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High Impact Practices and Collaborative Teaching to Enhance Learning and Engagement in Engineering Design Project Course

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***Abstract*—**Conceptual teaching-learning process in engineering disciplines fosters a deep understanding of content and facts and leverages students' domain knowledge to solve real-world problems. Combined with high-impact practices and collaborative/joint teaching in Engineering Design Project (EDP), this process enables students to apply captured expertise and skills in team-based project settings. Many conventional instructional methods for EDP are less effective because little consideration is given to conceptual learning, especially abstract design. The present research examined an experimental approach, which involved collaborative teaching in the EDP course at an engineering college in India jointly with a faculty at one of the largest higher education systems in the United States. The project's fundamental goal is to enhance teaching-learning of EDP using experience with real-world problems to enable concrete understanding of Design techniques through a co-teaching approach. The concept-based learning included team-based project experience in learning the Software Engineering Design concepts. Peer-Code Review was used as a powerful High Impact Practice (HIP) and student retrospective surveys. The empirical results of this study suggested that such HIPs and collaborative teaching-learning practices mandated Bloom's taxonomy of more critical thinking at increasingly higher levels among students by improving the quality of learning. Further analysis of demographic survey questionnaire using descriptive statistical methods demonstrate the knowledge gain, attitudes, and interests of students from varied backgrounds to pursue higher studies in foreign universities.

Keywords*—High impact practices; International academic collaboration; Collaborative teaching; Engineering design project; Co-teaching; Peer code review*

JEET Category—Research

I. INTRODUCTION

In the pandemic world in which we live, technology's importance is undeniable in all spheres. Recent technological innovations in information, communications, and computer technology have profoundly impacted how engineers can interact with one another across the globe for knowledge transfer. Two such radical changes in technology that engineers are continuously working on are improving multi-institutional collaboration and using High Impact Practices (HIPs) in engineering education to enhance the traditional teaching-learning processes and improve the learning experiences. Conceptual learning enables students to connect knowledge and experience to promote critical thinking and problem-solving to better able to transfer ideas to new situations to foster a deep understanding of engineering concepts (how they interrelate, build on prior knowledge, and make connections with similar exemplars), (Giddens, Caputi, & Rodgers, 2015; Giddens, 2016).

The conceptual teaching-learning process in Engineering Design Projects (EDP) places engineering students in the context of trans-disciplinary themes, which lead them to think about content and facts at a much deeper level and leverage their domain knowledge to solve real-world problems. The emphasis on concepts is rooted in cognitive science research findings that conceptual understanding is necessary for understanding facts and ideas in a particular context. It allows learners to apply what they have learned to new situations, helps them learn related information, and creates a connected web of knowledge (Bransford, Brown, & Cocking, 2000).

Many conventional instructional methods for EDPs are less effective because little consideration is given to conceptual learning, especially abstract concepts. National Survey on Student Engagement (NSSE) defines the active learning practices capable of promoting student engagement by deep learning as High Impact Practices (HIPs). George Kuh and his colleagues at the Association of American Colleges and Universities (AAC&U) define HIPs as the experiences that result in the achievement of deep learning, significant engagement gains, and positive differential impact on historically underserved student populations (Kuh & O'Donnell, 2013). In their empirical research work, the impact

of the collaborative project-based learning (CBPL) method is employed to measure the improvement of student self-efficacy where the participants considered in this study are undergraduate students from a state university, Los Angeles (Pearl Chen et al., 2015).

Peer Code Review (PCR), a widespread static code analysis practice to enhance peers' software quality, is prevalent in the software industry. Researchers demonstrated the efficacy of PCR activities in reducing the number of defects post-release along with code coverage and dedicated involvement of peers (McIntosh et al. 2014). It is considered an effective tool that allows programmers and reviewers to gain knowledge through collaboration and collective ownership of the production code (Thongtanunam et al., 2016).

The present research investigates how HIPS and the interface design for collaborative teaching-learning impact students' learning, performance, and motivation in EDPs. It applies advanced high-impact practices (e.g., joint teaching/learning, peer-code reviews (PCR), capstone projects) to increase clarity in learning abstract Engineering design courses. Therefore, this research enhances teaching-learning practices of design courses in the engineering disciplines.

