FINAL REPORT - COLLABORATIVE RESEARCH: CYBERTRAINING: CONCEPTUALIZATION: PLANNING A SUSTAINABLE ECOSYSTEM FOR INCORPORATING PARALLEL AND DISTRIBUTED COMPUTING INTO UNDERGRADUATE EDUCATION

(NSF AWARD # 2002649, PROJECT PERIOD: 09/20/2019 - 12/31/2022)

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EXECUTIVE SUMMARY

In this era of pervasive multicore machines, GPUs, cloud services, big data, machine learning, and the Internet of Things, CDER has been working over a decade to infuse parallel and distributed computing (PDC) concepts into undergraduate computing curricula with clear implications for national security, research and development, and workforce and economic development. Sponsored by an NSF institute conceptualization planning grant, CDER has conducted an extensive stakeholder community input study via a series of four workshops to identify the underlying impediments to more effective adoption and to formulate the key attributes of an institute to help eliminate the longstanding barrier of the sequential computing paradigm (Award #2002649). The breadth and complexity of the impediments and the scale of impact together justify the need for an institute-level investment to bring computing curricula into the 21st century.

The Problem: Modern computing systems pervasively employ PDC, which new computer science and computer engineering graduates (and graduates of computational and data related disciplines) are not prepared to work with, according to multiple stakeholder groups (national labs, research institutions, government agencies including DoD and DOE, and industry). Recent graduates do not understand the modern software development process and ecosystem, which relies on parallelism, distribution, asynchrony, scaling, integration across disparate libraries and data sources, test-driven design, and pervasive concerns for security.

Due to this lack of preparation, the nation is suffering a loss of competitiveness with respect to other countries that are addressing the problem (including China, India, and Russia). Affected areas include national security (cybersecurity, intelligence analysis, cyber warfare, defense systems), research and development (high performance computing, data science, AI, and modeling for critical applications such as pharmaceuticals, advanced materials, climate forecasting, chip design and manufacturing), and the economy (high onboarding cost of new graduates, cloud computing infrastructure, renewable energy, smart electrical grid, secure e-

commerce, and healthcare systems).

The lack of preparation originates in the obsolete model of computing taught at the introductory level. This model, based on systems of the late 1970's, presents computing as inherently sequential and synchronous, in a uniprocessing context, with a local file system, and a command-line user interface. The model continues through the coverage of data structures, algorithms, complexity theory, and software engineering, leading to a computational problem-solving mindset that is inherently sequential, and thus unable to engineer software for modern systems. Once this model is established, some students may encounter PDC in an ad-hoc manner via electives on web programming, operating systems, parallel computing, etc., but then it is treated as a specialized concept that is only relevant within a limited context.

As an example, to illustrate the scale of economic impact, we heard from employer stakeholders that it takes up to six months of training to onboard new computer science graduates so they can be productive. Based on data from the Bureau of Labor Statistics and the National Center for Education Statistics, even if only 20% of new graduates require this amount of training, modernizing the computing curricula would have an ancillary impact on the US economy saving $880B per year.

Education stakeholders said that changing the model is nearly impossible because of a lack of incentives and systemic impediments. Industry still hires graduates, there is no funding to support major curriculum change, and accreditation standards don't require it, so there is little pressure to change. Impediments include a lack of exemplars of modern curricula, few teaching materials, lack of instructor training in modern computing, lack of release time for updating courses, articulation agreements with community colleges, advanced placement exam standards, development environments and PDC language features that are not suitable for beginners, and a lack of computing resources and support for students to experience scaling of parallelism and distribution.

The Solution: The model of computation that is used to introduce computing students to the concepts and approaches of computational problem solving needs to be updated to reflect modern PDC systems, tools, methods, algorithms, use cases, challenges, datasets, and threats. It will take a significant investment to overcome the inertia in the education system and to change the expectations of employers and accreditation boards. Funding is needed not just to enable but to incentivize pioneering efforts to develop exemplar courses and curricula in a diverse set of institutions. This set must be large enough to create a critical mass of change and a bandwagon effect across the computing disciplines. This also opens up an opportunity for curriculum-based rethinking around broadening participation in computing goals. The pioneering efforts need to be coordinated so that their work can be collaborative, both to leverage each other's efforts, and to produce approaches that are sufficiently coherent to create a new standard for accreditation and advanced placement, as well as articulation across multi-institute systems.

In addition to coordinated curriculum development teams, there is a need for a centralized repository of developed materials that is curated to ensure quality and portability. As the exemplars are developed, there must be an effort to transfer them to new institutions, so as to evaluate their effectiveness in different contexts, which also necessitates investment in training and support for adoption. The need for student-friendly software, turnkey environments, and broad dissemination implies centralized technical support during the pioneering and transfer phases. An outreach team is needed to shift employer expectations, foster collaborative partnerships, and work with standards organizations. Perhaps most importantly, there is a need for a marketing team to continually assess stakeholder needs, provide input to the other efforts, and promote the benefits of the changes to each stakeholder community.

Conclusion: It is clear that incremental or piecemeal approach has not worked. Such a transformative effort requires a major institute to provide the necessary coordination, well-structured services, and focal point to ensure success. The expected benefit of this investment is a modernized computing workforce that restores and maintains competitiveness of the US with respect to national defense, research and development, and cyberinfrastructure in support of scientific, social, and commercial goals. The savings to the US economy will provide an annual return on the investment that will be four orders of magnitude compared to the total cost of the program.

1. INTRODUCTION

Parallel and distributed computing (PDC) now permeates most computing activities. The ubiquity of computing devices containing multicore CPUs and GPUs, along with the rapidly growing importance of data science and machine learning, are making most users dependent on parallel processing. Increasing use of web-based services, cloud computing, and the Internet of Things is weaving distributed computing into the fabric of modem society. Problem solving for PDC systems, however, takes a shift in mindset from traditional, sequentially oriented, computational thinking. The issues of concurrency, coherence, and consistency in systems that are working simultaneously and asynchronously, often with significant communication delays, necessitates a different algorithmic paradigm. Unlike many fields in computer science, where specialized languages represent domain-specific abstractions, PDC arises directly from the physics of modem systems, which must use parallelism to continue to advance performance, and which must cope with geographical distribution of data and processing. PDC is now a factor that cuts across all domains, and will increasingly affect how higher level abstractions are expressed. It is becoming a universal element of computational thinking and problem solving.

However, Computer Science (CS) and Computer Engineering (CE) education has not kept up with these changes. Therefore, we face significant challenges for transforming CS and CE education to prepare students to enter the 21st century workforce. The commercial sector and government agencies are desperately seeking employees whose approach to computational thinking has the flexibility to embrace parallelism and distribution. That type of thinking is also a fundamental aspect of both coping with the explosion of data volumes at the root of data science and the threat models inherent in computer security.

While the virtual Center for Parallel and Distributed Computing Curriculum Development and Educational Resources (CDER), with its work on the NSF/TCPP Curriculum guideline on PDC and its adoption, together with other related projects, has made significant inroads toward our goal of transforming CS and CE education to address the needs of 21st century computational problem solving, the discipline has yet to transition to fully adopting PDC as a core component of early undergrad-uate education. It is time to prepare a major push that will take CS and CE programs worldwide across a threshold that makes PDC a self-sustaining, essential element of teaching computational thinking. We view this transformation as analogous to the one that occurred in the 1990s, with the transition from structured programming to object-oriented programming (OOP), which necessitated a paradigm shift in problem-solving from a procedural mindset in which control flow acted on passive data, to one in which data objects are self-contained actors that interact dynamically.

We saw the questions that depend on greater input as having three aspects: actors, factors, and strategies. Specifically, what are the factors that stand in our way? What are the factors necessary for igniting a transformative effect on the discipline? Who are the actors who impede the transition? What is the strategy for changing those actors to become allies and enablers? Who are the actors who can apply leverage to effect major change? What is the strategy for getting those actors on board with the mission of the institute? What are the strategies, both technical and political, for coordinating the actors so that the most significant impeding factors are overcome at the same time that the most enabling transformative factors reach fruition?

This institute conceptualization project sought support for a broad and inclusive gathering of input from a diverse set of stakeholders that can guide a vision for a large-scale, institute-level effort to comprehensively work with the identified actors, factors, and strategies to achieve this transformation. The gathering happened

through a series of three stakeholder input workshops (Nov'21@SC, March'20@SIGCSE, and July 20) and a fourth institute design input workshop (March'21), each planned to support attendance by thirty to fifty stakeholders from a diverse range of communities. A final reporting-out workshop to NSF and other federal agencies was held in Fall 2021 by NSF in Alexandria, VA.

The first stakeholder input workshop held at SC'19 was geared towards identifying the most important factors that inhibit introduction of PDC in the curriculum, strategies to alleviate these bottlenecks, and the actors needed to implement the strategies. The second workshops by SIGCSE in March'20 primarily interfaced with the community of educators and course instructors, identifying more specific factors and actors in that part of the ecosystem. The third stakeholder input workshop looked toward the ecosystem beyond academia, focusing on leaders across industry, labs, and academia, and how the two parts of the ecosystem can be made to work synergistically. The fourth workshop in March'21 examined the lessons learnt from the last three workshops, and considered the design of the institute itself, its mission, strategies, and activities. We organized our final reporting-out workshop to the NSF In October'21 for overall conceptualization in a hybrid mode to ensure attendance by as many program directors from NSF and other agencies as possible.

Organization: The rest of the report is organized as follows. Section 2 describes our key activities and their logistics for the five workshops conducted. We also describe our successful utilization of the "World Café Model" – conducted in person, online and hybrid – to discuss and gather stakeholder inputs. Section 3 describes our findings for each workshop. Appendix A contains our unfunded collaborators who are also key CDER affiliates. Appendix B contains the full list of attendees, broken down by workshops. Appendices C contains summarized discussion data for the first three stakeholder input workshops. Appendix D contains the discussion and update data from the participants of the Institute Design Input Workshop on the PDC institute's goals, strategies, and activities.

2. ACTIVITIES

Workshops' World Café Model (in person, online and hybrid): Each meeting successfully employed the World Café model, which involves small group discussions. A question would be posed for discussion, with the participants divided into groups of 5 or 6 at tables in the same room (or virtual tables on different GoToMeeting channels). A host would be chosen by each table to encourage participants to make notes. After 20 minutes, everyone except the hosts move to new tables. The host begins by summarizing the discussion from the preceding round, and then a new host is chosen. After three rounds, there is a gathering phase where participants identify common themes. The model ensures that all participants have time to speak, and that ideas are rapidly diffused throughout the meeting. After a break, the organizers ask a follow-up question, based on the themes identified, and the process repeats. A World Café meeting comprising 4 questions usually results in over 100 pages of notes. For online workshops, individual Google docs were seamlessly employed for different virtual tables.

2.1 STAKEHOLDER INPUT WORKSHOPS

2.1.1. FIRST NSF INSTITUTE PLANNING WORKSHOP, NOV 18, 2019, DENVER, ALONGSIDE SC'19 (IN PERSON)

The key goals for this inaugural workshop on Planning a Sustainable Ecosystem for Incorporating Parallel and Distributed Computing (PDC) into Undergraduate Education were as follows:

- o Institute's place in the ecosystem
- o Factors that inhibit introduction of PDC in the curriculum
- o Strategies to alleviate these bottlenecks
- o Actors needed to implement the strategies

There were 24 funded and 9 unfunded workshop participants (list provided in the Appendix B). These included (non-mutually exclusively) 22 academic, 10 women, 3 from government labs, 5 from industry, 6 from NGO's, 2 international experts, 1 from NSF (a co-PI), 2 from URM-serving institution (including the PI), 4 past CyberTraining workshop trainees and 3 early adopters of TCPP curriculum, 4 book authors, and 5 past Edu* workshop attendees. CDER center collaborator, IBM, facilitated the complimentary workshop space.

The participants were briefly given an introduction on the goals of the workshop and about CDER center and the TCPP curriculum initiative, and then the workshop agenda and the process logistics.

The agenda included four sessions, each 1.5 hours long, organized around discussion around a question. Each session employed the world-café model, with three rounds of breakout groups of 4-6 individuals, followed by a gathering round (described in detail later on). The workshop ended with a half-hour session on closing discussions.

2.1.2 2ND NSF PLANNING WORKSHOP, MARCH 11, 2020, ALONGSIDE SIGCSE'20 (ONLINE)

This workshop was intended to primarily engage the educators who typically attend SIGCSE conference, alongside other stakeholders. This was planned to be in-person, but due to COVID'19, it had to be taken fully online.

The key goals for the second workshop were learning and discussing the following aspects on institute planning:

- o Workforce needs, and how to meet those
- o Synergize non-academic and academic community
- o Roadmap for the iPDC institute

There were 20 funded and 13 unfunded workshop participants (list provided in Appendix B). These included (non-mutually exclusively) 24 academics, 9 women, 2 from government labs, 3 from industry, 5 from NGO's, 3 from NSF, and 3 from URM-serving institutions (including the PI).

The participants were briefly introduced to the goals of the workshop, and about the CDER center and the TCPP curriculum initiative, and then the workshop agenda and the process logistics. There was a detailed on-line logistics planned out as follows. We had 6 GoToMeeting channels for a plenary channel and 5 virtual breakout groups (virtual world-café model table), 6 shared Google doc for each channel/table, and a detailed permutation for mapping participants to various tables to ensure that each meet with as many as possible through four question sessions, and 3 rounds of 20-min breakouts per session. The virtual tables were coordinated by PI, co-PIs, and Drs. Ghafoor (TTU), Saule (UNC) and Barnas (IU). A rigorous planning allowed us to successfully conduct

this as well as the in-person discussions. It also allowed for capturing all the discussion notes directly into shared documents.

2.1.3 3ʳᴰ NSF INSTITUTE PLANNING WORKSHOP, JULY 17, 2020 (ONLINE)

The third workshop was intended to engage the industry, labs, federal agencies, and professional societies, and administrative personnel from academia such as department chairs and deans. We did manage to have 1/4th of the participants from industry, and 3/8th belonging to labs, agencies, NGO's, and professional societies, and 3/8th from academia. The key goals for the third workshop were discussing the following aspects on institute planning:

- o   Major curriculum changes and factors for adoption
- o   Actors involved in driving the change
- o   Impediments and enablers
- o   Process needed to facilitate adoption

There were a total of 51 participants and observers with fully online format helping with larger participation. This included 11 organizers, with an undergraduate REU student and a graduate student. There were 20 funded and additional unfunded workshop participants (list provided in Appendix B). These included (non-mutually exclusively) 11 from industry, 15+ academic, 4 women, 15+ from labs, agencies, NGO's, etc., 3 international experts, and 4 from NSF as observers.

