special attention in terms of instructor mentoring.
2. Course projects require support involving multi-disciplinary skills and
3. The volume of students offered another challenge to instructors in terms of catering to all need students, just in time.

Parallel to related initiatives discussed below, many documented evidences are seen in the area of mentorship. The mentors can be upper-classmen, graduate and/or undergraduate students and faculty members, or a collaborative engagement between them [11]. On similar lines, the following initiatives were conceived during the last three years to support the students enrolled in Engineering Exploration course.

A. *Project Clinic*

One of the critical supports that freshman students need during their course project is timely mentoring. However, individual faculty members may not possess all the skills required to mentor students' teams through the life cycle of course project prototyping. Project Clinic is separate facility that offers just in time help to students doing their course projects. As opposed to individual mentoring, a team of faculty members make themselves available during fixed hours every day. Reviewing, validation, testing and debugging are the typical types of support given in Project Clinic. It is observed that this facility is able to significantly improve the completion rate of course projects [16]. The success of this initative may be attributed to the multi-disciplinary team of faculty members who made themselves available for team mentoring of course projects.

B. *MITRA - The student buddy initiative*

MITRA is an acronym for **M**entors **I**n **T**hinke**r**ing L**a**b. In this initiative a group of alums of Engineering Exploration course are recruited to mentor the current students of the course during the prototyping phase of course project. This support consists of offering services during prototyping in terms of training on new equipments and tools in addition to testing and debugging support. While current students are getting timely help during their course projects, seniors are also benefitted by learning from the new practices introduced due to redesigning of the course.

VI. EVOLUTION OF ENGINEERING EXPLORATION COURSE

The first version of Engineering Exploration course was delivered in August – December session of academic year 2015-2016. There was an intentionally conceived effort to observe and learn from the experiences of our stakeholders, both students and instructors. Both formal and informal means were adopted to collect the experiences and measure the effectiveness.

A. *Instructors' Feedback*

Instructors Feedback was considered critical because of the large of size of students' population of about 550 students every semester and the practice of team teaching. Two methods are used to collect instructor's feedback:

1. Session Feedback through WhatsApp group: Instructors involved in delivery of the course are expected to record their observations in the Whatsapp group consisting of the course instructors. They are expected to share their observations and learning from a particular session immediately after the delivery. This feedback helps quick learning and improvement within a module across sessions. And this feedback log is used at the end of the semester as input for re-designing of the course.
2. Weekly meeting: Weekly meeting of instructors discusses the current week's experiences and readiness assessment of next week's module. By readiness assessment, the authors refer to instructor and resource readiness. The experiences recorded in this meeting are used as feedback for next delivery.

B. *Students' Feedback*

Students' feedback is a critical component of course redesign as the students are consumers of the course content and engage with it to create meaningful artefacts of learning. Focus group discussion (FGD) has been used as a means to collect feedback from students and it is an end of semester activity. This has been another major source of input for improvement of the course.

From each division, three to four randomly selected students participate in the FGD, with a total of 15 to 20 students bringing their perspectives on the following elements: course content and relevance, course structure, activity-based learning, teamwork, assignments, exams and grading, instructor effectiveness, project clinic, course projects, project exhibition, learning space: Learning studio and Thinkering lab, and additional points of interest. The FGD is conducted after the end semester assessment with the intention of collecting critical and unbiased feedback from the students which may not be possible during the semester as students. The proceedings are moderated by faculty members who are aware of the protocol of conduction and subsequent analyses of content. The proceedings are also video/audio taped. Two scribes also record the highlights of the discussion which are later used for triangulation of findings. These observations and learning are used to improve the course design and delivery.

Table 1 traces the evolution of the course in the last six deliveries. The table also indicates the contributing engineering discipline as a driver of the improvement. The involvement of multiple disciplines in each of these improvements clearly indicates the collaborative efforts of the instructors.

