Faculty Development Workshops for Integrating PDC in Early Undergraduate Curricula: An Experience Report

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Parallel and Distributed Computing (PDC) has become pervasive and is now exercised on a variety of platforms. Therefore, understanding how parallelism and distributed computing affect problem solving is important for every computing and engineering professional. However, most students in computer science (CS) and computer engineering (CE) programs are still introduced to computational problem solving using an old model, in which all processing is serial and synchronous, with input and output via text using a terminal interface or a local file system.

Teaching a range of PDC knowledge and skills at multiple levels in Computer Science (CS) and related Computing and Engineering curricula is essential. The challenges are significant and numerous. Although some progress has been made in terms of curriculum recommendations and educational resources in computer science, trained faculty, motivation, and inertia are still some of the major impediments to introducing PDC early in computing curricula. The authors of this paper conducted a series of week-long faculty training workshops on the integration of PDC topics in CS1 and CS2 classes, and this paper provides an experience report on the impact and effectiveness of these workshops. Our survey results indicate such faculty development workshops can be effective in gradual inclusion of PDC in early computing curricula.

CCS Concepts: • **Social and professional topics** → **Computational thinking**; **Computational science and engineering education**; • **Computing methodologies** → **Parallel computing methodologies**.

Additional Key Words and Phrases: computer science education, parallel programming, faculty development

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1 Introduction

The emergence of multicore and GPU-based computing systems in recent years has brought about significant changes in the computing landscape. Every computing device from supercomputers and server farms containing multicore CPUs and GPUs to individual PCs, laptops, mobile devices, and embedded computing devices now relies on of parallelism and distribution. Parallel and Distributed Computing (PDC) has now become an integral aspect of nearly all computing activities. PDC concepts such as asynchrony, concurrency, decomposition, distribution, and parallel processing of big data objects has become fundamental aspects of learning to program computer applications. This shift in the computing landscape implies that programmers, regardless of their level of expertise, must possess at least some understanding

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of how parallelism and distributed programming influence problem-solving. Merely relying on traditional sequential programming skills is no longer sufficient, particularly for entry-level programmers. Consequently, there exists a clear demand for incorporating a comprehensive skill set in PDC technology throughout the educational programs offered by Computer Science (CS) and Computer Engineering (CE) programs, as well as in related computational disciplines. However, the rapid changes in hardware platforms, devices, languages, supporting programming environments continues to challenge educators in ascertaining appropriate content for curriculum and how to teach them effectively.

In many programs, foundational PDC concepts/topics are not introduced until upper level courses, many of which are electives. By this time, sequential programming patterns have been established in the student, and they think, and code, sequentially. Because this pattern has been reinforced for most of their academic career, many students who are exposed to PDC in this manner backslide and return to sequential programming once the course has been completed. Introducing PDC concepts in lower level classes can begin the task of allowing students to think in parallel, a notion that is extremely important in today's multicore world. Challenges are many, some of the significant challenges of integrating PDC in undergraduate curricula are:

- Lack of awareness among instructors about the need to integrate PDC concepts in their undergraduate programs
- Lack of trained instructors in PDC concepts
- Lack of instructor motivation to augment existing course with PDC concept
- Lack of teaching resources, such as text book, lecture slides, handouts, lab examples etc.
- Lack of sizable community
- Introductory courses are already overloaded with course material

We contend that organizing short training workshops for instructors whose graduate training and research areas are not PDC related and who typically teach early computing courses is one approach to alleviate some of the above-mentioned challenges. The authors of this paper had developed some curriculum materials for PDC integration in CS1 and CS2 (ref iPDC Modules). These curriculum materials cover some of the foundational concepts in PDC. We had also organized several faculty training workshops between 2018 and 2022. In this paper we report our experiences and lessons learned from the faculty development workshops as well as our evaluation of the impact of the workshop on faculty participants in integrating PDC in early computing classes. The evaluation results indicates that faculty training workshops are effective and impactful for integration of PDC in undergraduate computing programs.

