

Revelations and Roadmaps: A Chronicle of Success, Insights Gained, and Future Horizons in the landscape of Indian Undergraduate PDC Education

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Abstract—At present, there is a notable focus on Parallel and Distributed Computing (PDC) initiatives within the realm of undergraduate engineering education in India. Owing to differences in education systems across borders, along with variations in university policies, these efforts must be curated to cater to specific stakeholders, ensuring the achievement of the desired outcomes. Understanding such scenarios is crucial for the landscape of Indian undergraduate PDC education. This paper unveils a success story of implementing PDC at the undergraduate level for the past decade and a half, offering valuable insights gathered along this extended journey. Reflecting the idea that “every master was once a beginner,” the narrative unfolds to inspire and empower educators who are just starting out. Whether introducing or already incorporating PDC education into the curriculum, this account is crafted to uplift and guide. Amidst the ongoing initiatives across the country, the time has come to progress and elevate PDC education beyond its current status. This paper presents a summary of potential efforts that the PDC community in India can explore for such initiatives.

Index Terms—PDC (Parallel and Distributed Computing); Undergraduate (UG) engineering education; PDC efforts; Curriculum design; Empower educators; University policies; Success story of PDC; Elevate PDC education

I. INTRODUCTION

The landscape of Indian undergraduate (UG) engineering education has undergone a remarkable transformation in recent times. Experiencing challenges such as placement uncertainties and the shift to remote learning amid the Covid pandemic, Indian undergraduate engineering education responded with resilience, gracefully overcoming these hurdles, and garnering heightened attention to the evolving realm of engineering education. The PDC (Parallel and Distributed Computing) community’s desire to integrate PDC education at the undergraduate level has come to fruition within a decade in the Indian undergraduate education system. Commencing with the introduction of a parallel computing module in existing courses, advancing to offering an elective PDC course, and ultimately culminating in the establishment of a core course on parallel computing, this journey marks a significant achievement. To progress from this stage to the next level, the PDC

community must exert further efforts, and the current environment in India provides the ideal momentum to introduce such strategies.

In conjunction with these endeavours, the Indian government has set forth the New Education Policy (NEP) [1], designed to offer students personalized learning experiences based on their capabilities and preferences. Notably, the government is actively promoting PDC education through the National Supercomputing Mission (NSM) [2]. The ever-evolving educational scenario in India is providing a distinctive opportunity by introducing a plethora of specialized courses aimed at nurturing skills in the emerging workforce of the next generation. While endeavours in undergraduate PDC (Parallel and Distributed Computing) education have been ongoing in Indian academia for over a decade and a half, the author contends that these efforts have been successful thus far. However, there is a call for a more focused approach by the PDC community to capitalize on the current transformation occurring in Indian undergraduate education. This paper aims to delve into the achievements witnessed in the initial phases of PDC education in India, share the insights gathered during this journey, and underscore the necessity for future strategic initiatives to elevate PDC education to new heights in the country.

The main objectives of this paper are as follows:

- 1) To provide readers with a flavour of the success narrative of the last decade and a half.
- 2) To enumerate the pathways and insights acquired during the last fifteen years of undergraduate teaching.
- 3) To initiate a discourse on numerous potential pathways for a significant leap forward in PDC education in India beyond its current state.

The paper is organized as follows: Section 2 unfolds the narrative of successfully introducing PDC education to undergraduate students since 2009. It outlines the process of enticing students and developing the curriculum, evolving from an additional module on parallel computing to an elective

course, and eventually progressing to a core course with a laboratory component, all chronicled up to the present date. Section 3 extensively lists the insights obtained through a decade and a half of PDC teaching. The enumeration includes a detailed exploration of the knowledge and understanding acquired through the process of instructing in Parallel and Distributed Computing over this significant time-frame. Section 4 delves into forthcoming strategies aimed at crafting a more robust PDC curriculum. It explores the opportunities and challenges ahead, along with strategies to effectively navigate and overcome them. Section 5 concludes the paper.

II. EPIC PDC VOYAGE: A DECADE OF TRANSFORMATIVE ENDEAVOURS SINCE 2009

The swift evolution of computer science in undergraduate engineering education necessitates frequent changes in the curriculum. The field is experiencing exponential advancements, and while witnessing substantial growth in various domains is promising, it poses a challenge in preparing a workforce equipped for the future of technology. To groom the workforce for the next generation, educators must undergo training to effectively impart knowledge to students. This training involves not only enhancing teaching skills but also providing resources in terms of software, hardware, and relevant reading materials. Simultaneously, active collaboration is essential, requiring industry and other stakeholders to engage in cooperative efforts with universities. A notable transformation in PDC education began in the mid-2000s, coinciding with the rise of multi-core architectures in the market. The author's endeavours in PDC education have been in progress since 2009, and a comprehensive overview of these initiatives is presented below.