The participants were updated on the past two workshops and also the goals in advance of the workshop. At the beginning of the workshop, they were briefly introduced to the goals of the workshop, about the CDER center and the TCPP curriculum initiative, and then the workshop agenda and the process. There was again a very detailed on-line logistics planned out: we had 8 GoToMeeting channels for a plenary channel and 7 virtual breakout groups (virtual world-café model table), 7 shared Google doc for each channel/table, and a detailed permutation for mapping participants to various tables to ensure that each meet with as many as possible through four question sessions, and 3 rounds of 20-min breakouts per session. The virtual tables were coordinated by PI, co-PIs, and Drs. Ghafoor (TTU), Saule (UNC), Barnas (IU), Newhall (Swarthmore), Bunde (Knox), and Freudenthal (UTEP). The rigorous planning again allowed us to successfully conduct this as well as the in-person discussions. It also allowed for capturing all discussions into shared documents.

The notes generated by the three workshops were distilled by a summer REU student, working with co-PI Weems (Appendix C).

2.2 INSTITUTE DESIGN INPUT WORKSHOP, MARCH, 2021 (ONLINE)

Following our three community input workshops in the first year, we collated and summarized the input into a single document. Due to challenges associated with the COVID pandemic, the last input workshop was delayed from May until the end of July of 2020. We then worked to understand the input in terms of the design of an institute to advance education for parallel and distributed computing. Our original plan had been to report our findings in late 2020 or early 2021. However, we realized that it would be useful to hold another meeting with a

select group of stakeholders across the different groups that met separately in the earlier workshops, so that they could review the full range of input and offer additional input on how best to structure an institute to serve their needs.

Because this was a smaller group than our prior workshops (31 attendees - see Appendix B4), we used a modified version of our online format for the World Café model for the meeting, where participants were given access to shared documents that were pre-populated with results from prior meetings, and told to use suggesting mode to edit them. There were five simulated tables in the meeting, with a predefined rotation of participants among them. The table hosts were members of the CDER center team, and did not change tables as would normally happen after a second round. The host's summarizing of the work from the prior round was augmented by being able to see the edits that had been done on the document.

The meeting was broken into four sessions. The first was concerned with reviewing, editing, and adding to the goals for an institute, with respect to each stakeholder group. In this session, each table considered all of the stakeholder groups, in part to get a broader perspective for discussions in subsequent sessions.

The second session addressed the strategies that could be used by the institute to achieve the goals with respect to each stakeholder group. Different tables were tasked with identifying strategies for different stakeholders, and participants rotated among the tables. Although it wasn't possible for every participant to explore strategies for every group, they were mixed so that each participant would encounter other participants who had collectively worked on all of the groups.

The stakeholder communities were distributed unevenly across the tables, in part because we anticipated different amounts of input, and in part because it was recognized that some would share common strategies. For example, the two prime stakeholders, students and faculty, each were addressed at their own tables. On the other hand, publishers, professional societies, and accreditation bodies were grouped at another table. A fourth table was for university administrators, related education projects, and international education efforts. The last table addressed industry, government labs, and federal funding agencies.

The second day of the workshop looked at identifying concrete activities that would address the strategies for meeting the goals of each stakeholder group. It was divided into a session for the academic stakeholders (students, faculty, administrators), and a session for the remaining stakeholder groups. Each session concluded with a plenary gathering round, where common themes were identified. In total, the workshop produced 122 pages of notes.

2.3 FINAL REPORTING-OUT WORKSHOP TO NSF, ALEXANDRIA, VA, OCT 22 2021 (HYBRID)

In October'21, we organized our final reporting-out workshop to the NSF for overall conceptualization in a hybrid mode to ensure attendance by as many program directors from NSF and other agencies as possible. The venue was the Westin hotel by NSF (with engaged remote participation option) on a Friday afternoon, 1pm-5pm EDT.

The diverse groups of personnel, about half representing NSF and other federal agencies (see attendance in Appendix B5), and some other stakeholder groups such as agencies and accreditation bodies, were sent background material and results from the previous four workshops. The agenda included a brief introduction, a session on issues and

problems found, another on solutions suggested by the stakeholders, and a final session on the institute design. Each session also involved group discussions (5 in-person tables and 5 virtual tables). We again employed the World Café Model for our breakout discussions. For robust hybrid meeting, we also hired a cameraman to ensure that remote participants were well immersed into live presentations and Q&A. For virtual tables, we employed GoToMeeting as previously done effectively.

1-1:05	**Introduction**
1:05-1:45	**Current issues/problems**
1:45-2:05	Small group discussions - breakout - Q&A
2:05-2:15	Gathering/reporting
2:15-2:25	Coffee break
2:25-2:55	**Solutions/suggestions from stakeholders**
2:55-3:15	Small group discussion - breakout - Q&A
3:15-3:25	Gathering/reporting
3:25-3:35	Coffee break
3:35-4:05	**Institute Design, Priorities, Budget**
4:05-4:25	Small group discussion - breakout - Q&A
4:25-4:30	Gathering/reporting
4:30-5	Agency Feedback

Total Attendance was 47 - 22 in-person and 25 remote attendees – with the following breakdowns:
- Federal Agencies (20): NSF (7 in person + 9 remote), ONR (1 in person), NASA (1 in person), DoE (2 remote)
- Representatives of key stakeholders (9) - Industry & National Labs (3), Professional Societies (2), Accreditation Bodies (1), Related Projects (3)
- CDER-center affiliates - 11 in person, - 7 remote

3. FINDINGS

3.1 STAKEHOLDER INPUT WORKSHOPS - SUMMARY RESULTS OF 3 WORKSHOPS

First Workshop Questions:

1. What are the most important factors you have experience with, that inhibit introduction of PDC in the curriculum?
2. What are some ideas for activities that an institute could engage in or support to help the community overcome these impeding factors?
3. Who are the actors we need to engage with respect to each of the identified barriers, so they can be overcome?
4. What activities and resources should be in the institute's portfolio, to help get those actors on board with the effort to overcome the impediments?

Second Workshop Questions:

1. Identify a major historical curriculum change that you have experienced, and the factors that caused the change to be adopted.
2. Given current circumstances (enrollment, hiring, modes of teaching, applications, industry needs, etc.), who are the actors who need to be involved in making change to PDC happen?
3. What are the enablers and impediments (people, organization, resources, tools, etc.) for a new major change (incorporating PDC)?
4. What would be needed from an institute for you to begin adopting PDC fundamentals in course in the first two years in your organization?

Third Workshop Questions:

1. Workforce needs: what kinds of jobs do you see needing PDC knowledge and skills?
2. Considering the needs identified, what can be done better to meet them?
3. What are the leverage points through which non-academic players can influence and help the academic community to make this major change in the curriculum?
4. How could an institute be of use to facilitate and coordinate such synergistic activities?

Summary Results

These twelve questions were posed to evaluate the challenges and needed factors that must be faced in order to successfully implement PDC into the curriculum. The responses consisted of both barriers that must be addressed, and solutions or ideas on how to do so. It was argued that computer science faculty do not prioritize PDC as they do other topics such as machine learning, because many faculty are not familiar with PDC concepts. Faculty in general do not see a reason to change their syllabus, nor do they want to undergo PDC training. Due to the absence of PDC in their courses, students too lack familiarity with the subject, leaving both graduates and undergraduates with no PDC skills for future jobs.

To incorporate PDC into the curriculum there must be space. The community must decide at what level PDC should be introduced, and what topics to replace with this one. However, before a class can incorporate PDC, access to materials such as textbooks, online videos, etc., must be available to both students and faculty. Therefore, authors and publishers must update their material to include PDC.

The lack of advertisement, publicity, and activities that encourage PDC knowledge is a barrier that can be an easy fix. Currently, jobs don't require PDC coding tests to become an employee, nor do they amplify the demand and benefits of hiring PDC skilled employees. However, once they do, the demand for students to develop these skills will rise. It is a common misconception among students to believe they are familiar with PDC by having experience using libraries, but most have not been exposed to realistic problems and the challenges of scaling. Support from industry, and deepening its relationship with academia needs to improve greatly in order to reach success.

To overcome these barriers, faculty must accept change, knowing that it will benefit the CS community and students as a whole. With the right training faculty, PDC can be smoothly integrated into the intro classes (CS1, CS2) with modest modifications. To simultaneously expose faculty members to PDC and have them gain PDC knowledge, sabbaticals in National Labs or industry were suggested. Once faculty are trained, and convinced of the value of PDC knowledge, it will then be easier to convince the chairs of CS departments to push for curriculum change at more institutions.

In adjusting the curriculum, PDC should be implemented early in CS1 or CS2 to make it available to not only CS students, but to include those who are outside the major. In several responses to these questions, it was suggested to remove one required course in exchange for adding two new ones. Other responses varied from starting introduction of PDC in high schools, moving the intro courses towards data science, or creating a PDC course online. A key enabler would be development of a common platform that runs on systems at different scales, to ensure availability to all undergraduates and graduates at all institutions.

The iPDC can also organize activities to motivate and engage students, such as: NSF workshops, internships, guest speakers, hackathons, algorithmic challenges, coding competitions and more. For example, senior capstone projects could give students a chance to work with real datasets to expand their knowledge. In addition, it was recommended that departments use more team collaboration, to get students to work together and build on each other's various skills and experience, so they have more to offer employers in the end. This will not only pique students' interest in PDC, but also provide hands on experience and demonstrate how beneficial it is for their future, to have PDC skills.

Most students are motivated by what will get them hired. Soon, most jobs will require employees with PDC skills. Currently, employers must extensively train new graduates as part of the on-boarding process. The National Labs and industry can contribute by providing more of the needed resources and materials, with greater relevance, for PDC education. For example, convincing the industry to release real datasets for instructional use would give students hands-on programming with realistic technology. Authors and publishers will also need to update their textbooks to incorporate PDC into current material.

The distilled responses to the questions are included in tabular form in Appendix C.

3.2 INSTITUTE DESIGN INPUT WORKSHOP

Institute Goals from Workshop: Based on our community input sessions, the following goals were identified for a PDC education institute with respect to the student and faculty stakeholder groups *prior* to the meeting.

Students:

- All computing students (CS, CE, Computational Sc) have foundational PDC knowledge, skills, and disposition, and pathway for specialization–based local context
- Think of PDC as a natural element of computation, and understand its relationship to other aspects of computing/courses
- Encounter PDC early and throughout the curriculum
- Be motivated to learn PDC skills

Faculty – individual:

- Be able to teach the PDC material
- Have access to ecosystems enabling easy and natural teaching of PDC
- Be motivated to teach PDC
- Understand the importance of PDC and its relationship to broader aspects of the curriculum

Additions to the student goals by the participants emphasized particular aspects of increasing student's exposure to PDC, including through multiple programming languages and more real-world examples, especially ones that develop an understanding of the challenges encountered in scaling up. Industry is particularly interested in reducing the effort needed for onboarding new graduates. Additionally, the goal of being motivated to learn PDC skills was broadened to include an understanding of the importance of PDC skills in computing careers. It was also pointed out that the implicit understanding that the institute would work to increase diversity (women, URM. etc.)should be explicitly listed in the goals.

Additions to the faculty goals mainly focused on training, including being able to work with large, real-world data sets, and being able to lead students through projects involving them. There was also a theme of changing faculty mindsets to view PDC as a central aspect of computational thinking, instead of being an add-on to sequentially oriented problem solving. Further analysis of the goals input was presented at the final meeting in Fall 2021.

Institute Strategies from the Workshop: The initial set of strategies for achieving the goals, with respect to student and faculty stakeholder groups, as presented to the participants are as follows.

- Students:
    - All computing students (CS, CE, Computational Sc) have foundational PDC knowledge, skills, and disposition, and pathway for specialization – based local context
        - Curriculum guidelines updated periodically
        - Incorporate PDC in early/core courses and advanced courses
        - Actions informed by pedagogical research
        - Student friendly, consistent programming language, tools, environment
    - Think of PDC as a natural element of computation, and understand its relationship to other aspects of computing/courses
        - Illustrate wide applications of PDC
        - Incorporate PDC in early/core courses and advanced courses

- o Develop and curate resources to enable PDC learning
    (e.g., white paper, wiki, video, YouTube channel, Khan Academy for PDC, stack overflow - staffed, seminars)
  - Encounter PDC early and throughout the curriculum
    - o See strategies for faculty and administrators
  - Be motivated to learn PDC skills (Intrinsic, Extrinsic)
    - o Promote experiential learning
      - Internships, REUs, Career, Placement, etc.
    - o Create opportunities for Informal learning
      - Hackathons in partnership with industry
      - Make online resources more available
      - Awards and competitions
    - o Certifications for students
    - o Intrinsic Motivations
      - Faculty enthusiasm/research, Peachy assignments, societally impactful, real-world problems, exciting tools
      - Pipeline from HS, middle school

- Faculty – individual (both PDC and non-PDC)
  - Be able to teach the PDC material
    - PDC training
    - Well-tested course packages (course/topics exemplars - tested and rated based on experience)
      - Detailed syllabi, slides, assignments, question/answer, textbook, evaluation methods
      - Staff for curation, high quality
  - Have access to ecosystems enabling easy and natural teaching of PDC
    - Raise awareness of available educational resources
    - Currently a challenging issue - lack of student-friendly and consistent language extensions, libraries, tools, exemplars - may need to develop, collect, enhance, or otherwise prepare for use
  - Be motivated to teach PDC
    - Generate curiosity
    - Incentivize
      - Provide seed grants
    - Enable support and encouragement of chairs/deans
    - Increase faculty enthusiasm and tie to research interests
      - Create/curate Peachy assignments
      - Workshops and special issues for intellectual contributions
    - Promotion of cool tools/lessons/ecosystem
      - Articles, special sessions, training, blogs
  - Understanding the importance of PDC and its relationship to broader aspects of the curriculum
    - Recruit PDC champions, educate and inspire non-PDC faculty
      - Outreach at PDC research conferences, focusing on the importance of broader aspects of curriculum

- Outreach at CS education conferences and education tracks at non-PDC research conferences, focusing on PDC awareness (e.g., SIGCSE TS, SIGARCH education track)

The input on the strategies was more extensive, in part because they were addressed for different stakeholder groups at different tables, so there was less duplication, and in part because the participants were more energized around discussing concrete approaches. Here we report on some key input for the student and faculty stakeholder groups. Further analysis of the goals input was presented at the final meeting in Fall 2021.

A few interesting points that stood out for student-focused strategies were increasing motivation to study PDC by developing resources associated with popular topics, such as data science or machine learning, and getting help from industry in creating versions of PDC tools that are easy to install and manage, possibly integrating them with integrated online texts that connect to cloud resources.

In the area of faculty strategies, it was emphasized that there is a need for tools that can be used in courses with low management overhead, because faculty at many schools do not have dedicated tech support with the skills to set up the kinds of PDC tools used in research and industry. Participants supported continuation of the strategy of seed grants for training and course development, with required reporting in workshops or conference tracks, with travel support for attendance. Multiple suggestions addressed using PDC curriculum development as a means to boost diversity, especially by enabling HBCUs and MSIs to distinguish their graduates as having more modern and relevant skills.