2 Related Works

Faculty development workshops are a recognized form of imparting new proficiencies and ideas across a number of disciplines, and have become a common practice in higher education to enhance the knowledge and skills of their faculty members. [8], [16]. The benefits for the faculty are numerous, according to [3], participating in these workshops can result in increased job satisfaction and motivation, as well as improved teaching effectiveness. In addition, participation can lead to increased collaboration and networking opportunities among faculty members, which can lead to the development of new research projects and teaching strategies. Several studies have investigated the effectiveness of faculty development workshops in different contexts. For instance, [7] conducted a systematic review of the literature on faculty development workshops in engineering education. They found that workshops that focused on active learning strategies, such as problem-based learning and inquiry-based learning, were effective in promoting student engagement, critical thinking, and problem-solving skills. Similarly, workshops that provided opportunities for faculty to collaborate

with peers, reflect on their teaching practices, and receive feedback on their teaching were also found to be effective in improving teaching and learning outcomes.

Major forces encouraging integration of PDC topics into Computer Science curriculums are the ACM Curriculum Recommendations [1] and the NSF/IEEE-TCPP Curriculum Initiative on Parallel and Distributed Computing [11, 12, 14]. The ACM curriculum recommendations are the ACM's response to the need for Computer Science curricula that can keep pace with rapidly changing technologies and educational needs. The curriculum recommendations attempt to have a broad coverage and include Parallel and Distributed Computing (PD). The recommendations have 5 Core-Tier1 hours and 10 Core-Tier2 hours of PD that span a range of fundamental topics to advanced. The TCPP curriculum initiative is a curriculum guideline that intends to incorporate Parallel and Distributed topics so that graduates have basic skills in parallel and distributed computing. Additionally, it has topic recommendations for advanced and elective courses. The initiative also supports early adopter programs, publishes a book [13], and hosts other resources for those adopting PDC into their curriculum.

Research is ongoing on course materials and curriculum development. In [2], Adams proposes that CS2 is the natural place to introduce PDC concepts, and the author teaches the students using minimalistic parallel programming patterns, called *patternlets*. However, Brown, Shoop and Adams [1] assert that PDC concepts should be taught at all undergraduate levels. Researchers that have attempted to integrate PDC throughout the curriculum include Burtscher et al. [5] who taught PDC in several lower division courses and a senior capstone course. The authors show encouraging empirical results that measure student outcomes, engagement, and interest. Mullen et al. [9] created a self-paced online course focussed on parallelizing common High Performance Computing (HPC) use cases. Hundt et al. created Sauce which is a web application for the automatic evaluation of source code that can be incorporated as an interactive component in HPC computing lectures. Trejo-Sánchez et al. [15] presents a case study over four public universities in Mexico that shows some strategies that have been developed to incorporate the HPC concepts. These strategies attempt to overcome significant challenge in universities in developing countries like Mexico. Dewan et al. [6] created a module for hands-on training in Java Fork-Join abstractions for use in an interactive workshop for the "training of trainers" model. Newhall et al. [10] designed an introductory systems course that incorporates parallel computing, whose only prerequisite is CS1. The authors found that introducing parallel programming early helps the student gain confidence in their PDC abilities throughout their CS education.

3 Faculty Development Workshop

We have conducted five faculty development workshops from 2018 to 2022, and have adapted the content and structure of the workshops over time, especially in response to the pandemic situation in 2020 and 2021. We conducted 3 week-long in-person workshops in 2018 and 2019. These workshops took place from 8:30 am to 5:00 pm with two 30 minutes coffee break and a 45 minutes long lunch break. We cancelled our 2020 in-person workshop by necessity because of the Pandemic situation. In 2021, we conducted the workshop over a two-week period, with two hours of virtual sessions each day via Zoom®. Additionally, we held one virtual office hour for the participants. In 2022, we conducted the workshop in a hybrid format. This format consisted of one week of two-hour virtual sessions over Zoom®, followed by three days in person. Each workshop had approximately 15 participants on average. Most of them received a stipend to defray the cost of attendance. The virtual participants also received a stipend as an incentive. We selected participants whose graduate research topics and primary area of research is not PDC/HPC and do not teach PDC/HPC related courses. The content of all three workshops were mostly similar, with minor adjustments for later workshops based on feedback and lessons learned from previous workshops.