Through systematic effort this course on Engineering Exploration has evolved to be a test bed for many experiments in engineering education including course design, delivery and assessment. The experience gained in this journey over the last three years is shared through publications and faculty development workshops.

TABLE 1. EVOLUTION OF ENGINEERING EXPLORATION ACROSS THREE YEARS

Delivery (Academic Year)	Observations and Learning	New Initiatives	Contributing Engineering Discipline
August 2015-2016	Introduced		
January 2015-2016	Most of the course projects were of poor quality. Projects did not portray mechatronics features	Introduction of platform based development module.	Electronics
		Setting up of Project Clinic – Course Project mentoring facility	Multiple disciplines
August 2016-2017	Course projects lacked mechanical strength.	Introduction of Mechanisms module.	Mechanical
January 2016-2017		Introduction of simulation in mechanisms module.	
August 2017-2018		Emphasis on testing	Multiple disciplines
January 2017-2018	Most of the course projects were incomplete.	Agile project management practice was introduced	Computer Science & Engineering

VII. SHARING OF EXPERIENCES

This experience of designing a freshman engineering course and evolving it over a period of three years has generated good experience among the instructors. Through the scholarship of teaching learning, the team is able to pursue research in engineering education resulting in significant number of publications. A total of 05 (1 in press) publications in peer-reviewed journals and 10 conference publications are due to this effort [17-27]. Further, faculty development programs are designed around these experiences and are offered as per announced schedule. These workshops empower faculty members with philosophy, practices and skills required to design student centred courses. A total of 163 faculty members from 05 institutions from different states of India have taken part in these workshops.

Additionally, the course has also captured the attention of India Electronics and Semiconductors Association (IESA), which through its initiative, National Electronics Research and Training Academy (NETRA) has mandated Engineering Exploration to be deployed in all institutes that are interested to collaborate with IESA-NETRA to develop electronics and system design and manufacturing skills (ESDM) among undergraduate students. So far, under this collaboration, two master trainers' workshops on Engineering Exploration course have been conducted by the course designers from our Institution for 21 selected institutes reaching out to 84 faculty members from multiple disciplines. As an aftermath, currently 18 institutes have initiated this course. And this has resulted in exciting faculty members to try engineering education innovations in their respective institutions.

VIII. CONCLUSION AND FUTURE WORK

The effort over the last three years in designing and delivering the course on Engineering Exploration has been able to make significant impact a number on aspects of creating and enriching the engineering education ecosystem of the university. The major ones may be summarised as below:

1. For students: The students are able to gain a holistic view of engineering profession in an exploratory manner. Multidisciplinary skills required in engineering problem solving, engineering design process and importance of teamwork and collaboration are the enduring outcomes of this course.
2. For Instructors: For instructors it has given an opportunity to explore beyond the disciplinary boundaries and innovate in multi-disciplinary space. It is also observed that a few of the faculty members are using the experience gained in this course in designing and delivering their courses in their respective departments.
3. For University: The course has triggered a number of innovations in the further part of the undergraduate engineering curriculum based on the learning from this course where the aim is to design an integrated curriculum that gels design experiences at each phase of program in a spiral configuration of developing professional competence. A course on Engineering Design and Product Realisation is one such effort in the second year where in further reinforcement of the concepts learnt in Engineering Exploration may be witnessed.
4. For Industry: The course is serving as a foundation course for building ESDM skills among the students. IESA – NETRA is able to leverage this collaboration to spread ESDM skills among other engineering institutions in India.

In this work, the authors have discussed in depth about the challenges involved in a designing and delivering "Engineering Exploration" course. Since three years the course has evolved by the collaborative effort of a multi-disciplinary faculty team and today unabashedly boasts of an ecosystem which nurtures freshman engagement through its multidisciplinary content, learning spaces and support systems. However, efforts are required to conduct longitudinal studies to gauge the impact of this course on students learning in terms of the enduring outcomes of the course viz. engineering design process, multi-disciplinary problem solving skills, team work and collaboration. The faculty team strives to put a concerted effort in this direction.

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