Institute Activities from the Workshop: Responses for activities were even more diverse. Here we present the notes from one of the five tables for the student stakeholder group, with participant additions in italics. Summaries for this and the other stakeholder groups were presented at our final meeting. Appendix D contains the discussion and update data in detail from the participants of this workshop on the PDC institute's goals, strategies, and activities.

Students:
- All computing students (e.g., CS, CE, Computational Sc) have foundational PDC knowledge, skills, and disposition, and pathway for specialization – based local context
    - Curriculum guidelines updated periodically
    - Incorporate PDC in early/core courses and advanced courses
        - Design curriculum as a "package"; content, environment
        - *Provide assessment of student skills and possible additional background materials*
        - *Develop materials with different applications to make them accessible to different students*
        - *Clearly identify background and prerequisites for lessons and provide a companion tutorial*
    - Actions informed by pedagogical research
    - Student friendly, consistent programming language, tools, environment
        - Integrated book & realistic/industry relevant tools (low pain to install/use)
    - Put PDC in the context of problems that are interesting to the students' majors

- Bridge the gap between under-graduate skillset and the skills needed to read and internalize research papers from the industry (eg: through more easily digestible articles in journals, IEEE Spectrum, etc.).
- ○ Think of PDC as a natural element of computation, and understand its relationship to other aspects of computing/courses
  - ■ Illustrate wide applications of PDC
    - *Survey the community to identify easy to understand HPC applications*
    - *Sponsor HPC expert/PDC-education expert to develop kiosk version of applications*
    - *Curate easy to find kiosk and hpc assignment to use in early CS courses*
  - ■ Incorporate PDC in early/core courses and advanced courses across the curriculum
    - *organize/fund training workshop for faculty who want to learn about PDC*
    - *organize/fund bringing non PDC experts to PDC technical conferences*
  - ■ Develop and curate resources to enable PDC learning (e.g., white paper, wiki, video, YouTube channel, Khan Academy for PDC, stack overflow - staffed, seminars)
    - *Offer counterpoints and discussions about propaganda and marketing of some popular software and "magic bullets"*
    - *Fund content creator to enter their content in well tagged databases for easy retrieval*
    - *Identify "missing materials"*
  - ■ Motivate students to take up PDC by meeting them where they are most interested (eg: most CS students these days prefer to study ML; can we pitch PDC as a domain that has many problems that can be solved using ML?).
    - *Offer more varied examples and problems, framed in many existing sciences, especially outside CS and CE. Consider humanities, social science, and other diverse subjects*
    - *Fund REU type projects where students can develop prototype solutions that apply to social problems*
  - ■ Provide motivating examples
    - Introduce as a useful thought process, then introduce problems that are of the size that makes them understand the practical implications of PDC. Understanding scale is hard - powers of 10. For example, a million is much closer to Zero than a Billion, though they are successive big measures and so on.
    - *Create online colloquium series of talks about cool things people are doing with PDC (can also include ads for positions, conferences, opportunities, etc)*
- ○ Encounter PDC early and throughout the curriculum
  - ■ See strategies for faculty and administrators

- ○ Be motivated to learn PDC skills (Intrinsic, Extrinsic)
  - ■ Provide incentives - immediate and both tangible and intangible long term
  - ■ Promote experiential learning
    - Internships, REUs, Career, Placement, etc.
    - *Provide compendium and review of self-directed tutorials*
  - ■ Create opportunities for Informal learning

- Hackathons in partnership with industry *(ideally sponsored by inclusion-oriented groups, e.g., women in CS)*
- Make online resources more available
- Awards and competitions *(choose topics with broader appeal)*
- Cluster competitions, *(making sure it's not a battle of the budgets)*
- Boot camps related to PDC topics
- *Create online colloquium series of talks about cool things people are doing with PDC (mentioned above as well)*
  - Provide certifications for students
  - Engender intrinsic motivations
    - Faculty enthusiasm/research, Peachy assignments, societally impactful, real-world problems, exciting tools
    - Pipeline from HS, middle school
    - Illustrate joy of making a complex program run faster (than their classmates)
    - Modeling and simulating highly parallel natural world, including brain
    - *Group-related activities to work on a current topic of concern (e.g., in the past year or so, COVID modeling)*
  - Promote Job opportunities and career paths
    - *Create a directory of opportunities? Resume bank? (Lots to maintain if we go this direction)*
  - Expose pervasiveness of PDC
    - Start PDC club or such student organization to motivate students
  - Understanding of job prospects and pervasiveness of PDC concepts across a variety of domains (AI/ML based inference, data-analysis, simulations and modeling etc.)
- Diversity, Inclusion and Equity
  - Encourage women and URM students in PDC education
    - *Start and support affinity groups in CS, have them co-sponsor PDC events, speakers, etc.*
  - Recruit and include diverse teams in extracurricular PDC
    - *Engage NCWIT /ACM-W to organize hackathon*
  - Identifying real world relevant problems that need PDC can attract a more diverse set of students
    - *Attend NCWIT/ACM-W meetings to identify "ambassadors" of PDC in these groups*

3.3 FINAL REPORTING WORKSHOP

Specific Objective - To report back to the NSF and to interested agencies on our findings from previous four community workshops on problems faced by the stakeholder communities, what solutions they expect from an institute, and possible design, roadmap, and impact of such an institute.

The workshop had three sessions, each comprising a presentation on our summary findings followed by a breakout session for discussions.

3.3.1 COMMUNITY INPUT - THE PROBLEM - WHAT WAS LEARNED FROM THE PAST FOUR COMMUNITY WORKSHOPS?

Stakeholders Identified
- Students
- Faculty
- Industry
- Government Labs and Agencies
- Funding Agencies
- Administrators (Chairs, Deans, Provosts, etc.)
- Authors/Publishers
- Professional Societies
- Related PDC and CS Education Projects
- International Educational Agencies

SUMMARY FINDINGS
- CS education is not meeting 21st century workforce needs
- Industry, labs don't know where to push to make change
- Students, faculty, administrators, professional societies, authors, publishers not feeling pressure to make change - massive inertia
- No leadership, no examples, no support, no incentives for change

What Do We Currently Teach?
- Current curriculum was designed for a sequential computing model
- Builds from an abstraction that is close to early hardware
  - Fairly low level concepts, all of it is based on sequential algorithms and complexity models
  - No parallelism, no asynchrony, no distribution, weak scalability
- Modern practice uses abstractions at a much higher level
- Gap is too great for a bottom-up approach that tries to anticipate every use, but can be bridged with a selective top-down approach
- Industry needs engineers who can work with APIs, work with PDC systems, design for test and security, sometimes build from scratch

Students

- Don't know what is needed
  - Look to faculty and media for guidance, motivation
  - May not learn until (possibly frustrating) internship experience
- Lack of access to suitable tools (OpenMP isn't for beginners)
- Lack of resources (YouTube, Stack Overflow tutorials)
- Not an expectation of recruiters, Hackathon organizers, etc.

Faculty

- Not trained in PDC, UI APIs, design for test and security
- No model curricula or courses - can lead to endless argument
  - Nothing to follow, nothing turnkey to pick up and use
    - Disconnected modules from a wide range of contexts
  - No complete curricular examples to point to in arguing for change
- No alternatives to choose from for different institutional need
- No reward for change - chairs, deans, students not asking for change
  - No support for effort to develop an all new approach
- Resistance from colleagues if change affects upper level courses
- Resistance for state schools with community college agreements
- Chairs unwilling to allow release time
  - Can't afford to give up course seats
- Technical effort to build, maintain student-appropriate infrastructure
- Modern model significantly affects first two years of courses
  - Multiple faculty need to coordinate change over multiple courses
  - Need release time, summer support, tech support, encouragement
- Can also affect other departments (service courses)
- Upper level may change in response (mostly new opportunities)
- Little incentive to "go it alone" - safety in numbers
- Until there is a bandwagon to get on, not going to start
  - Need a critical mass of colleagues, peer institutions
- No groundswell of enthusiasm in CS education community
- Need to see what success looks like, and benefit, before trying

Administration

- No outside motivation - industry not complaining, no pressure from above, no demand from students
- Change takes resources, in a resource constrained environment
- Change creates controversy, to be avoided unless necessary
- Bucking the mainstream could affect enrollment
- Accreditation, thus far, only has vague expectations that can be addressed with modest course revisions

Authors and Publishers

- Market isn't demanding books with a modern model
  - Reviewers wouldn't even know how to evaluate a new text
- Current text designs are a huge investment of effort - 2000 hours
  - Art, test banks and answers, slides, code files, market position

- No clear model, language, API-set on which to base new texts
  - Changing the whole early curriculum will obsolete multiple texts
- Authors lack experience teaching a modern model
  - New texts come from people enthusiastic to share a new approach

Industry

- ***Employer Stakeholders***
  - Onboarding new CS grads can take up to 6 months
  - Students don't understand modern software engineering
  - Need experience with parallel, distributed, asynchronous, scaling, integration across disparate libraries, test-driven design
  - In many cases, easier to onboard grads with other degrees
  - Computer science education is fundamentally broken, and needs a coherent refactoring to meet modern needs of industry/labs
  - => Economic Impact: Assuming even 3 months of extra onboarding for just 20% of computing grads, economic cost is $440B per year - possibly $800B
  - Need to coordinate efforts, but no clear way to do so - proprietary needs
  - How to supply resources for advancing education? What and where?
  - Need to appreciate importance of naming PDC, scaling, etc., in job listings

    => All of these are calling for a single point of contact to help educate employer management, and be guided on how best to connect with educators.

- Not aware of how listing specific skills in job ads (versus application domain) would motivate students, faculty, administration
- Academia is a foreign land - hard to understand how to influence
  - Professional societies are also challenging
- So focused on company-specific technology that it is hard to generalize — supporting change = "certification"
- Academia resists what many companies offer as support
- Money given to academia seems to vanish, with unclear results
- Sharing tools, datasets can be problematic and take much work
- Sending employees to teach courses encounters challenge that most are not teachers
- Hosting faculty to learn skills encounters challenge that most lack industry engineering experience
- Even knowing how to arrange guest lectures is challenging
- Don't know how to coordinate influence

Professional Societies

- Many constituencies, many activities, much depends on volunteers
  - E.g., student chapter activities, hackathons, conferences, SIGs and TCs - no single point of leverage
- Some awareness of issue in curriculum working groups, but not a priority elsewhere, and no group coordinating activities
- No motivation to make curricular change a priority
- No coordination of activities to effect change

Accreditation Bodies
- Not motivated to change criteria - cost of change creates pushback
  - Not getting demand from industry, professional societies, academia
- Lack of model on which to base new criteria
- Lack of evaluators with experience to review implementations
- Need to be able to train evaluators

Government Labs
- Many tools and resources, but not suitable for students
  - Little support for reworking tools for student use
- Lab personnel usually can't get release for working with academia
  - Performance evaluation doesn't include supporting education
- Budget cycles are long and complex, making it hard to coordinate with short (i.e., 3-year) grant-funded projects in academia
- Don't know how best to make connections to academia

Federal Funding Agencies
- Generally focused on research, rather than transforming institutions
  - Despite mission to develop workforce and increase diversity
- Lack flexibility to shift funds quickly to exploit key opportunities
- Modern model is fragmented (e.g., separate programs for PDC, software engineering, security, theory, HCI, networking) and rooted in academic/research perspective
- Typical grants too small, short term, for pervasive transformation

PDC and CS Education Projects
- Need better coordination, communication, meetings
  - Less duplication, more sharing, more mutual encouragement
- Need a collaborative resource site with professional curation
  - Establish and help meet common standards for shared resources
- Need technical support for interoperability, dissemination
- More venues for cross-promotion of efforts

International Education Agencies
- Mostly acting independently, some with strong government direction
- Some already ahead of US in implementation
- Lack of coordinated effort in US to evaluate international efforts
- Lack clear point of contact in US for international efforts to work with
- Lack of funding in US for educators to collaborate internationally

BREAKOUT SESSION 1 DISCUSSIONS

In Breakout Session 1, following our presentation, there was a consensus on the need for inclusive education, with participants acknowledging that non-profit organizations and government agencies should play a role in making education more accessible. Participants recognized the need to define

what PDC (Parallel and Distributed Computing) skills every graduate should know and acknowledged that CS education has not changed significantly in the past 40 years and that it needs to evolve. There also was recognition that PDC concepts should be introduced early in the curriculum and should go beyond just computer science. Some emphasized on teaching PDC in the context of real-world applications and highlighting its impact on various fields. Some participants highlighted the potential role of non-profit EdTech companies in bridging the training gap through successful partnerships with universities. Some participants questioned the extent to which accreditation bodies can dictate curriculum content. Funding challenges were subjects of debate, with some participants highlighting the difficulty of partnering with the NSF by other agencies, while others emphasized the value of internships and faculty support. There were discussions over the focus of PDC education, with some advocating for a broader computing-oriented approach and others emphasizing CS principles.