The objectives of the faculty training workshop were the following.

- Train faculty who usually teach introductory computing courses to write parallel programs in a shared memory environment.
- Train non-PDC faculty to use the iPDC instructional modules support system
- Disseminate findings/results/resources of successful PDC education programs
- Build a community among instructors teaching introductory computing classes
- Share PDC integration strategies, research-based practices and field-tested PDC resources

The approach of the workshop is to treat the participants somewhat like advance graduate student and have them go through a short intense course on parallel computing in shared memory environment that involve many hands on program writing using different technologies. This is followed by a participatory exercise and discussion on how to integrate PDC concepts and exposure of technologies to students in early computing courses through collaborative discussion, showing examples of successful examples, and sharing curriculum materials developed by the authors and others in the PDC education committee. Primarily there are three different types of activities in the workshop 1) introduction of foundational concepts of parallel computing through lecture and unplugged activities to illustrate foundational concepts, 2) plugged shared parallel program writing using technology such as OpenMP, Java thread, and 3) discussion and presentation how to integrate PDC in early computing classes and community building. The model of our approach is shown in figure 1.

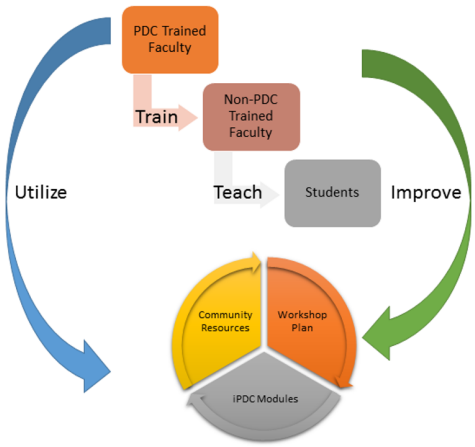


Fig. 1. Training workshop Model

3.1 Foundational Concepts

The objective of this activity was to explain core foundational concepts of parallel computing to the participants. The concepts that are generally covered are:parallel architecture including interconnect and memory hierarchy, asynchrony, concurrency, locality, task and data decomposition, metrics for parallel programs, Amdahl's law etc. This is primarily done through lecture, discussion, unplugged activities, and small in class assessment and quiz.

3.2 Plugged Hands-On Activities

During these activities participants were introduced to hands on shared memory parallel programming using OpenMP in C/C++, OpenMP with Java and Python, parallel programming with Java thread. These activities involve some lectures but mostly program writing exercise. The lecture generally covers parallel program design methodologies, intro to parallel program technologies; the participants then are given series of problems, and they develop parallel solutions to those in groups. In some cases, participants were supplied with a serial solution of the problems. Participants are given a certain amount of time to solve the problem. After that allotted time, the instructors will discuss their solutions with participants. These activities are repeated for every exercise problem.

3.3 PDC Integration and Community Building

From the beginning of the workshop, the participants are asked to develop a plan to integrate PDC for their respective classes.This is done incrementally as the participants progress through the workshop. Each workshop day, time is set aside to discuss their plan. This done collaboratively, other participants and the organizer would provide critics and suggestions. On the last day of the workshop, each participant has to submit a written implementation plan on how they will integrate PDC topics in their class and present their plan. The organizer and other participants provided feedback to the presenter. During the in-person part of the workshop, the participants attend lunch and coffee breaks together. In addition, generally one afternoon an excursion is arranged (usually a short hiking trip or sightseeing) followed by a working dinner at a local restaurant. Participants also mostly stay at a workshop designated hotel. These generally helps in bonding and community building

4 Results

To aid in determining the impact of our faculty development workshops, we conducted a survey among the workshop participants. About 10% of the participant's contact information had changed, and unfortunately, no updated contact information was available. Therefore, the summative survey link was sent to the remaining 62 participants that participated during the five years of the study. Of these respondents, 31 (50%) completed the survey. This can be considered a very good email survey response rate. In addition, at least one faculty member from each of the individual workshops responded.