The experimental approach involved collaborative teaching of the EDP course by a local faculty member at Thiagarajar College of Engineering (TCE), an Autonomous institution, Madurai, by interfacing Design Concepts with a faculty at the University of Wisconsin-Parkside (UWP) – a part of one of the largest higher education systems in the United States. The concept-based learning of the Design phase in Software Engineering involved team-based project experience and the use of Peer-Code Review as powerful HIPs.

The empirical results of this study suggested that such HIPs and collaborative teaching-learning practices mandate Bloom's taxonomy of more critical thinking at increasingly higher levels among students by improving the quality of learning (Bloom 1956). The further statistical analysis explored helped measure learning gains of cognitive characteristics as a pre/post instrument before and after the course interface. The proposed collaborative teaching-learning through online mode could easily be implemented in abstract design courses in engineering.

The remainder of this paper is organized as follows. Section II provides an overview of the research motivation and literature evidence of collaborative teaching and HIPs in higher education. Section III presents the design of the empirical study using the demographic and student reflection surveys, including data acquisition and possible research questions that are analyzed in the study. Section IV presents the detailed analysis of the data organized around the study goals and a discussion of the experimental results, followed by concluding remarks and future directions in Section V.

II. Research Motivation and Background

The U.S. Bureau of Labor Statistics (BLS) 2019–29 employment projections report the growing number of jobs in the Science, technology, engineering, and mathematics (STEM) field in the next decade, which is twice as fast as the total of other jobs. India's average shortage of skilled talent engineers has increased exponentially from January 2014 to 2020, despite producing the maximum number of graduates globally. According to the National Science Foundation (NSF), it is predicted that 80% of jobs created in the next decade will require some form of analysis and design skills (Lin et al., 2021). By 2029, the expected growth of STEM jobs is 8.0%, compared with 3.7% for all occupations (Alan & Lindsey, 2021).

Youth share an essential portion of the population in the 21st century of India. NEP stated that "Quality education is the building blocks for the future generation of India". India produces the most prominent number of engineers in the world. However, most of them could not secure jobs due to a significant gap between understanding the projects thoroughly and their design with their domain subjects, as mentioned in National Education Policy (Zhigang Jiang et al., 2020).

Teaching Engineering Design courses is challenging for teachers and educators, especially in engineering, to interface the design concepts with their domain knowledge of real-time problems. Due to the lack of interest and distractions, the cognitive level of graduates has drastically reduced. Collaborative teaching in our EDP course is an efficient methodology to enhance students' higher-order thinking. It is an educational approach that motivates students to learn by using expertise from higher learning institutes professors in online learning environments. The goal is to maximize productivity through collaborative teaching/learning to root the strong educational plan to every youth of our nation through revamping the education system.

Most engineering graduates are considered unemployable due to a lack of skill in their discipline and the lack of bridging the conceptual understanding of design with their discipline subjects. Investigators of this proposal carried out innovative, collaborative teaching in the EDP course, which revealed a positive impact.

The above instigation motivated the investigators to initiate this proposal for an actionable solution to bridge the gap between project and product-based engineers in the education space. A study by a leading job site indicates that the average level of shortage of skilled talent graduates in India in STEM (Science Technology Engineering and Mathematics) has raised from 6% in January 2014 to 12% in January 2018, despite producing the maximum number of graduates globally (Lin et al., 2021). With the socio-care, the investigators of this proposal wish to revamp the Teaching-Learning Process (TLP) through Joint-Teaching and Learning (JTL) of Engineering Design subjects.

There is no computational enjoyment in handling EDPs without real-time project experience. Our college has decided to collaborate with reputed higher learning institute professors to deliver/ share their experience and best practices with our students to eliminate vagueness and uncertainty that remain in TLP. The outcome of the elaborate dialogue resulted in a joint teaching scheme which is an innovative way of initiating a

collaborative class. With most appreciable feedback and the student's demand for the same type of JTL for all abstract design topics, motivates to carry out a project to measure the cognitive characteristics through exploration of statistics in TLP of JTL.