The era of multicore architecture programming unfolded around 2006-07, initiating a transformative phase that prompted computing enthusiasts to explore various parallel computing options. While OpenMP (Open Specification for Multiple Processing) [3], [4] emerged as the most widely used Application Program Interface (API), the author embarked on a learning journey about OpenMP through diverse online resources. Initial attempts to introduce a shared-memory program as a module in an undergraduate course proved successful, earning appreciation from students in their course feedback. Encouraged by this positive response, the author aspired to integrate a comprehensive course into the undergraduate curriculum for the academic year 2009-10. Leveraging the presence of dual-core systems in the existing laboratory, the author approached Intel for assistance in delivering a shared-memory programming course. With 100 licenses provided by Intel for VTune Analyzer to profile applications and identify hotspots to parallelize the code, the course content for multicore programming was developed.

Figure 1 illustrates the typical curriculum update process for a course in our university. Faculty members develop the course content based on the requested credits, the students' prior course completion status, and the defined course objectives. The course outcomes are then mapped to program outcomes according to the National Board of Accreditation (NBA)

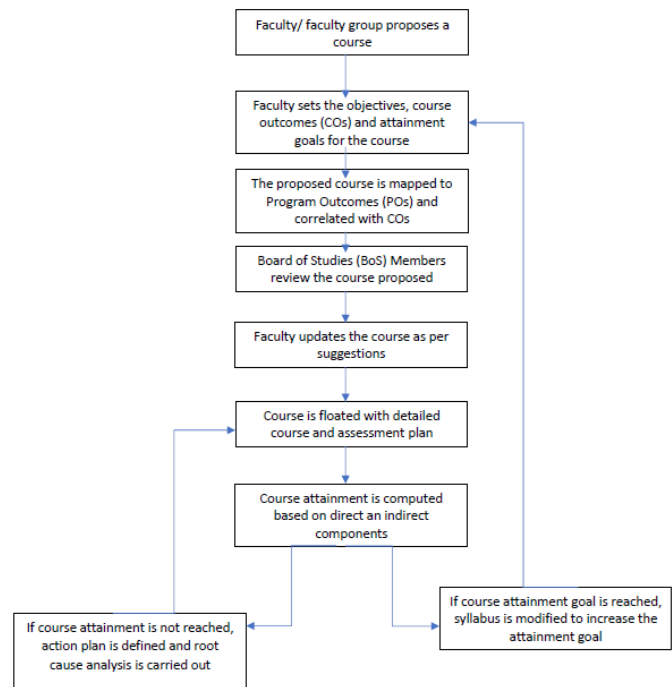


Fig. 1. Course development flowchart

[5] format. Additionally, the lecture and assessment plans are integrated into the course content. The course content, prepared with these parameters, is termed the course plan. This course plan undergoes submission to the Board of Studies (BoS) for approval.

Upon approval, the course is scheduled for the next appropriate semester, allowing students to register. The course is introduced with a defined course attainment goal, and after assessment, the achieved course attainment level is computed. This assessment encompasses both direct and indirect evaluations of the course. As depicted in Figure 1, if the course attainment goal is achieved, further enhancements and higher goals are set. On the contrary, if the course attainment goal is not met, a root cause analysis is conducted, and an action plan is defined for implementation in the next iteration. Employing this process, a course on multicore programming and architecture was proposed for approval in 2009. After receiving approval, the course was offered as an elective in the spring-2010 semester.

An enrolment form allows students to choose their elective courses, and typically, this process occurs towards the end of the preceding semester. However, for the PDC elective, only a limited number of students enrolled. Understanding that the course couldn't be offered without meeting the minimum student requirement, the author didn't lose hope. Recognizing this challenge, the author initiated a campaign in 2009 to highlight the significance of the newly offered elective in future prospects. The campaign had a positive impact, attracting students who then enrolled in the course. Consequently, during the Spring-2010 semester, the author successfully launched

PDC as an elective course.

Within the first week of the course commencement, students have the option to drop the course. Some students who initially joined the PDC course, after campaigning efforts, reconsidered due to the perceived complexity of architecture fundamentals and parallelism concepts. To address this challenge, the author presented real-world applications of PDC in various industries such as entertainment, industrial production, modeling, and simulation.