As can be seen in figure 2, 77% of the faculty have continued to implement at least some of the material presented in the workshops to their students. For a variety of reasons which we will touch on later in this section, 23% of the respondents have discontinued using the iPDC material in their coursework.

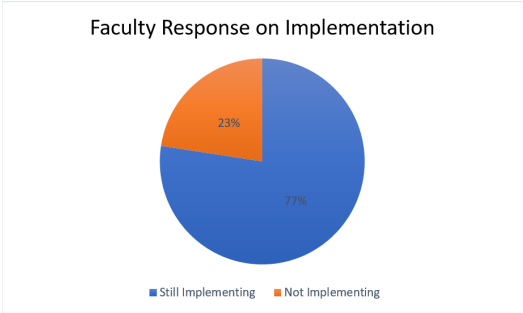
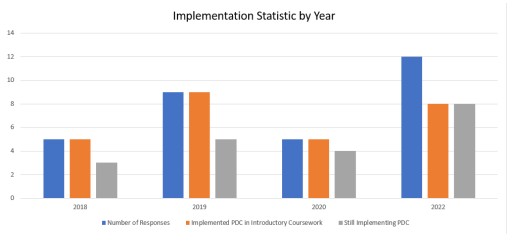


Fig. 2. Faculty Implementation

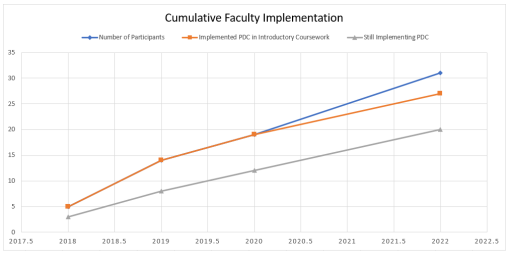
The highest number of responses, perhaps not surprisingly, was from the participants of the most recent workshop in 2022, with about 78% percent of those participants responded (figure 3a). The response rate was lowest from the 2020 virtual workshop, at about 26%. The response rate from the 2018–2019 workshops were 33%. Surprisingly, and perhaps due to last minute changes in

scheduling, the 2022 class is also the first class where not all respondents had incorporated material into their coursework. All told, 87% (27 out of 31) have incorporated some PDC topics in their respective classes.

Figure 3b shows that because of the retention of faculty presenting the material year after year, the total number of faculty utilizing the iPDC training materials continues to grow.



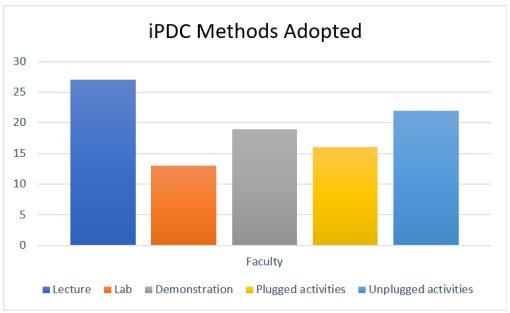
(a) Implementation Statistics by Year Attended