In the recent past, new subjects, including engineering exploration, design thinking, appropriate technology, system thinking, disaster management, and sustainable development, have been implemented in the engineering curriculum. These courses mainly deal with the practical implementation of Higher Order Thinking Skills (HOTS) of Bloom's taxonomy, which incorporates proper design for solutions in engineering disciplines.

Students need to explore the design phase for industry-ready cutting-edge technologies for the Engineering Design Project course in the sixth semester. The Students developed a prototype model up to the fifth semester and participated in several contests like Toycathon 2021, TNSI (Tamil Nadu Students Innovators) as an outcome of the course. Furthermore, we planned to conduct joint teaching with international higher learning institutions to improve students' creativity, particularly in the design phase, and provide hands-on training. Therefore, the main objective of collaborative teaching is to enable the students to acquire in-depth knowledge in their discipline, handle real-time applications through detailed design and introduce them to new learning and assessment by professors from reputed higher learning institutes (HLI)/ R&D labs.

The unprecedented situation due to the pandemic has paved the way to analyze the trends and factors affecting study abroad programs (such as immigration and visa policies), thereby redefining the education abroad concept. Many universities have established international collaborations across the globe by signing the Memorandum of Understanding (MOU). These MOUs facilitate co-teaching undergraduate/ graduate STEM courses with international faculty and exchange faculty/student for short-term teaching/internship experiences.

In conjunction with the globalization of economies and internationalization of labor markets, study abroad programs and short-term co-teaching activities in collaboration with international faculty have gained momentum in recent years. This increased international exposure not only has positively impacted the students' academic knowledge and employment prospects but also personality development, multi-lingual fluency, intercultural competencies, and wage growth in their professional careers (Nets et al., 2020, Teichler 2011, Zimmermann and Neyer 2013, Luo and Jamieson-Drake 2015). While the demand for international education remains increasingly evident among Indian students, one of the many major barriers to international education is socio-demographic inequalities.

This research intends to describe the relationships between students' interests in study abroad programs, response to co-teaching, knowledge gain in various demographic and performance lenses, summarizing explanations for the observed patterns, and discussing initial evidence on how impactful the HIPs used alongside the short-term co-teaching experiences. The study results show that these small steps to augment international teaching-learning experiences might help make significant differences in STEM disciplines for those who aspire for international education and those who don't get access to it. It helped us better understand how these practices may bring small if not global changes compared to study-abroad programs that offer a life-changing experience.

III. Study Design

This study was conducted in the Engineering Design Project course at the third-year Information Technology majors at TCE, India. The study data constitutes 131 students that elected to participate (33 teams of four) from the sixth semester of different sections of the EDP course taught by the two instructors. We got approval from TCE for concept inventory-Demographic information survey through Institutional Review Board (IRB) for the research study. As shown in Table 1, the demographic information consists of details about student CGPA, gender, first graduate, location, board of studies, interest in doing masters in UWP. Eighty-seven students volunteered to participate in the survey. The demographic information helped the authors investigate the impact of the HIPs in collaborative teaching environments using various parameters such as gender, being the first graduate in the family, and board of studies, and the student's perceptions in establishing an international portfolio.

Following are the research questions (R.Q.s) that the study attempts to answer.

RQ1: What impacts do the intervention of international faculty in co-teaching have on the EDP course with the demographic positioning of students?

RQ2: How effective are the HIPs (team-project, PCR) used in EDPs?

Finally, the student surveys were used to evaluate the usability and effectiveness of the joint teaching and HIPs in the EDP course. The study results and the insights drawn from the experiments are presented in the following section.

IV. Experimental Results and Discussion

We collected demographic and student reflection survey data from the student participants to investigate the joint-teaching efforts and HIPs used during the activity. The data was used to analyze the impact these enhanced practices of joint-teaching and HIPs have on student learning. The univariate and multivariate analyses are performed using Seaborn's visualization library, built on top of matplotlib in Python.

Table I summarizes the preprocessed data consisting of 87 records used for further analysis.