3.3.2 COMMUNITY INPUT – SOLUTIONS - WHAT COULD AN INSTITUTE PROVIDE?

SUMMARY FINDINGS
- Each stakeholder group contributed ideas and wishes
- The general theme is examples, leadership, and coordination
  - Leading an inclusive effort to develop exemplar curricula
  - Helping stakeholders to connect in ways that are effective
  - Providing a central clearinghouse, resources, support, training
  - Connecting computing education efforts to help them coordinate

Industry
- Help industry understand how and where to lobby for change
- Provide guidance on how to develop appropriate training materials
- Provide clearinghouse training materials, tools, datasets, PDC internships
- Help management understand significance of PDC, scalability
  - In curriculum
  - In job postings
  - Understand value of providing resources
    - Need for "real" datasets, problems, faculty training
    - Central point of contact to gather input on industry needs, skills
    - Advisory board

Government labs
- Much of the above, plus…
- Connect faculty/students with internships, training, job opportunities
- Outreach to lab/agency leadership for buy-in, internal support
- Facilitate adoption of tools

Implications
- Institute needs staff for *outreach* to employer stakeholders
- Institute needs an *advisory board*
- Institute needs professional *repository* curation and management

Faculty
- Institute could provide examples of full courses and curricula

- Teaching resources (texts, syllabi, slides, problems/solutions, datasets, videos, evaluation methods)
- Training - dedicated PD workshops, short courses at conferences
- Tools - student-friendly environments, APIs, packages
- Marketing to admins, departments, to show value of adopting changes, meet accreditation
- Convincing admins of value of working on tool and material development
- Arranging for industry recognition of efforts to modernize curriculum
- Venues for publication of PDC education research
- Motivate and incentivize faculty and admins to implement changes
- Promote common tools, lessons, ecosystems, articles, special sessions, blogs, YouTube videos, Stack Overflow tutorials
- Build a community that is mutually supportive, collaborative
- Recruit PDC champions
- Outreach at PDC and CS Ed conferences
- Broaden participation by outreach to HBCUs, MSIs with specific training, resources
- Emphasize computing for the common good, socially relevant applications

Implications
- Institute needs to run a critical mass set of full-curriculum ***development teams***, tasked with providing transferrable, turn-key, course sequences
  - Teams need to cover a diverse set of institutional needs, while coordinating and collaborating to create a consistent conceptual framework that establishes a new standard approach
  - Teams need to be focused on transferability, and participate in transfer training of faculty from other institutions
- Institute needs a ***marketing division*** to
  - promote change to stakeholders
  - raise awareness
  - publicize availability of tools, resources, development team activities
  - create a perception that modernizing curriculum is a growing bandwagon
- Institute needs a ***training division***
  - Continue ongoing training efforts during startup period
  - Guide development teams in preparing training plans
- Institute needs a ***technical support division***
  - Help develop common, student-friendly versions of APIs, tools
  - Help transform industry software, datasets, problems into teaching resources
  - Work with repository curator to ensure contributed modules are high quality and portable

Students
- Promote importance of students encountering a modern computing model from the beginning
- Promote dispositional concepts that
  - Software engineering is more about understanding disparate components, possibly in multiple languages, evaluating their potential, and working out how to connect them, to meet rigorous testing standards
  - Concurrency, parallelism, distribution, asynchrony, scaling, security are fundamental elements of computational problem solving
- Develop student-friendly, consistent, career-relevant tools, videos, tutorials, online lessons

- Sponsor student chapter activities, hackathons, guest speakers
- Sponsor awards, competitions, boot camps
- Provide internships/REUs at institute
- Help partners connect with students who are learning PDC early
- Develop standards for certificate programs
- Work to build faculty enthusiasm
- Develop resources for career preparation, how to interview
- Work on HS pipeline
- Use change as a means to increase diversity
  - PDC enables use of problems/project that have broader appeal
  - More opportunities to engage non-CS students (e.g., data science, computational science, computational social science)
- Ensure that sponsored activities have diversity and inclusion plans
  - Support participation from NCWIT, ACM-W, CRA-W, HBCUs

Implications
- Institute's outreach div. must have a student component
- Outreach must include diversity organizations
- Marketing must include students, and faculty on their behalf

Administrators
- Marketing, outreach via employers, to convince them of PDC's importance
- Help them find resources - training, seed grants, employer partners
- Work with accreditation bodies to encourage change

Implications
- Marketing div. needs effort toward administrators
- Outreach div. ensures admin is aware of potential partnerships

Authors/Publishers
- Help publishers to see market potential
- Motivate existing authors, develop new authors
- Include supporting technology that can be transferred

Implications
- Scale of project is key to moving authors/publishers
- *Curation department* needs to transfer materials to publishers
- Marketing and outreach need author/publisher plans

Professional Societies
- Continue work with curriculum efforts
- Identify TCs, SIGs, other groups as partners
- Encourage promotion of PDC in curriculum through publications
- Sponsor student events at chapters, conferences, awards

Implications
- Outreach div. makes connections between stakeholder communities
- Training div. ensures teams are publishing work
- Curriculum div. continues engagement, expands to new groups

Accreditation Bodies
- Help advance their criteria, broaden to other computing disciplines
- Develop a consistent set of standards to facilitate service courses
- Help with training of evaluators

Implications
- Curriculum div. needs accreditation effort
- Training div. needs evaluator training effort
- Teams must consider impact on accreditation, breadth of usability
- Outreach div. helps employers on how to encourage updating of criteria

Related Projects/International
- Facilitate communication, coordination, sharing, interoperability,
- Collaboratively develop common curation standards
- Promote and market all activities in a coherent manner
- Facilitate more virtual/local options at conferences

Implications
- Institute's *scale* will make it central to a larger effort
- *Curation department* needs to work with other projects
- Training div. needs to draw from/coordinate with other efforts

Funding Agencies
- Help understand critical need for future domestic workforce to work with modern computing in STEM, manufacturing, health, defense, security
- Work with Program Directors on white papers, workshops to set funding priorities, create programs
- Increase efficiency, flexibility of funding PDC training efforts
- Help develop standards for publishing CyberTraining materials
- Help gain backing for additional funds for CS education, including school pipeline, diversity
- Help connect agencies, proposers with organizations promoting diversity

Implications
- The outreach and marketing divisions include funding agencies
- The scale of the institute and its resulting connections enables marketing, influencing policymakers

BREAKOUT SESSION 2 DISCUSSIONS

During Breakout Session 2 following our presentation on our findings, participants generally agreed on the importance of a sustainable timeframe for the proposed institute and the need for department buy-in to drive meaningful change. There was consensus on the magnitude of the task at hand and the recognition that substantial changes would take time. Views differed on the involvement of marketing professionals, with some suggesting the need for external consultants to promote the idea, while others emphasized the role of faculty members and collaboration within the institution. There was recognition that existing resources and similarly scaled projects can provide valuable models and insights for the PDC institute.

3.3.3 DESIGN AND ROADMAP OF AN INSTITUTE ON PARALLEL AND DISTRIBUTED COMPUTING (PDC) EDUCATION

SUMMARY - WHAT MUST USA DO TO MODERNIZE COMPUTING EDUCATION?

- Clear Risks – Leaving US behind, Hurting the computing workforce and the US economy
- What must USA do?

  - o Incremental or piecemeal has not worked - An institute level effort alone can turn the tide.
  - o Goal: Ensure ALL computer science and computer engineering undergraduates (and related computing disciplines) are well-versed in PDC skillset to meet the modern workforce

- Impact

  - o Boost Economy and National Security
  - o Recruit and retain women (currently 20%) and URM (15%)
  - o Increased productivity of CS interns and employees
  - o Reduce on-ramping dollars for 20% of computing workforce by ~$800B

What are the current limitations?
- Scale
  - o Changes have been by individual early adopter faculty in 1-2 courses
  - o Departmental adoptions seriously lacking (in over 4K colleges and universities with computing programs)
- Key Gaps
  - o Turnkey Exemplars, particularly for 1st and 2nd year curriculum, for diverse institutions
  - o Support ecosystem
  - o Limited relationships of faculty/students to key stakeholders including industry, accreditation bodies, university and system administrations, publishers, and authors
- CDER center and other projects have seeded activities, fostered community, but organic growth will take time, while other countries jump ahead and capture markets
  => Must leap to large

What is new, Why will PDC Institute work?
- Institute - holistic, with capacity to work with all stakeholder communities, including with industry
- Bold and Transformative
- Eliminate key gaps – e.g., full 1st and 2nd year curriculum exemplars for diverse institutions, adoptable by even community colleges

   => Scale all needed activities supported by national PDC ecosystem for a "Collective Impact"

   => Carrot and Stick (from accreditation bodies, funding agencies, univ administration and systems, industry)

Impact - Success measures, How long will it take?
- Short term
  - Tiger teams established; exemplar courses produced
  - Adoption at various institutions/levels – #courses/curriculums, #instructors, #students impacted, #partnerships/workforce represented, professional societies (CRA, ABET, ACM/IEEE, etc.)
  - 5 yrs. for full-curriculum development/evaluation/early adoption, training the trainers & evaluators
- Long Term (next 5 yrs.)
  - Productivity of interns/employees/graduate students
  - Increase enrollment of women and URM students
  - Industry changes its ways on in-house training and onboarding costs reduction
  - Key aspects sustained by stakeholders, spun off to companies, innovation in pedagogy
    - ⇨ the *PDC institute ceases to exist*

PDC INSTITUTE'S DESIGN AND PRIORITIES

Executive Leadership (*Backbone organization*)
1. Curriculum development division
2. Training division
3. Technical support division
4. Community development/outreach division
5. Marketing division
6. Advisory Board

Curriculum development division
- Coordinate development of curriculum and instructional material
  - Competitively recruit Tiger teams to develop and test transferable exemplars for 1st and 2nd year full curriculum and instructional material for diverse institutions, books and provide instructor training
    => full scale changes
  - Provide technical support to Tiger teams, Authors, and Trainers
  - Maintain courseware repository - Curate, collect, and coordinate reviews
  - Update PDC curriculum in collaboration with professional societies
  - Adoption and other metrics

Training division
- Develop training material, and conduct and support training
  - Develop and conduct instructor training to adopt and use instructional material, pedagogy, for 1st and 2nd year core courses
  - Support trainees, create cohorts
  - Train the trainers
  - Develop asynchronous online training
  - Train the curriculum evaluators for core and advanced courses (e.g., ABET)

Technical support division
- Support instructors with Environment/tools/HW/SW resources (in-house and/or third-party)
  - Turnkey support for resources, tech support
  - Support introductory courses and advanced courses
  - Support instructors in installing PDC software, debug sample code, find resources
  - Leverage industry partnership for resources for scaling experiments, skills and cloud resources

Community development/Outreach division
- Foster educational and other stakeholder communities
  - Outreach to professional societies, authors, publishers
  - Help sponsor/provide materials for hackathons
  - Create relationships with people/organizations/university systems/policy makers
  - Partner for sustainability
  - Coordinate educational research workshops on PDC at major conferences, journals, books
  - Maintain list of guest instructor speakers, internships

Marketing division
- Public relations and marketing
  - Conduct market research using connections of Community Development/Outreach Division
  - Develop media, newsletters, evaluation and metrics
  - Partner with media and major publishers, publish articles

EXEMPLAR DEVELOPMENT

Tiger Team Products
- Goal is turn-key course materials for a two-year curriculum
  - Six exemplar curricula overall for diverse set of institutions, but may have common units
- All in a curated public repository
- Curator and marketing staff work with teams to identify products, help get them into high quality, standard format for repository
- Promote materials beyond teams, and gather feedback from wider community

Tiger Teams
- 6 institutions, selected to provide diverse approaches, examples
  - e.g., HBCU, Women's College, Hispanic/Native serving, small college, 2 large universities, with geographic dispersion
- 4-6 faculty working on full curriculum revisions at each institution
- Selected during 1st year via proposal process that includes advisory board input, independent oversight
- Supported by institute technical staff, repository curator, industry partners arranged through outreach staff
- Funded four years at level to ensure success and department buy-in

Test and Evaluation Teams
- Each Tiger Team has a partner institution for testing curriculum
- Requires Tiger Teams to create transferrable exemplars, conduct training
- Test team has 1 liaison in years 1 and 2, 2 faculty in year 3, and 4 in year 4 (equivalent to 2 per year for 4 years)
- Consults with Tiger Team during planning, 1st year implementation
- Begins transfer and evaluation of 1st year courses no later than year 3, adds 2nd year courses no later than year 4

Tiger Team Coordination
- Meetings three times per year of team representatives, institute staff, advisory board, industrial partners
  - Co-located with major conferences - present work, brainstorm, share, make decisions about areas where commonality can be incorporated
- Bi-weekly check-in and collaboration meetings, including with outreach and marketing staff, repository curator
- Bi-weekly (alternate weeks) Tiger and Test team meetings
- Annual site visits from institute staff

Exemplar Development – Complete, New Curricula for 1st and 2nd Year
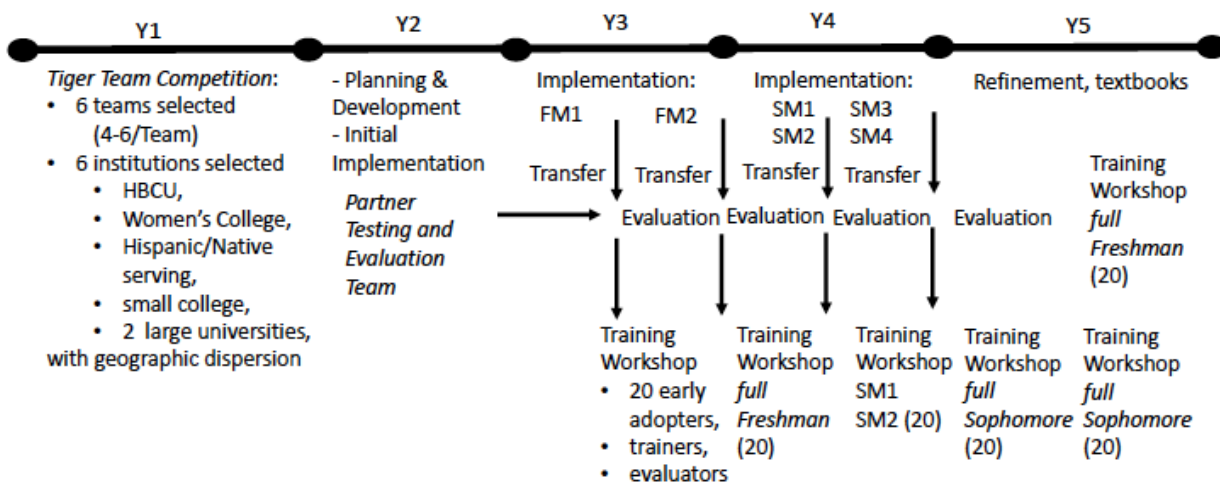
STAFFING, BUDGET ESTIMATES

- Executive Leadership (Backbone organization)
    - PI, Co-PI'S, Staff: 1 Senior administrative staff, 1 Webmaster/Repository Administrator
- Curriculum development division
    - 2 Co-PIs, Staff: 1 Curator Y1-Y2, 2 Y3-Y5 (with PDC content knowledge, MS/PhD)
    - 6 Tiger teams funded for Yr. 2- Yr. 5, average team size 5
- Training division
    - 1 Co-PI, 1 training coordinator (both technical and teaching expertise, MS/PhD)
    - Trainers: Tiger teams, PI's, Senior Personnel, Faculty rotators on sabbatical, Industry partners
    - Trainees and early adopters – 26 summer workshops (Y1-Y3: 3/yr; Y4, Y5 10/yr)
        - 20 trainees/workshop - $5K stipend/trainee for about 500 trainees
- Technical support division
    - Co-PI, 1 CS technical staff person for Y1-Y2, then 2 for Y3-Y5
- Community development/outreach division
    - Co-PI, 1 staff for Y1-Y2, then 2/yr
- Marketing division
    - Co-PI (marketing expertise), 1 staff for Y1-Y2, then 2/yr staff: media developer/writer, marketing research
- Advisory Board (representing the stakeholder communities)

Institute Budget Estimate: Total $27-30M (~$3M year 1, $6M year 2-5)

BREAKOUT SESSION 3 DISCUSSIONS

In Breakout Session 3 following our presentation on our findings and roadmap for an institute, participants expressed agreement on several key points presented. There was a shared understanding of the need for the institute, increased outreach and the importance of engaging government and industry expertise and buy in to enhance the program's impact, and reasonableness of duration and staffing level. There was some agreement that many universities face constraints in modifying their undergraduate curriculum, particularly in the early years and by smaller institutions, and that alternative approaches, such as certificate programs or masters courses, may also be considered to facilitate implementation. Participants acknowledged the need for collaboration and support beyond universities, such as involving community colleges (perhaps creating a PDC-oriented program for these, or one being a Tiger team producing exemplar courses), high schools, and industry partners, to foster broader engagement and promote effective curriculum changes. The scope of the proposed PDC institute was a concern and the naming of the institute also generated differing viewpoints, with suggestions for a more encompassing and appealing term. There were suggestions on how Tiger teams should be constituted and concerns on making the exemplars portable. Overall, there was general understanding of the institute level funding needed – with significant impact, and there were several suggestions on funding sources, with recognition that NSF may not have a suitable program for such a large scale educational project. Some participants suggested embedding PDC within an AI institute, exploring IUCRC funding – corporate/academic partnerships, and leveraging industry.