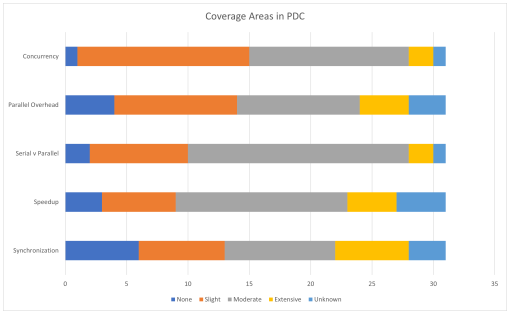
(b) Faculty Retention

Fig. 3. Faculty Implementation

Faculty were asked to specify which materials provided in the workshops they had utilized in their classrooms, primarily to help us develop new materials. As shown in figure 4a, each of the types of material was selected on at least 33% of the responses, with lecture notes and unplugged activities being the most popular choices. As part of the workshop, we introduced the faculty attendees to fourteen separate areas of PDC knowledge. Figure 4b shows the implementation statistics of the 5 areas the individual faculty members deemed to be either most important, or easiest to implement into their existing coursework.



(a) iPDC Methodology Used

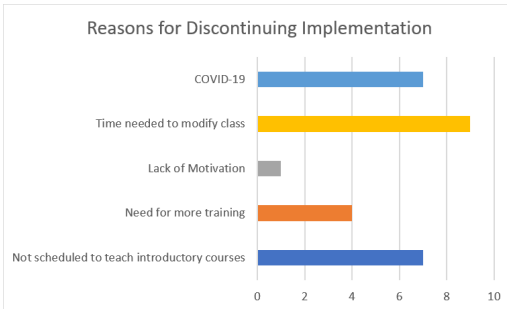


(b) Areas of Concentration

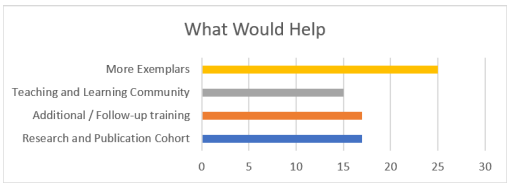
Fig. 4. Faculty PDC Implementation Statistics

We also surveyed the faculty members who had stopped using the iPDC material in their coursework on the reasons behind the decision. The responses, seen in figure 5a varied, with the most common being that they simply no longer were teaching introductory coursework, the time commitment that was required to continue to update their course curriculum to add new material, and the COVID-19 pandemic changing the way their courses had to be constructed.

Further development of exemplars and simulations, additional training, and a cohort dedicated to continuing research and publishing on PDC topics (figure 5b) are some of the main conditions that would help the trained faculty continue their implementation efforts.



(a) Reasons Faculty Have Discontinued PDC



(b) What Would Help Continuation

Fig. 5. Rationale

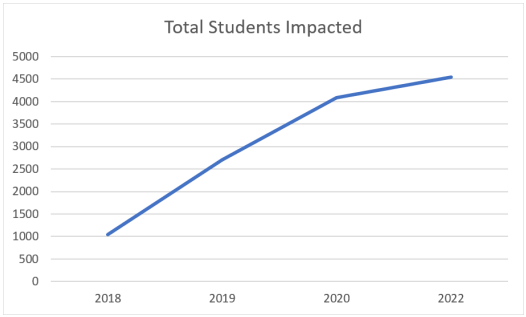


Fig. 6. Students Introduced to PDC Topics

The biggest takeaway from the survey is probably the most important statistic we need to discuss, how many students were introduced to PDC material that otherwise would have no understanding of the capabilities and concerns. As you can see in figure 6, because of our high retention rate the number of students we have seen introduced is continuing to rise and currently is over 4,500.

5 Lessons Learned

We identified the issues that occurred and the improvements that we can make in our workshops. The intent of identifying what did and did not work is so that our future workshops, as well as similar workshops that will be hosted by others, can be more successful. We learned important lessons in *practical community building*, *the longevity of PDC topic integration*, and *the density and content of workshop activities*.