TABLE I

SUMMARY OF DEMOGRAPHIC DATA COLLECTED

Gender	**Male**	**Female**			
	44	43			
Home Location	**Village**	**Town**	**City**		
	27	17	43		
Mother's Occupation	**Homemaker**	**Working**	**Entrepreneur**		
	62	22	3		
Father's Pay	**< 100K**	**100K - 500K**	**> 500K**		
	35	23	29		
Board	**Diploma**	**State Board**	**Central Board**		
	3	73	11		
Knowledge Gain	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
	12	48	26	0	1
Cumulative GPA	**5-7.5 (low)**	**7.51-9 (moderate)**	**9.1-10 (high)**		
	3	65	19		

Bivariate Data	**Yes**	**No**	**Bivariate Data**	**Yes**	**No**
First Graduate	17	70	**Webinar**	44	43
First Women College	4	39	**Internship**	32	55
Visit UWP	29	58	**Study Abroad**	27	60

The student demographics data include Gender, First Graduate/First Woman College status, Home Location, Mother Occupation, Father's Annual Pay, Number of Siblings, School Type, Board of Study, and Languages Known. The student reflection survey contains data about the students' Interest to Visit UWP, Interest in Webinars, Interest in Internships, Interest in Higher Studies Abroad, Knowledge Gained, Cumulative Grade-Point Average (CGPA).

An exploratory data analysis on the data collected helped us understand the data by gathering more insights about student perceptions and identifying interesting patterns and outliers. The survey data containing 90 records were preprocessed to change the question tags into meaningful column names, remove redundant records, apply one-hot encoding (convert categorical attributes into numeric values), and remove outliers. The data of three students with a Diploma are considered outliers and are not used for analysis and visualization.

A. Gender-based and demographic analysis

This research study investigates the impact of socio-demographic factors, gender in particular, in engineering education. The relationship of gender and different attributes of students' interests was analyzed.

Fig. 1 highlights the differences in the students' interests in attending webinars and virtual internships with the UWP between male and female students categorized by cumulative GPA in different school education boards (state board vs. central board). It can be observed that female students from state board education are more interested in attending webinars and virtual internships in both moderate and high performer categories than male students. On the other hand, while among the moderately performing students who studied in the central board, 50% male students and 40% female students are interested in virtual internships, all the outstanding male and female students are interested in these opportunities.

The central board students with moderate GPAs interested in the virtual internships were less than half compared to about a third in state board. While students from the central board tend to be more interested in pursuing their higher studies abroad, in general, male students, regardless of their school type, are more interested in higher studies abroad. Around a quarter of both male and female students from the state board opted to study overseas. Whereas all male students and less than a half of female students from the central board will go abroad.

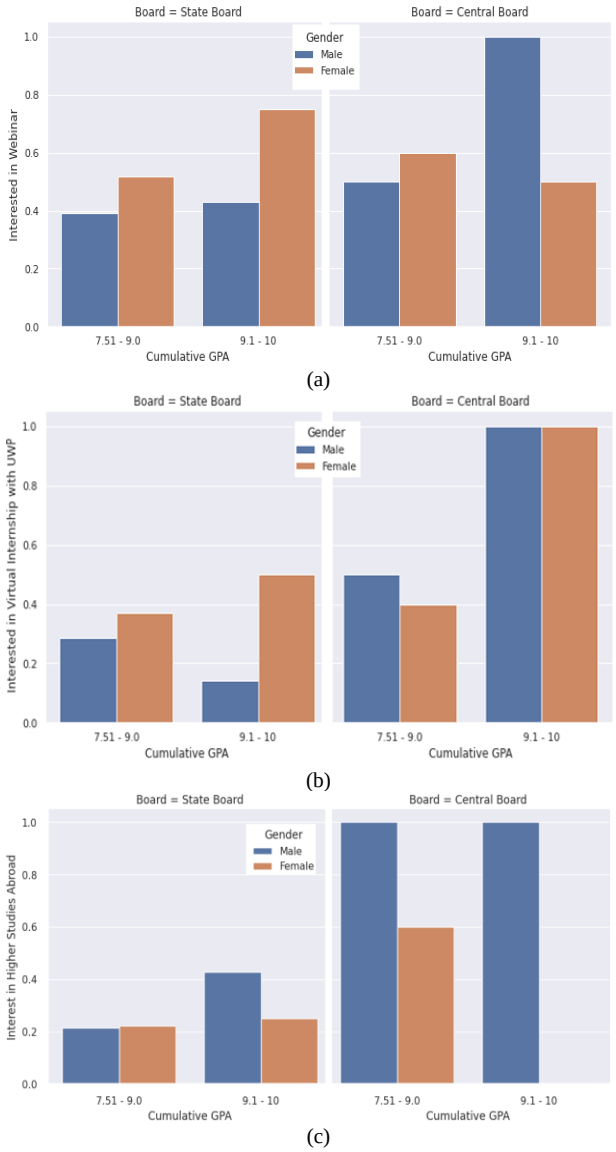
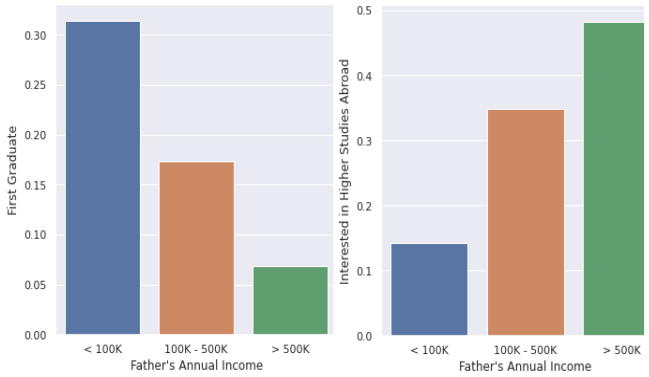