APPENDIX

A. PROJECT COLLABORATORS

1. Martina Barnas (IU)
2. Trilce Estrada (UNM)
3. Debzani Deb (Winston Salem)
4. Sheikh Ghafoor (Tennessee Tech)
5. David Bunde (Knox College)
6. Krishna Kant (Temple)
7. Kunal Agrawal (Washington, Saint Luis)
8. Henry Gabb (Intel)
9. Eric Freudenthal (UTEP)
10. Erik Saule (UNCC)
11. Joel Adams (Calvin College)
12. Tia Newhall (Swarthmore)

B. WORKSHOP ATTENDEES

B1. PARTICIPANTS OF THE FIRST NSF INSTITUTE PLANNING WORKSHOP, NOV 18, 2019, DENVER

1.	Sushil Prasad	UT San Antonio
2.	Alan Sussman	NSF
3.	Joe Bungo	NVIDIA
4.	Kirk Jordan	IBM
5.	Craig Stunkel	IBM
6.	Cynthia Phillips	Sandia National Laboratory
7.	Henry Gabb	Intel
8.	Linda Akli	Xsede
9.	Andrew Lumsdaine	PNNL/U. Washington
10.	David Leubke	NVIDIA
11.	Chip Weems	UMass, Amherst
12.	R. Vaidyanathan	Louisiana State
13.	Joel Adams	Calvin College
14.	Rajendra K Raj	RIT, ABET
15.	Umit Catalyurek	Georgia Tech, TCPP
16.	David Bunde	Knox College
17.	Debzani Deb	Winston-Salem State University
18.	Trilce Estrada	University of New Mexico
19.	Alexandru Iosup	Vrije U., Netherlands
20.	Steven Bogaerts	DePauw University
21.	John Dougherty	Haverford

22.	Libby Shoop	Macalester, CS in Parallel
23.	JP Fasano	CSTA
24.	Kate Cahill	Xsede
25.	Duane Bailey	Williams College
26.	Mary Smith	Hawaii Pacific U.
27.	Srishti Srivastava	S. Indiana
28.	Michelle Zhu	Montclair
29.	Ana Gonzales	U. Puerto Rico
30.	Apan Qasem	Texas State U.
31.	Yves Robert	ENS Lyon, France
32.	George K. Thiruvathukal	Loyola U. Chicago
33.	Vivek Sarkar	Georgia Tech
34.	Richard LeBlanc	Seattle University

B2. PARTICIPANTS OF THE 2ND NSF PLANNING WORKSHOP, MARCH 11, 2020 (ONLINE)

1	Chip Weems	UMass, Amherst
2	R. Vaidyanathan	Louisiana State
3	Rajendra K Raj	RIT, ABET
4	Kinnis Gosha	Morehouse University CS4All,
5	Ruth Farmer	NCWIT - OSTP
6	Neena Thota	UMass, Amherst
7	Erik Saule	UNC Charlotte
8	Sheikh Ghafoor	Tennessee Tech
9	Memo Dalkilic	Indiana University
10	Dorian Arnold	Emory - CS, education
11	Saturnino Garcia	Univ San Diego
12	Karen Karavanic	Portland State
13	Susan Wang	Mills
14	Dick Brown	St. Olafs
15	Ewa Deelman	USC
16	Clay Breshears	Omics Automation
17	Brad Richards	University of Puget Sound, LACS
18	Doug Lea	ACM/IEEE CS Curricula
19	Sushil Prasad	UT San Antonio
20	John Impagliazzo	Hofstra
21	Martina Barnas	IU
22	Henry Gabb	Intel
23	Chan, Ellick	Intel
24	Joel Adams	Calvin College
25	David Bunde	Knox College

26	Debzani Deb	Winston-Salem State University
27	Robert Robey	Los Alamos National Laboratory
28	David Brown	Elmhurst College
29	Suzanne Matthews	West Point
30	Tia Newhall	Swarthmore
31	Li Yang	NSF
32	Nigamanth Sridhar	NSF
33	Erik Brunvand	NSF

B3. PARTICIPANTS OF THE 3RD NSF INSTITUTE PLANNING WORKSHOP, JULY 17, 2020 (ONLINE)

1	R. Vaidyanathan	LSU
2	Sushil Prasad	UT, San Antonio
3	Erik Saule	NC State
4	Tia Newhall	Swarthmore
5	Eric Freudenthal	UT, El Paso
6	Sheikh Ghafoor	Tennessee Tech
7	David Bunde / Alan Sussman	Knox / Maryland
8	Sean Gallagher	Lowes
9	Bobby Simidchieva	Raytheon BBN
10	Kirsten Hatch	Intel Corporate University Research
11	Julia Levites	NVIDIA
12	Sundar Dev	Google
13	Joe Swartz	Lockheed Martin Space
14	Mathew Rheault	Hubspot
15	Dan Grossman	University of Washington
16	Dan Garcia	UC Berkeley, CSP
17	Prabhanjan Kambadur	Bloomberg
18	Dilma da Silva	Univ Texas A&M
19	Virendra Bhavsar	University of New Brunswick
20	Joe Bungo	NVIDIA
21	Akshaye Dhawan	Bloomberg
22	Henry Gabb	Intel
23	Ajay Gupta	Western Michigan U.
24	Michela Taufer	U. Tennessee, Knoxville
25	Satish Puri	Marquette
26	Jim Kurose	UMASS, NSF
27	Ken Birman	Cornell

28	Remzi Arpaci-Dusseau	Chair, Univ Wisconsin
29	Steven Gordon	Xsede
30	Darko Stefanovic	Chair, Univ. of NM
31	Nancy M. Amato	UIUC
32	Sandeep Gupta	ASU
33	Tony Skjellum	UT Chattanooga
34	Randy Bryant	CMU, OSTP
35	Paul M. Leidig	Grand Valley State University, ABET, ACM
36	Rajesh Sankaran	Argonne National Laboratory
37	Mike Kirby	Assoc. Sch. Director, U. Utah
38	Andrew Lumsdaine	PNNL/U. Washington
39	Lawrence Rauchwerger	UIUC
40	Vladimir Voevodin	Lomonosov Moscow State University, Russia
41	Sanjay Wandhekar	CDAC, India
42	Almadena Chtchelkanova	NSF
43	Balakrishnan Prabhakaran,	NSF
44	Anindya Banerjee	NSF
45	Hai Jin	Huazhong University, China
46	Andrew Lumsdaine	PNNL/U. Washington
47	Manish Parashar	NSF/OSTP
48	Deb Debzani	WSSU
49	Martina Barnas	IU
50	Chip Weems	UMass
51	Hannah Jones	UMass, REU student

B4. PARTICIPANTS OF THE INSTITUTE DESIGN INPUT WORKSHOP, MARCH, 2021 (ONLINE)

1	Alan Sussman	NSF
2	Chip Weems	UMass, Amherst
3	David Brown	Elmhurst College
4	David Bunde	Knox College
5	Debzani Deb	Winston-Salem State University
6	Erik Saule	UNC Charlotte
7	Henry Gabb	Intel
8	Krishna Kant	Temple University
9	Neena Thota	UMass, Amherst
10	Sushil Prasad	UT San Antonio
11	Tia Newhall	Swarthmore

12	Sheikh Ghafoor	Tennessee Tech
13	R. Vaidyanathan	Louisiana State
14	Cynthia Phillips	Sandia National Laboratory
15	Eric Freudenthal	UT, El Paso
16	Martina Barnas	Indiana U., Bloomington
17	Ana Gonzales	U. Puerto Rico
18	Andrew Lumsdaine	PNNL/U. Washington
19	Apan Qasem	Texas State U.
20	Joe Swartz	Lockheed Martin Space
21	Joel Adams	Calvin College
22	John Impagliazzo	
23	Kate Cahill	Xsede
24	Rajendra K Raj	RIT, ABET
25	Rajesh Sankaran	Argonne National Laboratory
26	Sean Gallagher	Lowes
27	Steven Gordon	Xsede
28	Sundar Dev	Google
29	Virendra Bhavsar	University of New Brunswick

Federal Agencies (20): NSF (7 in person +9 remote), ONR (1 in person), NASA (1 in person), DoE (2 - remote)

1	Alejandro Suarez	NSF
2	Manish Parashar	NSF
3	Li Yang	NSF
4	Nigamanth Sridhar	NSF
5	Paul Tymann	NSF
6	Alexandra M (Sandy) Landsberg	ONR
7	Tsengdar Lee	NASA
8	Bonnie Green	NSF
9	Seung-Jong (Jay) Park	NSF
10	Almadena Chtchelkanova	NSF
11	Matt Mutka	NSF
12	Tevfik Kosar	NSF
13	Marilyn McClure (Mimi)	NSF

14	Tom Gulbransen	NSF
15	Wu He	NSF
15	Bogdan Mihaila	NSF
17	Gurdip Singh	NSF
18	Hal Finkel	DOE
19	Margaret Lentz	DOE
20	Li, Juan J.	NSF

Representatives of key stakeholders (9 - 2 in person) - Industry & National Labs (3), Professional Societies (2), Accreditation Bodies (1), Related Projects (3)

21	Apan Qasem	Texas State U.
22	Joe Swartz	Lockheed Martin Space
23	John Impagliazzo	CC 2020
24	Ana Gonzales	U. Puerto Rico
25	Kate Cahill	Xsede
26	Rajendra K Raj	ABET, RIT
27	Rajesh Sankaran	Argonne National Laboratory
28	Joe Bungo	NVIDIA
29	Doug Lea	ACM/IEEE CS Curricula - PDC section

CDER-center affiliates - 11 in person

30	Alan Sussman	Maryland, NSF
31	Chip Weems	UMass, Amherst
32	David Bunde	Knox College
33	Erik Saule	UNC Charlotte
34	Sushil Prasad	UT San Antonio
35	Tia Newhall	Swarthmore
36	Sheikh Ghafoor	Tennessee Tech
37	R. Vaidyanathan	Louisiana State
38	Martina Barnas	IU
39	Krishna Kant	Temple University
40	Eric Freudenthal	UT, El Paso

CDER-center affiliates - 7 remote

41	David Brown	Elmhurst College

42	Debzani Deb	Winston-Salem State University
43	Henry Gabb	Intel
44	Neena Thota	UMass, Amherst
45	Anshul Gupta	IBM
46	Cynthia Phillips	Sandia National Laboratory
47	Joel Adams	Calvin College

C.1. FIRST NSF INSTITUTE PLANNING WORKSHOP, NOV 18, 2019

The findings of the discussion are summarized in the following tables. The notes generated by the three workshops were distilled by a summer REU student, Hannah Jones, working with co-PI Weems at UMASS.

Question 1 (Workshop 1)

What are the most important factors you have experience with, that inhibit introduction of PDC in the curriculum?

Responses	Frequency of response
Faculty issue/inactivity	18
PDC not used as a CS term (majority of CS faculty students unfamiliar with PDC	3
Lack of communication between industry and academia	2
PDC contributor vs user	2
Programming language tools	3
Priority of PDC (faculty and CS departments)	8
Trusting students (motivation/ engagement to PDC)	2
Advertisement and marketing	9
PDC skill (in students and faculty)	2
Demand of PDC (employers demanding PDC skill)	4
Orientation of CS topics (order in curriculum)	4
General interest in PDC	5
Curriculum (what courses to add/subtract)	11
Difficulty level	4
PDC resources (textbooks, tools)	11
Difference between HPC and PDC	3

Training and knowledge (faculty, students)	9
Relevance	6
Other	12

Question 2 (Workshop 1)

What are some ideas for activities that an institute could engage in or support to help the community overcome these impeding factors?

Responses	Frequency
Faculty motivation	2
Industry collaboration	12
Partnership with ABET, IEEE, ACM	6
Assuring Resources (reading and curriculum material)	18
Branding	4
Student motivation	5
Faculty development	7
iPDC formation	3
Assessment	2
Clearinghouse	2
Others	11

Question 3 (Workshop 1)

Who are the actors we need to engage with respect to each of the identified barriers, so they can be overcome?

Responses	Frequency
Advertisement agents	11
Students (motivation, eagerness, excitement)	2
Funding agencies	7
Academic actors	20

ACM, IEEE, ABET, CRA, CAC	9
Industry (support/contribution materials, tools)	7
Textbook authors and publishers	5
Early adopters of PDC	4
International actors	2
Employers (demand for PDC)	7
Training and workshops	3
Vendors	3
Motivators (outside cs major sources)	3
Government	2
Press release	2
Others	11

Question 4 (Workshop 1)

What activities and resources should be in the institute's portfolio, to help get those actors on board with the effort to overcome the impediments?

Responses	Frequency
Workshop (annual, weekly)	5
Certification (for students as motivation)	9
Training and workshop (faculty, students)	5
Strong infrastructure	3
Proving relevance	2
Job description	5
Survey (students)	3
Material and resources	8
Curriculum development	2
Advertisement (demand for PDC)	4

Relationship with ACM, IEEE	2
Assessment	3
Committee of actors	2
Others	10

C2. 2ND NSF PLANNING WORKSHOP, MARCH 11, 2020

Question 1 (Workshop 2)

Identify a major historical curriculum change that you have experienced, and the factors that caused the change to be adopted.

Responses	Frequency
Historical curriculum change (covid-19 remote learning, transition from object oriented programming, tedious process switching to Bryant O'Halloran, switching to python in CS1, switch to high-level data centric programming)	
Faculty adapt to change	13
Student motivation/applications/career	12
Curriculum changes/additions/expansions	25
Training/knowledge/workshops	11
Orientation of topics	9
Material/resources (textbooks, cs tools)	7
Relevance/job recruiting (PDC skills in demand)	7
Industry (support, contribution of tools/materials)	6
Institution (large universities, small liberal arts colleges)	4
Other	5

Question 2 (Workshop 2)

Given current circumstances (enrollment, hiring, modes of teaching, applications, industry needs, etc.), who are the actors who need to be involved in making change to PDC happen?

Response	Frequency
Student motivation	6
Faculty/other colleagues	10
Contribution from organizations (ABET, ACM, IEEE)	20
Industry support/recruits	8
Textbook authors/publishers	7
Training/workshops	6
Academic actors (buy-in)	8
Curriculum development	6
Institutions (size of institution playing a role in PDC)	7
Employers (jobs seeking PDC skills)	4
Funding agencies/NSF/National Labs	3
Other	9

Question 3 (Workshop 2)

What are the enablers and impediments (people, organization, resources, tools, etc.) for a new major change (incorporating PDC)?