This approach proved successful, and eighty percent of the initially registered students chose to remain in the course, ultimately completing it successfully for that semester. A key takeaway from this experience highlighted the existence of awareness issues among students, prompting some to shy away from exploring new subjects. Factors such as seeking feedback from seniors and a desire to maintain a higher CGPA (Cumulative Grade Point Average) by opting for less challenging coursework were identified as reasons why students hesitated to choose this elective over others.

To foster awareness among students, a summer internship program was designed specifically for those selecting their elective after the summer break. The first two weeks of the program served as a rapid introduction to parallel programming fundamentals. The primary learning approach for the internship was Project-Based Learning (PBL). For the internship, familiar algorithms like merge sort and selection sort were assigned as projects, challenging students to convert them into parallel code. Students were grouped based on their areas of interest. This hands-on exercise generated genuine excitement as participants witnessed initial results, successfully parallelizing their initial programs, thus fostering a sense of comfort within the realm of parallel computing. The inaugural internship concluded with a significant number of students opting for the PDC course offered in the following semester. Additionally, they demonstrated keen interest in undertaking major projects focused on applications within the parallel computing environment.

The available infrastructure was limited, hindering students' ability to conceptualize and implement more extensive problems at this stage. While efforts were dedicated to distributed programming using the Message Passing Interface (MPI) [6], [7] and shared memory programming through OpenMP (Open Specification for Multiple Processing), NVIDIA proposed the use of Graphics Processing Units (GPUs) for scientific computing, leveraging CUDA (Compute Unified Device Architecture) [8]. Consequently, GPU computing was incorporated as a course module in the same PDC elective for the following academic year.

However, at that time, there were no GPU cards available for students to gain hands-on experience. In response, emulators were utilized for learning GPU computing through online searches. As students invested significant time in an internal summer internship program, university approval was obtained to convert the program into an audited course. Lecture delivery and assessment for credit allocation were meticulously planned and executed.

As the students enrolled in the semester course and initiated their major projects in PDC, initial understanding and demonstrations of GPU computing were conducted using emulators. Simultaneously, the author discovered the Professor Partnership Program offered by NVIDIA through an acknowledgment in a research paper and contacted NVIDIA for support. Since the program had not been introduced in India at that time, they conveyed the same. Several months later, they invited expressions of interest for the Professor Partnership Program initiated in India.

Through this program, NVIDIA GPU cards were awarded, facilitating hands-on training on GPU computing for the students. Subsequently, students enrolled in the summer internship and the elective course, choosing GPU computing for their projects. This semester marked a significant milestone in the journey, as the students submitted their work to a conference and received the Best Poster Awards. The detailed account of this journey is explained in [9]. As the enrollment in this course surged, the PDC elective was proposed to transition into a core course, albeit without a laboratory component, due to credit adjustments. To familiarize students with parallel coding, a few hands-on lectures were incorporated. The school secured funding under TEQIP-II (Technical Education Quality Improvement Programme of Government of India) [10] for infrastructure enhancement, acquiring numerous quad-core machines and GPU machines. Leveraging this upgrade, the PDC course was offered in the subsequent year as a course with a laboratory component, with increased credits.

This trajectory persisted until the student intake expanded to encompass four different classes, necessitating the need for extensive training in this course. Recognizing this requirement, several faculty development programs were organized with the support of industry leaders such as NVIDIA [11], Intel [12], AMD [13], and HP [14], offering sponsored training sessions. NVIDIA, through its GCOE (GPU Center of Excellence) at IIT (Indian Institute of Technology) Bombay, conducted a region-wide faculty and student training initiative that proved instrumental in enabling many universities to introduce parallel computing courses at various academic levels. Over the span of a decade, the outcomes included research students engaged in PDC, the establishment of a PDC postgraduate course, a core PDC course for undergraduate students, and a team of faculty proficient in teaching PDC courses. However, the impact did not end there. The demand for PDC course requirements transcended the Computer Science and Engineering (CSE) domain, extending to other branches where faculty members sought this training. Faculty development courses were attended by members from various branches, and students were offered an open elective PDC course. The PDC course became deeply integrated with the evolution of machine learning (ML) and the progression of deep learning (DL) in undergraduate teaching. The expansion of the PDC course was not envisioned fifteen years ago. It began with a modest interest in incorporating a parallel computing module into an existing course. The narrative of this fifteen-year journey is presented here to illustrate the current ease of adoption, facilitated by abundant

online resources, training facilities, and available equipment.