Fig. 1. Comparison of cumulative GPAs of state and central boards of education vs. (a) Interest in attending webinar, (b) Interest in pursuing virtual internships, and (c) Interest in higher studies abroad respectively.

We analyzed the first graduate students in the families. Fig. 2(a) shows those female students whose mothers are homemakers and the father's annual income is less than Rs. I Lakh, about ~21% are the first women members being educated in their community. This trend is not seen when the mothers are either working or entrepreneurs.

Given that a student studied in the central board, the family members are educated, and there are no first graduates (Fig. 2(b)). On the other hand, among the students from state board schooling background, 29% born in the village are the first graduates, which is higher than that of both town and city of about 18%.

The father's annual incomes are highly correlated with the first graduation rates and interest in study abroad programs, as shown in Fig. 3. It is apparent from Fig. 3 (a) that students with lesser family financial support are more likely to be the first graduate of their families. Students with their father's annual income less than 100K are expected to be about 31% first graduate students. Therefore, the yearly income is a significant factor determining the first graduation of children in their families.



(a) (b)

Fig. 3. Father's Annual Income vs. (a) First Graduation status and (b) Interest in Study Abroad Programs

From Fig. 3 (b), it could be inferred that the students with better financial support from the family are more interested in pursuing higher studies abroad. About a half and a third of them, whose father's annual income is more than 500K and between 100 and 500K respectively, are interested. Whereas, only less than a sixth of the students with a father's annual income (up to 1 lakh) are interested in going abroad for higher studies.

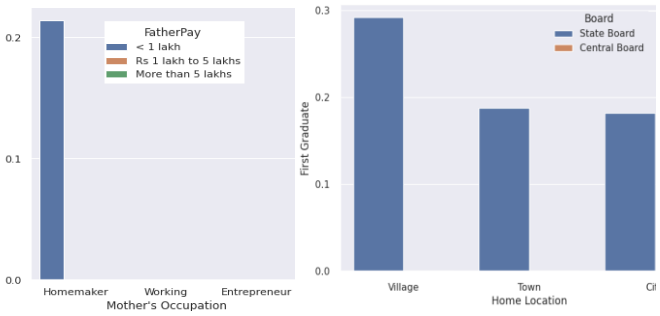
From the student reflection survey on the co-teaching program, it is evident that they show a keen interest in learning core concepts using HIP techniques used by the international faculty. They have realized the impact of HIPs by effective time utilization by understanding the concepts better.

B. Analysis of the effectiveness of HIPs in EDP course

The success of the EDP course in stimulating students to pursue their higher studies abroad and the interest in visiting UWP was investigated. Table II shows the cross-tabulation results of students' interest in pursuing higher studies abroad and visiting UWP.