Response	Frequency
Student (initiative/motivation)	13
Faculty mindset/change	7
Curriculum (changes/development)	13
Contribution of organizations (ABET, ACM, IEEE)	7
Training / workshops (faculty and students)	9
Industry (support/contribution of materials, tools)	6

Textbooks authors/publishers	7
Institutions (big universities, small liberal arts)	6
Platform (online, bowser based PDC, common language/environment)	4
Funding agencies (National Labs, NSF)	1
Other	5

Question 4 (Workshop 2)

What would be needed from an institute for you to begin adopting PDC fundamentals in course in the first two years in your organization?

Response	Frequency
Training (faculty, students)	15
Faculty (mindset, change)	10
Student initiative/activities (coding competitions, hackathons)	10
Institution support/contribution (larger universities, small liberal arts colleges)	14
Curriculum development	16
Resources/materials (textbooks, cs tools)	7
Advertisement (jobs seeking PDC skills)	10
Funding agencies (National Lab, NSF)	4
Industry/alumni (Guest speakers)	3
Other	16

Question 1 (Workshop 3)

Workforce needs: what kinds of jobs do you see needing PDC knowledge and skills?
●   Responses to this question varied from actual specific job positions to the skill sets they require. Below there is a table for each.

Jobs requiring PDC:

Big data and cloud service providers	5
Software engineers	3
Machine learning researchers or developers	2
(Data) Architecture and managing infrastructure	2
Jobs require understanding of concurrency	2
Services like banking/financial sectors	1
Project managers	1
Climate study, nuclear engineering and simulations, general physics applications	1
Industry, academia, and labs	1
Lowes needs data engineers, harder to find than data scientists	1
Need for computer scientists but a larger need for software developers and data scientists	1

Required skills for the jobs listed above:

(Only select responses listed here)

Responses	Frequency

Student initiative/projects/exposure/teamwork
   • Giving students projects that need to be solved by teamwork (3)
   • Need students to understand all types of parallelization types and how to apply them (2)
   • Desirable that students come out of a data structure and algorithms class being exposed to parallelism (1)
   • Using libraries, they do not understand, using libraries does not count as PDC experience (4)
	17

Computer science community/focuses/accessibility • Need to focus on nonlinear scaling and the concept of computational efficiency (1) • Companies need experience migrating off old tech to new (2) • Companies to convince other of benefits of PDC, struggling to apply PDC in their growing collections of big data (3)	12
Institution size/contribution/ initiative • Universities need to move away from OO coding and more towards predesign algorithms and top down design (1) • Universities need courses that forces students to work in "teams" work on real world problems (2) • Gap between what is taught at institutions rather than what is needed in the industry (1)	9
Curriculum development • Expose students to science, engineering and CS in the 1st year (2) • Networking and distributed system courses covers thinking outside of the box that is desired for PDC (1) • Need curriculum that gives relatively "hard" problems for groups to work on (1)	8
Employers/recruiters/hiring • Need graduates that have real hands on experience in courses that turn a problem from serial to parallel (1) • Expect hires to know how to work within a distributed computing environment (1) • Tired of interviewing candidates who claim to understand PDC because they use parallel AI/ML frameworks (1)	7
Relevance data growing exponentially/ ML taking over • Data is growing exponentially processing the amount of data will require PDC (3) • "Machine learning has taken over" (3)	6
Training/skill sets • Distributed computing calls for an engineering skill to think through failure (3) • Lack of training for faculty and students (1)	4
Faculty teaching techniques • Teach modern, industry-strength tech stack in advance courses (1) • Teach modern parallel architecture (1) • Teach software engineering along with high performance computing (1)	3
Internship/apprenticeships • Most interns receive an offer because they get real world experience working in a high traffic distributed environment (1) • Hands on experience- real world experience will drive interest(2)	3
Materials • Tool realtors need to know how to innovate systems/materials by distinguishing difference in parallel computing vs distributed computing (2)	3

• Book on PDC with chapters including GPU (1)	
Other -to some extent every project requires some type of PDC	2

Question 2 (Workshop 3)

Considering the needs identified, what can be done better to meet them?

Responses	Frequency
Students initiative/projects/exposure • Students capstone projects (8) • Work with large real life data sets (4) • Students projects, giving them buggy programs, teaching how to identify (2)	20
Industry partnerships/release materials/collaborations • Industry and academia play a role in working together to fill gap in education (5) • Needs to release publicly accessible datasets that are representative of problems they are tackling on a day to day basis (4) • Industry doing reviews of final projects (2)	16
Curriculum development • Introduce PDC concepts in first year of CS (4) • Adding PDC to data structures and algorithms class (4) • Old fashion curriculum needs entire update (2)	16
Materials needed/accessibility • Update teaching material from 1980 to 2020 to drive PDC knowledge (3) • Develop teaching material/interactive material such as YouTube videos (2) • Datasets are not the only component, add labs and practical problems for learning material (1)	10
Internships/apprenticeship • Students gain real world knowledge through internships (5) • Hands on experience (1) • Summer internship and job training (1)	7
Workshops/ training • Individualized training to broaden participation and diversity (2) • Train faculty/students PDC (1) • Training on real world problems (2)	5
Programming Languages • Real world programming languages/techniques critically important (2)	5

• Focus on teaching PDC is C++ and java but it needs to be functional language like Scala or python (2) • Diversity of languages (1)	
Institution size/contribution/initiative • Institution plays a role in teaching students because efficiency is critical to give hands on experience (1) • New ways of teaching, more individualized (2) • Speak to large groups of CS students to develop material that would work specifically for them to learn best (1)	4
Companies/Businesses/ Organizations • Google puts their SW engineers go through a six month-one year engineering residency program to train them in PDC and infrastructure (2) • Some organizations can't train employees, exposure before is important (1)	3
Employers • Need students who have 3-5 programming languages (1)	1
Other • For the cloud space, it is fundamental to understand working with asynchronous data (1) • Difference between developers and users of libraries (1) • Difference between parallel programming and distributed programming (1)	3

Question 3 (Workshop 3)

What are the leverage points through which non-academic players can influence and help the academic community to make this major change in the curriculum?

Responses	Frequency
Industry partnership/support/collaboration/release of material	20
Access to students initiative/projects/exposure	10
Institution size/contribution/ initiative	7
Faculty initiative/support/teaching	7
Make available internships/apprenticeship	6
Provide/make accessible needed materials	6
Encourage diversity of programming languages	5
Provide access to platforms/one common platform	4

Help with curriculum development	3
Workshop/training	3

Question 4 (Workshop 3)

How could an institute be of use to facilitate and coordinate such synergistic activities?

Responses	Frequency
Institute can arrange industry partnership/collaboration/release of materials	22
Institution coordinator ● Host industry speakers (3) ● Curate course material to teach PDC (2) ● Lack of homogeneity across academic institutions (1) ● Role of institute: relationship coordinator with research labs and academia, data holder (3) ● Library of real world problems (1) ● Can give out certifications (1) ● Could provide advice on how to market jobs (1) ● Serve as clearing house (5) ● Formulate policies and frameworks (1) ● Institute can CS curriculum to teach PDC from day one (1)	20
Lead curriculum development	9
Manage repository materials resources	6
Marketing	5
Coordinate faculty sabbaticals	4
Organizing students projects/events	3
Offer internships/apprenticeships	2
Other	5

Designing the PDC Institute: Goals, Strategies, and Sample Activities

The workshop participants worked on updating our initial input at all levels – goals, strategies, and activities – through various sessions. Their updates and suggestions are shown in **blue shades.**

Format of information below

– **Top Level: Stakeholder group**
  - ○ First level are shared *Goals* between constituencies and the future PDC Institute.
    - ▪ Second level are *Strategies* for the PDC institute to address the goal
      - ● Third level are *Activities* which the institute may undertake to serve the given goal and strategy

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Stakeholder Constituencies –
- Students
- Faculty
- Department and Administrators
- Industry
- Govt Labs
- Authors/Publishers
- Professional Societies
- Federal funding agencies
- Related PDC and CS Education Projects
- International Educational Agencies

- **Students:**
  - ○ All computing students (e.g., CS, CE, Computational Sc, Software Engineering, IT? (See ACM's definition of the field for subdisciplines)) have foundational PDC knowledge, skills, familiarity with applications, and disposition[*], and pathway for specialization – based on local context

    - ▪ Curriculum guidelines updated periodically
      - • Holding regular competency meetings with faculty
      - • Institute leads yearly or bi-yearly meetings to review and update guidelines
      - • Measuring pedagogical effectiveness

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[*] From CC 2020 (pg. 80): "Success is knowledge skillfully applied characterized by dispositions that instill the practitioner's actions with value. The intertwining dimensions of competency (knowledge, skills, and dispositions) offer a comprehensive vocabulary with which to describe a curriculum that enfolds the objectives of learning natural to the teacher, the student, and the respective profession that the educational enterprise aspires to serve."

- Provide exemplar curriculum and textbook to schools for adoption
- Advocate for faculty membership on committees that set curriculum guidelines
- Present in terms of CC2020 Competencies
- Encounter PDC early and throughout the curriculum (develop appropriate **mental model(s)** to think about PDC - as an addition to "computational thinking": able to recognize potential parallelism issues (and some idea of how to solve it), familiar with pervasive themes (locality, races….), aware of the nuance that is required to use it)
  - Design curriculum as a "package" (specifies dependencies, has content)
  - Provide assessment of student skills and possible additional background materials
  - Develop ready to adopt hands on modules on PDC topics and concepts that faculty can adopt for their classes
  - Train faculty on PDC, PDC, adoption and pedagogy
  - Develop materials with different applications to make them accessible to different students
  - Clearly identify background and prerequisites for lessons and provide companion tutorials
  - Encounter PDC skills in internship and research settings
  - Develop spectrum of computer science for presentation so faculty can describe the field which includes PDC
  - Develop snippets for insertion into courses that provide simple examples of PDC
  - Suggest a course 'Introduction to Computer Science' that would include PDC
  - Provide integratable modules that can be plugged in to courses across the curriculum for faculty with little to no PDC knowledge
  - organize/fund training workshop for faculty who want to learn about PDC
  - organize/fund bringing non PDC experts to PDC technical conferences
- Actions informed by pedagogical research
  - Make the pedagogical research on PDC available to students via a web portal and encourage faculty to explain it to students
  - Develop set of evidence-based "best practice" guidelines for PDC activities
  - Define set of dispositions for PDC
- Student friendly, consistent programming language, tools, environment
  - Integrated book & realistic/industry relevant tools (low pain to install/use)
  - Interactive e-books with embedded exercises and visualizations.
  - Students learning a single programming language is not helpful - how do we encourage a set of languages (C, Java, FORTRAN, etc.) to help them build a tool kit and understand that different tools work in different situations?
  - Facilitate (funding) development tools (such OpenMP binds for Java and Python)
  - Good way to illustrate importance of locality of data and computation
- Think of PDC as a natural element of computation and understand its relationship to other aspects of computing/courses.
  - Illustrate wide applications of PDC

- Facilitate seminars by industry and lab to illustrate applications in for example, modeling and simulation, bioinformatics, AI, …
- Provide listing of industry and lab PDC related internship and REU opportunities.
- Survey the community to identify easy to understand HPC applications
- Sponsor HPC expert/PDC-education expert to develop kiosk version of applications
- Curate easy-to-find kiosk and HPC assignments to use in early CS courses
- Create a "Why PDC?" video showing its applications to a variety of fields, that faculty could show / students could view to motivate PDC
  - Put PDC in the context of problems that are interesting to the students' majors
    - Build a set of computer science problems from a spectrum of industries and regularly update those problems
    - Curate a set of exemplars from various application areas that are of interest to students across different majors, with different backgrounds, including teaching materials such as lecture notes, videos, programming assignments, etc.
  - Incorporate PDC in early/core courses and advanced courses (across the curriculum)
  - Develop and curate resources to enable PDC learning
  (e.g., white paper, wiki, video, YouTube channel, khan academy for PDC, stack overflow - staffed, seminars)
    - Develop self-contained modules to use in blended learning
    - Provide resources for curation of virtual learning resources, including help in rich-content like audio and video tutorials - editing, Closed-Captions from video etc. These things are time consuming and need a lot of effort to easily convey key concepts using illustrations or viz.
    - Offer counterpoints and discussions about propaganda and marketing of some popular software and "magic bullets"
    - Fund content creator to enter their content in well tagged databases for easy retrieval
    - Identify "missing materials"
- Be motivated to learn PDC skills (Intrinsic, Extrinsic)
  - Provide incentives - immediate and both tangible and intangible long term
    - Students should get academic credit for participation in experiential learning and some activities listed below as only being "informal"
    - Show interview questions that contain PDC topics
    - Provide expert talk akin to ACM's distinguished speaker that demonstrates why PDC is important
  - Motivate students to take up PDC by meeting them where they are most interested (e.g.: most CS students these days prefer to study ML; can we pitch PDC as a domain that has many problems that can be solved using ML?).
    - Reach out to popular technical YouTube channels to organize interview of PDC experts

- Understand the emerging science fields, predict directions that are likely to be key domains where PDC will play a key role, and are also of interest to the student population due to job growth and marketability
- Offer more varied examples and problems, framed in many existing sciences, especially outside CS and CE. Consider humanities, social science, and other diverse subjects
- Fund REU type projects where students can develop prototype solutions that apply to social problems
- Provide motivating examples
  - Introduce PDC as a useful thought process, then introduce problems that are of the size that makes students understand the practical implications of PDC. Understanding scale is hard - powers of 10. For example, a million is much closer to zero than a Billion, though they are successive big measures and so on.
  - Create online colloquium series of talks about cool things people are doing with PDC (can also include ads for positions, conferences, opportunities, etc.)
- Promote experiential learning
  - Internships, REUs, Career, Placement, etc.
  - Connect industry opportunities with wide variety of institutions
  - Provide compendium and review of self-directed tutorials
- Create opportunities for Informal learning
  - Hackathons in partnership with industry
    - (e.g., Intel, Argonne National Lab, and CERN cosponsored a coding challenge around heterogeneous parallel computing: https://www.codeproject.com/script/Contests/View.aspx?cid=1098, the cash and internship prizes attracted a lot of students to the competition), include social relevance in the contest judging criteria
  - Make online resources more available
  - Awards and competitions
  - Cluster competitions (making sure it's not a battle of the budgets)
  - Boot camps related to PDC topics
  - Create online colloquium series of talks about cool things people are doing with PDC
- Provide certifications for students (Tag this in with existing certificates/minors/etc. That already exists - maybe as an extension?)
  - Introduce option/concentration on PDC/HPC in departments, so that students are encouraged to take related courses and have this in their certificates.
  - The institute could develop criteria for students to earn a PDC certificate by meeting some course requirements (at their institution) plus other activities such as REUs, internships, competitions, and items covered elsewhere
  - Encourage professional societies to award such certifications
- Engender intrinsic motivations
  - Faculty enthusiasm/research, Peachy assignments, societally impactful, real-world problems, exciting tools
  - Pipeline for HS, Middle school