As mentioned earlier, GPU computing was taught to students in one semester even without GPU cards, utilizing emulators. In today's world, the PDC course has become an essential component, and the associated facilities have significantly expanded. For more specific insights on teaching and learning enhancements in the PDC course, additional details are provided in Section III.

III. TEACHING DISCOVERIES: A PATHWAY PERSPECTIVE

Highlighting the lessons learned along the way is essential to facilitate the education of future generations, allowing them to build upon these insights, uphold valuable practices, and devise enhanced solutions. This section represents a concerted effort to underscore the insights gained during the past fifteen years of undergraduate PDC education. The following content is divided into subsections based on the category of PDC challenges and strategies.

A. PDC Course Development

As outlined in Section 3, many Indian university undergraduate engineering programs receive accreditation from the NBA, which places a strong emphasis on outcome-based education. The process of developing a course adheres to the guidelines of outcome-based education and includes planning, design, implementation, and evaluation of a course. Many universities adopt a similar approach. The introduction of any new course into existing curricula requires approval, a decision made by the Board of Studies (BoS) contingent upon the availability of necessary facilities. While a decade ago, this posed a significant challenge, the current scenario sees the BoS prioritizing the implementation of PDC courses.

Present challenges primarily revolve around the effective execution of these approved courses. The decision to offer a PDC course as an elective or a core course rests with the faculty team. If designated as a core course, it becomes mandatory for all students to enrol, necessitating a course design that considers the average learning level of the class. The design should accommodate both the delivery and evaluation aspects of the course. On the other hand, if the course is elective, student enrolment may be based on prerequisites, providing faculty members with flexibility to establish higher goals for the course.

B. PDC Course Delivery

The crucial observation to record revolves around enhancing the effectiveness of PDC course delivery, marking an ongoing learning journey for educators. Tailoring PDC course delivery requires careful consideration because students enrolled in this course have undergone sequential learning for approximately 17-18 years. It is imperative to convey the concepts of parallelism and concurrency within existing code to these students. Educators face the distinctive challenge of addressing this issue, necessitating the adoption of specific teaching methodologies. The following points delineate various factors

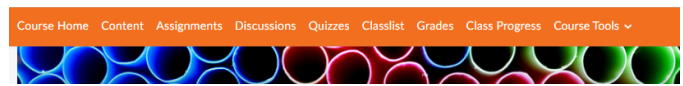


Fig. 2. Course management options in LMS

that have substantially contributed to an improved course delivery:

- 1) Integration of online platforms like Piazza [15], Moodle and Learning Management Systems (LMS) for course delivery.
- 2) Utilization of tools such as Kahoot and Learning Management Systems (LMS) for quiz administration and assignment submissions.
- 3) Thorough alignment of the syllabus with comprehensive learning resources.
- 4) Incorporation of self-learning elements within the syllabus.
- 5) Provision of video links for individuals who require additional time or have missed classes, aiding in grasping key concepts.
- 6) Commencing classes with spontaneous questions and real-life examples related to the upcoming concepts.

The initial key to success in any course lies in delivering course content in a structured manner, particularly in the case of PDC, where resources like books and reading materials must be condensed to the course content, providing insights into advanced learning concepts. The introduction of Moodle, utilizing internal network services for uploading lecture notes and resources, and the subsequent incorporation of Piazza and Learning Management Systems (LMS) significantly improved the delivery of PDC.

While Moodle operated exclusively through intranet services initially, limiting students' access to outside networks, the adoption of Piazza in the following academic year garnered appreciation. This tool not only allowed external access but also served as an interactive learning platform facilitating classroom discussion-style communication. Students could post questions and receive responses not only from faculty but also from their peers who saw the messages first.

Upon the university's integration with the LMS system, challenges associated with auto-linking student evaluations and grading through Piazza were addressed, and LMS presented a comprehensive solution for various course delivery options. Figures 2 and 3 provide snapshots of the course management features available in LMS, and course evaluations through LMS are accessible to both faculty and students, ensuring anytime access for respective needs.