5.1 Practical community building

Based on the participant feedback, hybrid workshops seem to be the most effective. In-person workshops enhance community building. The added interactivity and collegiality helps the participants determine the best approaches to implement PDC in early classes. In-person workshops provide opportunities to discuss ideas with fellow participants and obtain feedback. However, week long in-person workshops can be impractical for participants because of the time commitment and cost required. Virtual workshops provide flexibility of participation. Participants can join from anywhere and thus save both travel time and cost. However, day-long virtual sessions have their own issue: the participants get *Zoom fatigue* [4]. A hybrid approach provides training in the PDC technologies (OpenMP, Java threads, etc.) via virtual training sessions, and provides the benefit of the community building aspects in a shorter in-person session. It also shortens the time commitment away from family and reduces travel costs. A virtual component also helps by incorporating environment set up (compiler, runtime libraries, etc.) so that participants can spend more time problem solving and interacting during the in-person component.

5.2 Longevity of PDC topic integration:

Unfortunately, the continuation of PDC integration efforts by workshop participants diminished over time. We believe that a few modifications to the workshops and some additions would improve the longevity of integration.

In particular, a formal way of community building is needed. Typically, immediately after the workshop, some participants keep in touch with each other and also with the organizers. Unfortunately, as time continues, this communication gradually subsides, and the decrease of communication was not affected by the type of workshop (in-person, virtual, or hybrid). Many participants mentioned additional follow-up training would help to continue integration of PDC. Therefore, an effort by the workshop organizers and members of the PDC community to keep the participants engaged through a follow-up training-discussion forum or conference participation would be helpful.

5.3 Density and content of workshop activities

Another important lesson that we learned from our experience and from participant feedback is to be careful with the number and variety of activities. If the participants are overloaded with too much, then the workshop becomes confusing, which affects participant morale. For example, in the 2018 workshop, we included an exercise in which each participant set up an account in our university cluster and submitted jobs. At first, the activity seemed to be a simple one, but difficulties in account setup, job script creation, compiling in an unfamiliar environment, etc. required significant time. The activity did not add to the participants' understanding, but only led to confusion and discouragement. Instead, we found that a focus on more hands-on programming activities in familiar environments (their own laptops) and less lecture led to better understanding and engagement.

As indicated in Figure 4b, the workshop participants provided important feedback about the content of workshops that will help us plan future workshops. In particular, the topics *serial versus parallel*, *speedup*, and *concurrency*, followed by *sychronization* and then *parallel overhead* were the topics the participants covered most thoroughly in their own classes. The reason that these topics were favored for coverage could be because either the topics were more easily integrated into their courses, the faculty determined that these topics were the most important, or both. Regardless, giving more focus to materials, exemplars, and instruction for these topics should increase the efficacy of future workshops.

6 Conclusion and Future Work

We have conducted a series of faculty training workshop on integrating parallel and distributed computing concepts and topics in early computing classes. Our approach was training of the trainers with the hope that will have a multiplicative effect. Our survey result indicate that our workshops were mostly successful. Most of the participants (77%) included some aspects of PDC in their courses, and the majority of those continued to integrate PDC as one of the topics in their classroom. There PDC integration efforts by workshop participants diminished over time, this is somewhat expected, time and effort required is one of the major factor. Informal conversation with the past participants at conferences indicate the PDC topics for early computing classes has not yet become mainstream and part of the accreditation process. As a result, there is an inertia that needs to be overcome. Lack of curriculum material is another major factor. Our survey also indicates that more PDC curriculum materials and exemplars (lectures slides, handout, labs, text book etc.) for early computing classes would help in broader continuing adoption of PDC for early computing classes. Even though ACM and ABET has recommended PDC as a required core knowledge area, PDC has not yet been adopted in most of the computing programs. Growing the community who will adopt, champion adoption of PDC concepts/topics

in early computing classes, develop new exemplars is needed to make PDC concepts/topics as one of the core topics for early computing classes. Faculty development workshops is one of the mechanism of growing the community.

In future we plan to continue the faculty training workshops. We plan modify our workshops based on the feedback and lesson learned. We also plan to develop a complete online version of the training workshop that and faculty can go through asynchronously and have it freely available for the community. Developing more curriculum materials is also part of our future plan.

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