- o Develop PDS activities for middle and HS students (summer programs, in class, hackathons, etc.) https://www.ohiocyberrangeinstitute.org/education
- o * Not sure if the SaTC NSF grant covers this, but I know it does for cyber security through their EDU designation. Need something similar to help develop this
- o Joy of making a complex program run faster (than their classmates)
  - Group-related activities to work on a current topic of concern (e.g., in the past year or so, COVID modeling)
- ▪ Promote job opportunities and career paths - articulation
  - Invite people from industry to give seminars on HPC/PDC
  - Create a directory of opportunities? Resume bank? (Lots to maintain if we go this direction)
- ▪ Expose pervasiveness of PDC
  - Start PDC club or such student organization to motivate students
  - Have PDC faculty mentor data science organization
  - Organize hackathons with PDC emphasis
- ▪ Start PDC club or such student organization to motivate students
- ▪ Modeling and simulating highly parallel natural world, including brain
- ▪ Understanding of job prospects and pervasiveness of PDC concepts across a variety of domains (AI/ML based inference, data-analysis, simulations and modelling etc.)
  - Taking up projects involving application of more trending domains (like applied ML) to PDC can help get more students and engineers involved in PDC
- ▪ Bridge the gap to industry jobs
  - Be ready for technical interviews that include PDC questions
  - Smooth and effective transition from academic world to real world
  - Be able to port knowledge from the technology learnt in class to the technology used in the job you end up in
  - Be able to deploy PDC tool to solve real problems (used something on a project)
  - Be able to use $COOLTECHNOLOGYOFTHEYEAR
  - Get more practical hands-on training in PDC.
  - Make the students aware of how PDC can make them more marketable in the job market
  - Make research more accessible to undergraduates (e.g.: through more easily digestible articles in journals, IEEE Spectrum, etc.).
- o Enhance diversity and inclusion of women and URMs
  - ▪ Encourage women and URM students in PDC education
    - Start and support affinity groups in CS, have them co-sponsor PDC events, speakers, etc.
    - PDC Student program events at conferences focusing on social justice issues
    - Have applications where PDC could be applied in social good kind of projects
    - Create opportunities for "non-CS" students to gain exposure to material to gain interest - article linked below mentions most populations outside the norm are drawn to computers based on relationships with instructor rather than long

term exposure (I think the article is
https://www.nationalacademies.org/news/2020/01/designing-learning-experiences-with-attention-to-students-backgrounds-can-attract-underrepresented-groups-to-computing)

- Provide special meet-a-professional kind of workshops/meetings/open-houses to encourage students from under-represented and underprivileged sections (schools, colleges, neighborhoods) to learn about PDC and opportunities. (Many times, I find that students have never heard of certain career paths).
  - HackHer for women
  - Recruit and include diverse teams in extracurricular PDC
    - May have some inter-department mentoring program to encourage junior minority students in this field, Girl's club etc.
    - Engage NCWIT /ACM-W to organize hackathon
  - Identifying real world relevant problems that need PDC can attract a more diverse set of students
    - More specifically applications in data science, machine learning, big data, cloud computing etc.
    - attend NCWIT/ACM-W meetings to identify "ambassadors" of PDC in these groups
    -

- **Faculty** – individual (both PDC and non-PDC): There is a sentiment to apply these points to reach across disciplines, application areas, constituencies, segments of society and geographic locations.
  - Be able to teach the PDC material
    - PDC training (including streamlined access to material developed outside the institute)
      - Faculty hackathons (sponsored by the center, industry or professional societies); can be under "Motivation" as well (see also "Distribute PDC Material" below)
      - Web-based tutorials, videos, workshops, hands-on exercises, etc.
    - Identify/provide access to well-tested tools, environments and course packages (course/topics exemplars - tested and rated based on experience); could also be part of the ecosystem.
      - Detailed syllabi, slides, assignments (including peachy), question/answer, textbook, evaluation methods
      - Staff for curation, high quality
    - Identify possibilities to incrementally augment existing courses with PDC topics
      - Where do curriculum topics fit in easily
      - Where can an exemplar or module be plugged in seamlessly
      - Identify and address competencies and dispositions that serve a good understanding of PDC (see CC 2020). Ensure that the level of "average" student is accounted for in specifying minimum competencies. Use industry input in specifying competencies.
      - Mentoring Support:
        - Faculty buddy
        - Industry mentor
        - Mentors from diverse academic settings

53

- o Distribute the PDC materials that faculty craft
  - ▪ Create communication channels to broadcast materials and maximize the broader impact of materials created by individual faculty (for instance nifty assignment)
  - ▪ Create workshop where "PDC materials" expert can train others
  - ▪ Venue for publication / academic credit for PDC tools, lessons using them, and experience reports related to their use
    - • Recognition from/by industry and univ administration for intellectual contribution of developing tool or effective teaching technique
- o Have access to ecosystems enabling support easy and natural teaching of PDC
  - ▪ Raise awareness of available educational resources
  - ▪ Provide learning support, including student-friendly and consistent language extensions, libraries, tools, hardware and software environments, teaching material, exemplars - may need to develop, collect, enhance, or otherwise prepare for use
    - • Create projects to go along with the theoretical aspects of PDC that will enable students to both learn and practice the skills in PDC
    - • Encourage industry engagement (including for teaching modules)
    - • Facilitate the adoption of real, big and relevant PDC problems that students can work on
  - ▪ Provide access to computing infrastructure (Cluster/cloud)
    - • Enable faculty teaching and student work on PDC activities
  - ▪ Question-answer Support
    - • forum/slack (guide to someone starting off)
    - • FAQs
- o Be motivated to teach PDC (including in courses not directly on a PDC topic); this motivation should ideally serve a wide spectrum of institutions
  - ▪ Generate curiosity
  - ▪ Incentivize faculty (including ideas that help faculty realize that PDC education can help their own research and benefit their students; see two bullets below)
    - • Provide seed grants
    - • Increase the available sabbatical opportunities in PDC for faculty
  - ▪ Generate student enthusiasm
    - • Provide information on PDC career paths and marketability
    - • Provide information on a variety of important real-world problems that need PDC for solutions (this can also provide teaching angles)
    - • Bring industry expertise into the classroom through talks
    - • Increase the available internships in PDC for students
  - ▪ Enable support and encouragement from chairs/deans
  - ▪ Provide letter of support of active members of the community for tenure/promotion
  - ▪ Increase faculty enthusiasm and tie to research interests
    - • Organize forums for publication, including workshops and special issues for intellectual contributions
    - • Identify and promote ways in which student research is/was facilitated by PDC
  - ▪ Promotion (by the center) of cool tools/lessons/ecosystem (across the curriculum, including in non-PDC courses)
    - • Articles, Books, Book-Chapters, special sessions, training, blogs
  - ▪ Identify PDC in everyday activities (encourage mental model conducive to thinking parallel and distributed)

- o Understanding the importance of PDC and its relationship to broader aspects of the curriculum and its interdisciplinary/pervasive impact
    - ▪ Recruit PDC champions, educate and inspire non-PDC faculty
        - • Outreach at PDC research conferences, focusing on the importance of broader aspects of curriculum
        - • Outreach at CS education conferences and education tracks at non-PDC research conferences, focusing on PDC awareness (e.g., SIGCSE TS, SIGARCH education track)
        - • Provide support for non-PDC faculty to attend relevant events such as supercomputing, EduPar, ...
    - ▪ Facilitate Broader participation
        - • streaming of events and remote collaboration
  - o Enhance diversity and inclusion of women and URMs
    - ▪ Reach out to MSIs, HBCUs, etc. with targeted PDC training
    - ▪ Provide real world problems that can be solved by PDC and that address the social concerns of URM
    - ▪ Make PDC computing resources available for education
    - ▪ Introduce ideas of social relevance to attract a broader audience
    - ▪ Emphasize computing for the common good
    - ▪ Gather statistics on diversity

- **Department chairs and Administrators** (dept/universities/system)

  - o Understanding the importance of teaching PDC and the need in industry and other constituencies
    - ▪ educate/do outreach through CRA/Snowbird/HBCU conferences
    - ▪ activity with group of chairs
  - o Be motivated to encourage adoption of PDC in the local curriculum and provide resources for the change
    - ▪ alumni, industry, state boards, system-wide administrators
    - ▪ industry letters/position papers
  - o Have resources and be able to provide incentives to faculty for going beyond faculty comfort zone
    - ▪ Center: seed/early adopter funds, certification of courses/curriculum, industry connections, hackathons, faculty training
    - ▪ Institutional incentives:
  - o Accreditation (ABET, etc.)
    - ▪ partnership with ABET/CSAB on minimum PDC skillsets, evaluator training
    - ▪ help CS/CE departments prepare for satisfying ABET's PDC curriculum requirements, training of faculty

- **Authors** (especially core courses)
  - o Understand the importance of weaving in PDC aspects of core topics
    - ▪ Outreach to traditionally non-PDC areas
  - o Institute directly contacts/motivates/supports authors
  - o Motivation to develop new editions that include PDC
    - ▪ Demonstrate instructors' need for PDC-infused content
    - ▪ Provide clear roadmap for update

- Certification of PDC curriculum coverage in a textbook
  - badge, award, competitions, reviews
- Promote PDC-relevant books
  - o Include relevant PDC concepts in textbooks on any CS topic
    - Provide expertise (example assignments, PDC researchers to talk with, comments)
    - Provide incentive to make revision
    - CDER book project (content and template for PDC material)
  - o Be aware of common approaches and best practices for teaching PDC
    - Provide guidance
      - Share Early Adopter/Trainees' materials and contents of Edu* workshops

- **Publishers**
  - o Understanding the importance of PDC in the market
    - education/outreach
    - surveys
  - o Understanding value to depts of PDC content coverage within (traditionally) non-pdc courses
  - o Motivation to encourage authors to include PDC
    - hear from the book adopters, surveys
    - Incentivize authors to write PDC-relevant books/chapters
  - o Able to find authors and textbook reviewers
    - consulting
    - connecting
  - o Expand kinds of material published
    - addendum to books (could be different authors)
    - Create interactive texts with peachy problems (motivated, interesting, impactful) (t4)
    - Topical materials (t4)
  - o (Motivate to) Publish/support PDC-ed tools & platforms.
  - o Be informed about curriculum guidelines/standards
    - exemplars/chapters for CS1/CS2/DS courses

- **Industry** –
  - o Reduce PDC onboarding/training cost and time, and to make training more effective
    - Students and graduates prepared for PDC-related jobs & internships
      - coursework and projects related to PDC in curriculum
      - Facilitate Capstone projects as a connection between students and industry
      - Externships to help train students for industry positions
      - Provide guidelines on curriculum that is relevant to the industry at the time
      - Industries organizing specific PDC related career fair/sessions
    - Deposit teaching materials into a courseware repository that is maintained, curated, and indexed by the Institute
    - Interface with the Institute to provide ill defined, partially broken problems
    - Enable students to understand that the real world computing systems are made of mismatched technologies and be able to live with that
    - Have student use and manipulate multiple systems to get them to understand that technologies change over time and it is not a big deal
  - o Have a point of contact on providing training materials for their new technologies

- Understand opportunity for greater role in moving the curriculum forward
  - industry lobbying efforts with legislature, boards of education, higher education commissions, etc., for periodic change in community college curriculum
    - How would a company formulate issues for use in lobbying?
    - The Institute can facilitate lobbying on behalf of the industry.
    - The center may need to get the ball rolling for this because medium and small businesses don't "lobby" much
  - organize key industry players to collaboratively call for major curriculum changes
    - CACM/IEEE Computer position paper
    - Special Issues on PDC education
  - Discuss /share the PDC skills they need
  - Understand high level requirements necessary to implement PDC, like security, cluster management, etc.
- Establishing better partnership with academia
  - outreach to industries
    - How to formulate NSF or other grant submissions to support industry interactions with the institute?
    - Institute can provide PDC expertise to the groups/boards who set standards to specific up-and-coming technologies (e.g., web assembly)
    - Seek advice on enhancing HPC/PDC in the curriculum
    - Provide "intern" opportunities for professors with the aim of them understanding industry needs
    - If industry doesn't take well to an employee known to leave in a set time (as faculty would), perhaps regularly scheduled knowledge transfer sessions or jointly developed projects would be appropriate: consider open source
    - Establish student developer clubs in collaboration with industry (e.g., Google developer club); PDC-focused
  - Promote internships
  - Consider coop programs
  - Seminars at universities
  - Faculty seminars (including 1 or 2 day workshops) at industries
  - industry advisory board
    - center level (institute)
    - department level
    - Review and endorse competencies proposed by the institute
    - Joint faculty appointments where faculty bring back industry reviews to academic institution
    - Review of current industry "hard" computer science problems
    - The institute could Invite HPC/PDC guest speakers from the industry to particular events
  - Establishing Center of Excellence in teaching PDC (e.g., NVIDIA)
  - establishing student developer clubs (e.g., Google developer clubs); PDC-focused
  - Industry-academic internships
    - Industry should provide more internships to students
    - Increase faculty-in-residence or sabbatical programs
    - Institute web page as clearing house for students to get to internship information at different company web sites
  - Improve collaboration, perhaps through the use of open source software

- Establishing better partnership with academia, and provide real-world examples where they use PDC
- Share data sets, system descriptions, etc. so academia can know what real problems are like
- Understand significance of including PDC (and [horizontal] scalability) in job advertisements (including use of appropriate terminology). This also helps in highlighting the marketability and job prospects of PDC - which can be a motivation for students.
  - raising awareness
    - Define terminology for use in advertisements so both students and employers are speaking the same language
    - Invited industry keynotes on PDC topics. E.g.: Amin Vahdat's talk at SIGCOMM on "Coming of Age in the Fifth Epoch of Distributed Computing: The Power of Sustained Exponential Growth"
    - Change the mindset of those already employed in industry towards PDC thinking in describing their projects in job advertisements, to interns, and to employees in general
    - Capstones and open houses
  - include PDC skillsets into postings
    - survey of job postings
    - Careers section defining job descriptions with PDC skills
    - employ PDC or HPC keyword into posting (just as ML is employed)
    - conceptual understanding of fundamentals of PDC, even for data-driven services-based architectures
    - Highlight industry projects to motivate students
    - use PDC terminology instead of just the problem being solved
    - Work with industry groups to explicitly call out requirements/preferences for PDC skills in job postings
    - Consider whether "scalability" in job adverts necessitates PDC instruction
  - Might have to offer training programs for new hires
- Understand importance of providing resources for PDC education, internship opportunities for students and on-the-hands training in sophisticated PDC tools
  - industry funding, experts, instructors, etc., for curriculum update (at center level or system/department level) which is not specific to individual industries
    - Contribution of real datasets and problems to use as exemplars in teaching PDC
    - Provide faculty training (specialized tools; DLI model from NVIDIA)
    - Center/Institute interfacing with industries to donate Hardware (e.g., GPUs)
    - Interface with industry to write grant proposals to support industry interactions
    - Facilitate setting up centers and grants to enable faculty and students to pursue research in PDC.
    - Nudge industry partners to provide real-world data sets and representative infrastructure to enable PDC students to do hands-on projects to apply the skills that they learn in the class.
    - This seems nearly impossible to accomplish; the motivation for an industry partner is unclear unless reward is coming through a different method (e.g., internship pipeline)
    - Explanations of existing processes into which new graduates would be involved if they started with a company
    - Engage industry to provide training to faculty (specific tools)