The introduction of PDC education for undergraduate students was swift, and the technological evolution in PDC progressed rapidly. The development of resources for learning and training the workforce, however, took some time to produce and make widely accessible. Despite the current limitations in available resources, it becomes a crucial responsibility for teachers to furnish curated materials for the class. Providing

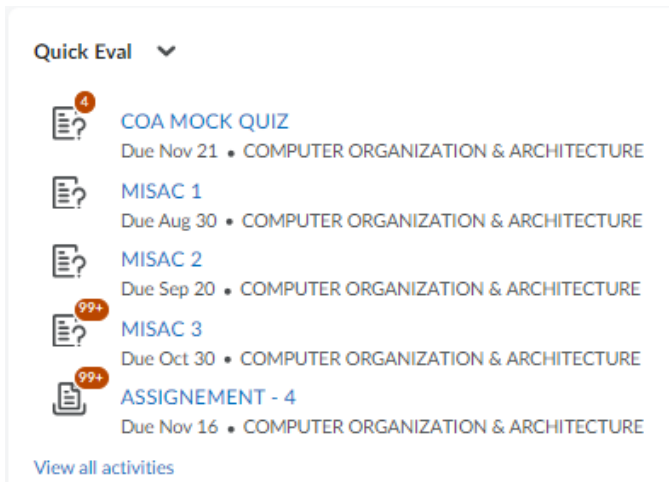


Fig. 3. Snapshot of course evaluation list for access in LMS

a comprehensive syllabus with topic-specific resources has proven instrumental in assisting our diverse learners in effectively grasping the subject matter.

Breaking away from the conventional approach of teaching and testing all concepts, the incorporation of self-learning components (SLC) for selected topics proved highly beneficial. Allowing students to delve into these topics in their own style yielded commendable results. Students were assigned specific linked concepts as SLC, accompanied by learning resources and guidance for advanced exploration. Their comprehension and learning outcomes for the assigned SLC were then evaluated.

With the integration of technology into education, several teaching methods have undergone transformation. One notable change is the adoption of video recording for regular classes, granting registered students access to these recordings. This approach proves advantageous for students who miss classes due to unavoidable circumstances, enabling them to catch up before the next session. Based on student feedback, this practice has proven beneficial, even extending its utility during exams.

Amid the COVID-19 pandemic, a plethora of online lectures covering various topics, including PDC, became available globally. Even before this, NPTEL recorded video lectures featuring faculty from premier institutes for the benefit of all. Selected videos from these valuable resources are curated for students to learn key concepts. Recognizing that not all students progress at the same pace as the faculty, these online videos serve as a valuable tool, particularly for slower learners, allowing them to grasp concepts at their own speed.

When engaging with present-day educators, the immediate focus often shifts to the attention-related challenges posed by Generation Z in the classroom. While it is accurate that the attention span of students seems to decrease over time, teachers must proactively tailor their lectures to align with the attention spans of their students, making the content more captivating for Generation Z. A particularly effective strategy

involves pausing the lecture every 8-10 minutes, initiating an interactive discussion, posing questions, or elucidating a case study. This not only enhances course delivery but also ensures that the efforts of the faculty resonate effectively.

To instill enthusiasm, incorporating real-life examples of the upcoming concepts into the discussion proves advantageous. Introducing questions that will be addressed throughout the lecture further engages students, fostering a dynamic and participatory learning environment. i experiences of PDC education in India can be referred in [16], [17], [18], [19].

C. PDC Course Learning Outcome Enhancements

The points mentioned above primarily centre around student-centric learning; however, the responsibility of homework lies with the teachers. The aim of learning outcomes is to encourage students to actively engage with the subject matter and elevate their levels of understanding. This presents a significant challenge, requiring ongoing enhancements, given that each batch of students brings a unique approach to learning and appreciating the educational material. Numerous advancements have occurred in this domain, driven by PDC educators globally. The subsequent pedagogical techniques have consistently yielded positive results for us, standing the test of time over various semesters.

Project-Based Learning (PBL) has been consistently successful since its introduction, starting from the inaugural batch of students and persisting to the present in the PDC course. It was initially implemented in early classes where no mandatory laboratory credit was associated with the PDC course, allowing students to actively apply PDC concepts. For the first group of students opting for the PDC course voluntarily, the inclusion of a minor project doubled their learning interest. In the initial phases, straightforward project definitions focused on parallelizing sequential code. A lot of PDC education efforts are compiled at [20] through its various activities namely EduHPC [21], EduPar [22], EuroEduPar [23] and EduHiPc at HiPC [24] and many PDC workshops in India through CDAC [25].

As the PDC course evolved across different batches, students were assigned selected research papers to implement. They had the opportunity to enhance the existing implementations, eventually leading to the publication of their work in peer-reviewed conferences and PDC journals. This process extended beyond a single semester and culminated when pursued as a major project. Faculty members emphasized time flexibility, prioritizing the project's depth over tight deadlines. The outcomes of this approach significantly contributed to students building their careers, whether through higher education or employment.