TABLE II
INTEREST IN HIGHER STUDIES ABROAD AND VISITING UWP

Is Interested in Higher Studies Abroad/ Visit UWP	Yes	No
Yes	51	7
No	9	20



(a) (b)

Fig. 2. Comparison of first graduate women in family vs. (a) parents' occupation, and (b) Home location w.r.t the board of study

From the above tabulation, it is evident that out of 87 surveyed students, about three-quarters interested in higher studies abroad also expressed their interest in visiting UWP.

The HIP effectiveness survey was conducted to gather insights about students' interest and usefulness of the PCR and team-based co-teaching activities. Fig. 4 shows the responses of the students to the following questions on a Likert Scale (1 – Strongly Disagree, 2 – Disagree, 3 – Neutral, 4 – Agree, and 5 – Strongly Agree) for the following questions:

Q1: The level of understanding of PCR concepts improved my learning goals.
Q2: Does PCR help you to understand the importance of Software Engineering (S.E.)?
Q3: Joint Teaching is necessary and relevant to the EDP course.
Q4: There is adequate time for effective coverage of course content in joint teaching.
Q5: The content delivery of the expert faculty member from UWP was excellent.
Q6: I can explore the concepts taught in joint teaching to higher-order cognitive skills.
Q7: The expert was available for answering questions and mentoring.
Q8: The expert faculty communicated the content effectively.
Q9: The assignments, mini-project, and PCR activity related to EDP was effective.

For all the survey questions, at least 85% of the students provided positive feedback stating that the PCR and other activities helped them improve learning goals and understand the importance of S.E. and the relevance of collaborative teaching in the EDP course. The students appreciated the effective course content (assignment and mini-project) and the well-organized delivery of the expert international faculty member that helped develop higher-order cognitive skills. The student reflection surveys thus revealed the usefulness of combining HIPs and co-teaching in the undergraduate EDP curriculum, which initiated students' interest in study-abroad

programs. Therefore, the team-based activities and PCR used to teach the Software Engineering Design concepts enhanced higher-order thinking and improved students' understanding of the course material and performance. The study makes it apparent that the co-teaching Engineering courses not only encourage active participation and help students improve cognitive skills but also enable eliminating the economic barriers and use technology to establish international academic collaborations to reap pedagogical benefits successfully.

V. Conclusion and Future Work

This work presented high-impact practices and co-teaching to enhance learning and engagement. Various comparisons have been made about different criteria to study the impact of these practices in student learning. The empirical analysis revealed important insights about students' goals to pursue higher studies abroad. The students who are more interested in going abroad are born in cities, studied in the central board of school education, and the father's annual incomes are higher. They are higher-performing students. At the same time, they are less likely to be first graduates. The study results demonstrate the necessary initiatives to uplift students with less educational privileges.

Furthermore, the empirical studies revealed female students' interest in attending virtual internships and webinars to improve their skillsets. In contrast, the male students preferred pursuing higher studies in foreign universities. This study will potentially be extended to analyze improving female students' participation, involvement, and contribution in Engineering disciplines. The future work includes collecting more demographic and reflection survey data, applying machine learning algorithms (decision tree classifier) to classify/predict the demographic features that determine students' perceptions and interests based on various class labels or independent variables.

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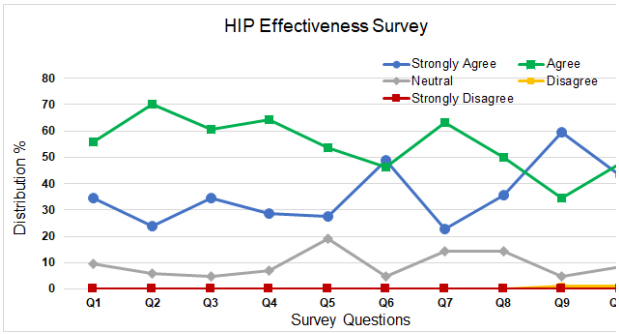
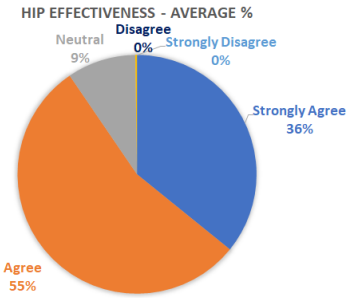


(a)



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