Presently, this project-based learning model has become more rigorous, incorporating laboratory credits into the PDC course. Students now have the autonomy to choose their application domain of interest and optimize codes using the PDC concepts they have acquired. The tangible outcomes of project-based learning are outlined below:

- 1) Successfully navigated through initial concerns and reservations about parallel computing, demonstrating active learning and engagement in the course.
- 2) Collaborating in teams facilitated the complementing of individual weaknesses, fostering improved communication and collaboration skills among students.
- 3) The analysis and design of parallel algorithms contributed to the enhancement of critical thinking and problem-solving abilities, boosting confidence in applying acquired knowledge to diverse applications.
- 4) Participation in external workshops and conferences beyond the university environment served as a powerful motivator, encouraging students to dedicate extra hours to bolster their profiles in the field.
- 5) The PDC project experience, in contrast to a non-research-focused undergraduate curriculum, provided students with the opportunity to choose between research and non-research career paths.
- 6) Project-Based Learning (PBL) allowed students to independently explore and delve into articles of their choice, offering a distinctive and personalized learning experience.
- 7) Recognizing the importance of professional societies, students learned to leverage their services for the advancement of their careers and overall professional development.

While project-based learning offers numerous benefits, it also poses challenges for both students and teachers. Students are required to employ unconventional methods, such as delving into research career papers, identifying suitable conferences, and dedicating more time compared to other credit-bearing courses. Motivating students to cultivate a passion for the PDC course is a critical effort in overcoming these obstacles.

Faculty members, operating in various capacities within the current system, face numerous challenges with a PBL-based course. This approach is time-intensive, resource-constrained, and involves evaluating students with diverse abilities. Defining the PBL structure in early classes, providing comprehensive notes in advance, and offering regular updates every fortnight allow students ample time to fulfill their expected tasks. Despite these challenges, the benefits associated with PBL are substantial and should not be overlooked. While PBL can be applied to any course, its inherent intricacies and learning complexities make it especially beneficial and suitable for the PDC course.

Other activities enhancing course learning include invited talks and expert lectures from professionals in the PDC domain, addressing students' inherent questions and providing a broader perspective on the significance of the PDC course for their careers. Additionally, a 30-day workshop, organized with industry support exclusively for students, received positive feedback, with students suggesting its incorporation into each semester. Various small activities, such as showcasing simulation videos and explaining PDC's role, or presenting job descriptions related to PDC, help students envision the

career paths available upon graduation.

Despite the existence of PDC education for some time, ongoing innovations are crucial for making PDC learning more accessible and fruitful.

D. PDC beyond Classroom

Teaching and learning extend beyond the confines of the classroom, especially in the realm of PDC. To ensure a comprehensive learning experience, students should engage in extracurricular activities. In the early stages of conducting the PDC course, where workstations were used for hands-on training, students had the opportunity to participate in a hackathon during a conference. This event provided access to high-end servers that were not readily available a decade ago. Participation in the hackathon exposed students to unfamiliar high-end machines and taught them effective problem-solving procedures within a team.

Despite the current accessibility of high-end machines and collaborative tools like Colab, hackathon participation continues to broaden students' thinking, challenging them to tackle larger problem-solving scenarios within a given timeframe. PDC courses vary across universities, focusing on distributed computing, shared programming, GPU acceleration, among other aspects. Throughout the course, students collaborate with faculty and researchers from both industry and academia for internships, offering diverse learning experiences.

Positive feedback from students highlights the value of ACM and IEEE-sponsored workshops on PDC, providing insights into the broader future of the field. Enrolled PDC course students actively participate in department-organized workshops or events, facilitating coordination and collaboration with guest speakers. Offering these opportunities is a significant contribution by PDC educators, enriching students with a multitude of learning experiences.

E. PDC Career Development

Teaching the course content is not the sole responsibility of faculty members. As educators, it is crucial to assist students in envisioning how the knowledge gained in the course will benefit their future. In the realm of PDC education, which is still in its early stages in the undergraduate community, conducting one-on-one or group meetings to facilitate open discussions and clarify students' interests plays a pivotal role. These interactions aid students in planning and establishing a robust PDC career path. The following initiatives have proven instrumental in guiding students towards a successful PDC career:

- 1) Students are actively encouraged to seek summer internships in the field of PDC based on their individual interests, and upon the completion of their internships, many transition into regular positions.
- 2) Students working under dual guidance, having an external mentor from other universities, often pursue higher education programs in esteemed institutes, enhancing their academic trajectory.

- 3) A recent initiative involving teaching assistant-ships for undergraduates has enabled numerous students to collaborate with their juniors. This opportunity allows them to reinforce their learning, extend their projects, and engage in collaborative efforts with their junior peers.
- 4) Within the university's honors program, each honor student is required to have a mentor. Students in the PDC course, opting to continue their work, often collaborate with PDC teaching and research faculty to advance their projects towards journal publication.
- 4) Organizing more frequent events of diverse scales, including conferences, workshops, hackathons, and PhD conclaves, is essential to foster a vibrant PDC community.
- 5) Offering curriculum enhancement training and ongoing support for faculty responsible for training the next generation of manpower is crucial for sustained progress.

IV. CHARTING THE FUTURE: EXPLORING PATHWAYS FOR ADVANCING PDC EDUCATION IN INDIA

Learning through hands-on experience is a fundamental principle that underpins every educational system. The above listed activities play a crucial role in helping students discern their career paths with confidence. The more robust the opportunities provided, enabling students to attain scholarly insights in the field, the more inclined they become to choose a career path in PDC. This, in turn, leads to their valuable contributions to the ecosystem, enriching the field with their acquired knowledge and expertise.

F. PDC Community Efforts

The momentum of PDC education in India is currently vibrant, and there is a pressing need to fortify the ecosystem across all levels of the student community. Recognizing that today's undergraduate students are the future graduates, and today's graduates are the future researchers, nurturing their PDC skill set through industry internships or training programs contributes skilled manpower back to the industry. Similarly, internship opportunities across universities provide students at different levels with valuable experiences, and these individuals can subsequently contribute to various programs within the university. This cyclical process strengthens the weakened units in the ecosystem, ultimately uplifting the PDC environment by creating a more skilled workforce.

While the PDC community acknowledges and values the importance of community-building efforts, there is a recognition that these initiatives often fail to reach the right people at the right time. To address this, professional societies and leadership should play a pivotal role in building bridges to broaden the reach and support for potential participants, whether they are institutes, faculty members, or students. The following are some existing initiatives that warrant a multiplicative increase, and new endeavours that every stakeholder in PDC education should contemplate contributing to further:

- 1) The promotion of extensive internships, summer, and winter schools is imperative until sustainable growth is achieved and the necessary manpower is readily available.
- 2) Mentorship programs at all levels for both faculty and students should be actively encouraged, possibly undergoing audits to ensure the effectiveness of both mentor and mentee engagement.
- 3) The facilitation of collaborative student project guidance aims to initiate larger, more active collaborations among students.

It is evident that PDC education for undergraduate students has become inevitable in the Indian undergraduate computer science curriculum. Many universities have embraced PDC education, making it a core subject with mandatory credits for all undergraduate students. While this momentum is commendable, it is essential to assess whether our approach is correct. PDC education has been integrated into undergraduate programs before the ecosystem is fully prepared, leading to challenges such as a lack of resources for parallelized code, students feeling compelled toward the subject, and faculty members who initiate the course without adequate preparation, often following a faculty development program or workshop. Strengthening the foundations of this ecosystem during its development is crucial for long-term sustainability. It is now crucial to encourage and motivate individuals to actively contribute to the quality of PDC education efforts in India. Some considerations for advancing PDC education in the country include:

- 1) Restructuring current PDC courses for undergraduate students
- 2) Augmenting the PDC education ecosystem
- 3) The imperative role of PDC
- 4) Aligning PDC education with the National Education Policy (NEP)

Restructuring current PDC courses for undergraduate students: PDC education has evolved well in the country's undergraduate programs over the past decade. While the evaluation of PDC courses typically involves formal written exams, there is a growing recognition that a more diverse range of evaluation methods, such as course credit based on projects and their outcomes, can enhance the learning experience. Despite the autonomy granted to many tier II universities, PDC course evaluation often follows traditional methods. Transitioning to more dynamic evaluation methods can engage Generation Z students in proactive learning beyond conventional textbooks. Although challenges related to uniform evaluation and grading exist, gradual steps can be taken to align with new-generation learning techniques. For example, one PDC course could adopt traditional evaluation methods, while students have the option to earn other credits based on projects, exams, publications, internships, etc., allowing for a more in-depth study.

A single PDC course may not be the most effective approach to prepare the workforce for PDC careers. Instead, a systematic integration of PDC content across various courses, spanning different semesters, is recommended. With the surge

in IT jobs and specialization in computer science, such as artificial intelligence and machine learning (AIML) or data science, PDC education should mirror this trend. Specialized PDC courses can be structured with content spread across multiple semesters, although challenges like providing high-end computer facilities need to be addressed. Faculty and the PDC community should advocate for more undergraduate PDC courses to excel in PDC education. Another challenge lies in the need to study larger applications from different domains to genuinely advance learning in PDC education. India's current promotion of virtual labs for various engineering courses, even in mechanical engineering, could serve as a model to overcome obstacles related to high-end machines and complex applications in PDC education.

Augmenting the PDC education ecosystem: PDC education entails significant economic investments, manpower, and a test of time to yield results. Achieving success in PDC education requires collaboration at multiple levels, involving individuals, teams, institutions, universities, and even nations. The existing ecosystem is in place, but its effectiveness is hindered by a lack of awareness and insufficient direction from key stakeholders. Several initiatives in India are currently underway and could benefit from further enhancements:

- 1) An assertive "Train the Trainer" program with regular regional and statewide meetings.
- 2) Promotion of PDC education through content sharing and the establishment of forums where stakeholders can contribute and derive benefits.
- 3) A focus on providing quality training for both faculty and students, actively encouraging their participation.
- 4) Involvement of non-computer science undergraduates in various PDC education activities.
- 5) Promotion of active collaborations across diverse domains.

The imperative role of PDC: The imperative for a PDC-aware workforce is undeniable, and PDC education must be embraced accordingly. While PDC education is commonly associated with computer science, there is a prevailing trend where domain experts collaborate to fulfill project requirements rather than considering the necessity of providing subject experts with foundational PDC education. Advanced PDC education is typically emphasized for individuals with a computer science background. However, computer science graduates with PDC knowledge may struggle to effectively deliver applications in other domains. Although this challenge has been addressed through various collaborations, it is now opportune to reconsider this approach.

At our university, an initiative has been undertaken to introduce undergraduate programs in collaboration with specific domains. Examples of such initiatives include programs like computer science with fintech (financial technology) engineering and computer science with life science engineering. This targeted training approach aims to cultivate a workforce proficient in both computer science and the respective domains, such as life sciences. The emphasis on PDC education within

the computer science part of the course necessitates thoughtful strategies to ensure the success of this inevitable journey.

Aligning PDC education with the National Education Policy (NEP): The National Education Policy (NEP) of India emphasizes fostering students' interest in learning through a combination of study and hands-on experience, offering entry and exit options based on individual preferences. The plan is set to be implemented across all levels of education by 2030, prompting numerous curriculum modifications from primary school through postgraduate courses. With many schools now introducing computer education from middle school onwards, it is prudent to integrate PDC education into high school or pre-university programs, even if just as small modules. This inclusion aims to cultivate parallel thinking in students, who are the future undergraduates. Early exposure to PDC concepts guides students in making informed career decisions before entering university.

The current PDC community holds the responsibility of extending PDC education further downstream, aligning with the long-term vision of embedding PDC education in the Indian education system. The NEP also introduces policies for undergraduate programs, allowing students to choose between three-year and four-year programs or opt for certified courses. For instance, if a student desires a three-year program in basic Computer Science and a certified course in PDC, our curriculum and training should be flexible enough to accommodate this preference. Therefore, PDC education efforts should align and intertwine with broader educational initiatives at various levels.

V. CONCLUSIONS

In conclusion, this paper has successfully fulfilled its primary objectives. Firstly, it provides readers with a comprehensive understanding of the success narrative in the domain of Parallel and Distributed Computing (PDC) education over the last fifteen years. By highlighting key achievements and milestones, the paper captures the positive trajectory and advancements made during this period. Secondly, the paper systematically outlines the pathways and insights derived from a decade and a half of undergraduate teaching in PDC. It distills valuable lessons, experiences, and strategies that have contributed to the growth and refinement of PDC education, offering readers a nuanced perspective on the evolution of the field.

Lastly, the paper serves as a catalyst for future discourse on the current state of PDC education in India. By initiating conversations about potential pathways for future development, the paper encourages stakeholders to contemplate innovative approaches. The aim is to inspire collaborative efforts that will lead to a transformative leap forward, contributing to the ongoing evolution of PDC education in the country.

Furthermore, the paper serves as a valuable resource for readers, offering insights into the challenges and triumphs of PDC education. It provides a roadmap for educators, policymakers, and stakeholders, guiding them in navigating the complexities of PDC education. The documented success

narrative and insights can inspire and inform future initiatives, fostering continuous improvement and innovation in PDC education.

In essence, this paper not only chronicles past achievements and insights but also sets the stage for future advancements. It acts as a catalyst for ongoing discussions and serves as a guiding document for those involved in shaping the future landscape of PDC education in India.

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