- Should find a way to incentivize industry. Trained students are better than untrained students that have to be trained on their dime and time. But how do we get the private sector do this overcoming their competition and IP related constraints
  - Encourage industry to provide publishers with PDC activities & tools (that they can resell) suitable for integration into a variety of CS textbooks (e.g., algorithms).
    - Ensure that the work that industry would do would actually get adopted and publicized
- Increase opportunities for collaboration with academic research in PDC and PDC education through joint projects and industry funded research involving PDC.
  - Guest lectures by faculty, or by industry experts would both be well received
  - Collaboration on software projects may also make great sense
  - Adjunct professorships may also be an option
  - Act as a facilitator helping connect industry representatives with PDC faculties at institutions
  - Create targeted working groups/task force for particular action
  - should include examples of PDC problems the industry folks are actually dealing with
  - Topics for industry personnel to build curriculum lectures on?
    - Building lectures may be a bit of a reach, not for time commitment as much as quality: these folks are not professors for a reason. But collaboration leaves much room for improvement
  - Host virtual industry interactions with university classes?
    - These may not need to be sponsored by whole companies; teams would often be willing to assist if the company merely allowed it
  - Enable research internship and co-op opportunities for students (not just PhD students, but also provide more research exposure to under-grad and master's students).
  - Clearinghouse/Facilitator by advertising needs and act as a conduit to introduce educators and industry leaders
  - Funding/enabling adjunct appts so that industry perspective & skills are taught
  - Fund development of lessons & tools that introduce PDC into classes
- Collaborate with academia on establishing minimum student competencies (knowledge, skills, & dispositions)
  - Advisory committee to review and recommend suggested competencies
  - Establish regular meetings with industry to define competencies
  - Host meetings with specific industry groups so that students understand which industry segments are contributing which minimums
  - Define concepts, mental models, tools and libraries that define a basic education in PDC.
  - Structure it into various levels of competence / PDC educational levels.
- Sharing real-world datasets that could be used for PDC education to create projects in PDC that are representative of practical systems and deployments
- Provide resources for PDC courses.
- Involve industry as multi-level financial supporters (diamond/platinum/etc.) for the institute

- **Professional Societies**
  - Understand the importance of PDC in academia and industry
    - Outreach to professional societies
      - Send representatives of the institute to professional society organizational meetings (e.g., ABET and TCPP annual meetings)

- Work with their curricular bodies (e.g., ACM/IEEE CS curricula task force)
  - Curriculum guidelines: Subject matter expert for societies (this is facilitated by center)
  - Also arrange for PDC experts in academia or industry to speak at University ACM Chapter meetings to promote learning PDC and highlight opportunities
  - Identify and collaborate with key personnel for championing PDC
    - Work with IEEE TCPP, IEEE TCDP, IEEE TCCA, ACM SIGHPC, NCWIT, SIAM/CS, SIAM CSE, etc.
  - Identify career pathways, mentor students
- Motivate incorporation of PDC in curricula (ACM, IEEE, SIAM, International Societies - Japan/Australia, American Society for Engineering Education (ASEE), domain science societies.)
  - Document/Create reasons for PDC inclusion
  - Sensitize to the PDC curriculum issues
    - Publicize PDC curriculum initiative
    - Write more articles in magazines
    - Develop outreach materials to highlight the necessity of PDC
  - Demonstrate value of incorporating PDC for students/faculty members
    - Develop and maintain archive of success stories
    - Create curated list of internship and job directories
    - Support faculty to attend conferences to discuss PDC education
  - Synchronize the PDC effort across multiple professional societies to prevent duplicated efforts
- Organize PDC related hackathon (facilitate reuse of events that were successful somewhere else)
- Develop PDC-related curriculum guidelines and foster adoption
  - Outreach to various societies and curriculum boards
    - E.g., PDC infusion into first year programming course(s) for ASEE; Computational Chem
    - Work with their curricular bodies (e.g., ACM/IEEE CS curricula task force)
    - Push for PDC competencies in curricular guidelines, especially in the CS202X for computer science that ACM, IEEE-CS and AAAI are working on
    - Sponsor events for students (hackathons, modeling challenges)
    - Encourage member feedback to publishers on adding PDC content to books (based on curriculum guidelines)
- Enhance diversity (Women and URM) and inclusion across the members and leadership of professional communities
- Recognize the cross-cutting nature of PDC
- Provide informal learning strategies through student chapters, conferences, technical committees
  - Interact with these entities to incorporate PDc related activities
    - Visiting speakers, industry partners
  - organize/synchronize PDC-inspired hackathon,
  - Provide PDC-expert that can visit student chapters
- Institute facilitates the connection of resources (for example tools) across constituencies (for example govt. Labs and the industry) - broad view of resources, not just narrow by each constituency
- Help organize keynote talks from industry leaders; get industry presentations to talk about PDC applications in the industry.

- o Provide more conference tracks for PDC presentations (at conferences like SIGCSE, the tracks are driven by the papers that are submitted + accepted, so maybe this really means to provide incentives for faculty to submit more PDC papers to conferences?)
  - o Provide more tracks within existing conferences that address HPC/PDC.
  - o Define and publicize careers that require PDC more precisely
  - o Include PDC in work of student chapters, education chapters (SIGCSE, SIGHPC Education)
  - o Provide a set of experts that can visit ACM student chapters to provide local training.
  - o Create spaces for student chapters to discuss/exchange ideas related to their PDC activities
  - o Provide resources for PDC instruction (e.g., IEEE parallel computing effort)
  - o Provide informal learning strategies through student chapters, conferences, technical committees
    - ▪ Interact with these entities to incorporate PDC related activities
    - ▪ organize/synchronize PDC-inspired hackathon,
    - ▪ Provide PDC-expert that can visit student chapters
  - o Create PDC related awards for student thesis and projects, and hackathons alongside professional meetings.

- **Accreditation Bodies** (ABET/CSAB, etc.)
  - o Developing PDC-related curriculum guidelines and foster enactment
    - ▪ Collaborate with curricular task forces on common PDC core
      - • Collaboratively develop common PDC core for ABET/CSAB
      - • Seems too soon for PDC special program criteria
  - o Understanding of what it means to include PDC in a curriculum
    - ▪ Spread awareness of existing resources and ability to avoid large-scale and disruptive changes while adopting PDC
      - • Provide examples of courses modified for adoption
      - • Make an "exposure" of HPC/PDC in all computing general criteria
    - ▪ Provide rationale for PDC for all computing, not just CS
    - ▪ Provide guidance to what is a minimum competency criterion for PDC
  - o Develop PDC-trained evaluators
    - ▪ Provide training to evaluate PDC coverage
      - • Workshops, sessions at accreditation-related conferences for evaluators
      - • Help develop online training material for evaluators
      - • Provide guidance on a minimum competency criterion for PDC
    - ▪ Make evaluators aware of PDC curriculum
      - • Collaborate on PDC curriculum refinement and reviews
      - • Teach and motivate evaluators to motivate (criticize?) depts to include PDC holistically
  - o Accreditation: PDC needed in all "computing disciplines" (Computer Engg.: ABET Engineering does not recognize PDC explicitly even for Computer Engineering while ABET Computing recognizes PDC for only Computer Science)
  - o Make ABET strengthen accreditation criteria to include specific PDC knowledge/competencies and their relevance in modern computing curricula (ABET currently requires all students to be "exposed to" PDC, which is extremely vague).
  - o Create a standards body that can establish the minimum standards for PDC concepts.
  - o Provide informal learning strategies through student chapters, conferences, technical committees
    - ▪ Interact with these entities to incorporate PDC related activities

- ▪ organize/synchronize PDC-inspired hackathon,
- ▪ Provide PDC-expert that can visit student chapters

- **Govt Labs**
  - o Have the ability to hire students for internships/jobs involving PDC
    - ▪ Students and graduates prepared for PDC-related jobs & internships
      - • coursework and projects related to PDC in curriculum
      - • Clearinghouse for opportunities
      - • Make universities (e.g., undergraduates planning to attend graduate school) aware of opportunities like the DOE Computational Science Graduate Fellowship (CSGF). This gives support at least as good as an NSF graduate fellowship and has a required summer internship at a national lab (paid for by DOE, so very appealing to lab researchers, free to them)
  - o Establishing better partnerships with academia and provide better access to PDC resources and material developed at the lab; and being exposed to the student body and their work
    - ▪ Establish channels of communication to identify need, challenges and successes
      - • Forum to bring together researchers from different constituencies
      - • Clearinghouse of tools/libraries, computations resources
      - • Facilitate lab personnel as guest (or course) lecturers (speakers, lecturers bureau)
      - • Facilitate lab campus tours for nearby colleges so students can be exposed to PDC resources and usage
    - ▪ Foster support for lab personnel to go "intern" in a university in support of PDC research/education
  - o Motivation to work with educators in developing libraries and tools that are suitable for student/academic research use
    - ▪ University-Lab Research/Education Collaboration
      - • e.g., work with ORISE personnel, lab directors, etc.
      - • Co-develop/teach PDC-related courses and modules
      - • Reach out to DOE leaders for buy in: Labs leadership would have to value this (for performance evaluation) and funding sources would have to support it.
    - ▪ Foster adoption of lib/tools by academia
      - • Relevant to specific type of industries
      - • Review and promote training modules produced by labs and HPC centers
      - • Encourage updating of online training materials
      - • Student internships are a way to cross-pollinate ideas, bring up knowledge-gaps and tools/skill gaps, and build tools/libs usage experience. Some labs also allow graduate students to do thesis parts in the labs - i.e. they work with academic advisor at univ and also have a lab advisor. (DOE has a SULI program for undergrads and also individual labs have strong academic / educational programs that pairs students with lab staff).
  - o Enhance diversity (Women and URM) and inclusion across the members and leadership of professional communities.
  - o Recognize the cross-cutting nature of PDC.

- **Federal funding agencies**
  - o Development of domestic workforce with PDC training
    - ▪ Foster PDC educational community
      - • create center-affiliates, PDC champions and ecosystem who develop educational/training projects
      - • collaborate with related projects
      - • Submit more HPC/PDC grant proposals
      - • Require grant recipients to make their courseware publicly available
    - ▪ Work with Program Directors on white papers, panels, workshops to help create funding priorities and programs
      - • Federal agencies outside of NSF may be interested more in funding only domain specific research, so PDC may need to be distilled out and developed as a cross cutting need across their funding portfolio.
    - ▪ Increase efficiency of funding PDC training efforts
    - ▪ Disseminate PDC-related funding priorities
      - • Clearinghouse of funding opportunities
        - o Or like WikiCFP
        - o https://www.fedconnect.net/fedconnect also acts like a clearing house and sends emails with FOA/RFI
    - ▪ Provide resources for PDC education
      - • obtain funding for developing tools, courseware, computational resources, awards, seed funding, etc.
      - • facilitate distributed REU sites
    - ▪ Provide greater promotion and funding for HPC/PDC for non-computing fields (physics, engineering, etc.)
    - ▪ Provide extra funding for PDC workshops and training
  - o Fund larger efforts by multiple groups toward a more transformative common goal
  - o Have a backbone of experts to serve on panels/review boards
  - o Prepare students and faculty for research and training in PDC pedagogy
    - ▪ Explore relevant funding opportunities
      - • Coordinate with agencies to identify funding
      - • Funding opportunities to promote PDC education in the K-12 curriculum
      - • Publicize the funding opportunities of the institute members that may not appear relevant at first
    - ▪ Suggest funding of lab/academia collaboration
  - o Increased diversity in PDC workforce
    - ▪ Connect funding sources with organizations promoting diversity
      - • NCWIT, Girls who Code, etc.
    - ▪ Must ensure there is equity … there is no point offering after-school programs, hackathons, etc. if all students cannot participate
  - o NSF funded resources targeted at education uses.
  - o Sponsor grants to fund PDC-activities even in the early stages of K-12 curricula so that students can understand the intuitions underlying PDC even at the K-5 level. Approaches to do this have been used in cybersecurity
  - o Provide incentives to create career paths that require PDC skills

- **Relevant PDC and CS Education Projects** (e.g., CS in Parallel)
  - o Collaboration, coordination, building on each other's work
    - ▪ facilitate regular communication and outreach
    - ▪ share resources
      - • Share index/reviews of available materials
    - ▪ Explicit coordination among efforts
      - • For each other CS Ed project, the Institute could appoint a person to act as a liaison between the Institute and that project
      - • Shared index or repository of different projects resources
      - • Institute could appoint liaisons to each PDC-Ed project
      - • Panel session at conferences/workshops (e.g., EduPar, EduHPC) where groups share current projects, needs, etc.)
      - • There are many parts in making these projects work. There is a need for a good idea, operationalize the idea, market it, and maintain it. The center could help identify experts that can enable these projects to work
    - ▪ Encouraging a common format
    - ▪ Have biannual meetings
    - ▪ Having a PDC education annual meeting would be great!
  - o Reducing the chance of duplicated effort between multiple PDC education projects
    - ▪ Some supervision by the institute to monitor such sites/projects
  - o Coordinate across different groups doing PDC education (teaching materials, curriculum guidelines, etc.)
  - o Foster communication between different projects; provide a central "clearinghouse" for access to PDC materials
  - o Curation of existing material to separate out the useful materials from the less than useful.
    - ▪ Better coordination of available resources to allow for curation to remove less useful material and to promote more...complete material
  - o Interoperability of the work
    - ▪ Regular communication
    - ▪ Better coordination of available resources to allow for curation to remove less useful material and to promote more...complete material
  - o Encourage cross-linking to each other's sites/materials, so that any educator visiting one site can easily find the others
    - ▪ Come up with a standard format to present PDC material for cross-linking and sharing.(good examples of formats are POGIL and csedresearch.org)
    - ▪ An alternative is a landing page that connects to all of them, with discussions of similarities and differences.
    - ▪ Encourage to license tools & lessons to publishers
  - o PDC Unplugged
  - o Regularly give relevant projects space to announce their recent accomplishments, future plans, and what they're looking for from the community (their Call for Participation) -- could also be an email newsletter

- **International educational agencies** (e.g., CDAC in India, Educational agencies in various countries, etc.)
  - o Effective international collaboration with relevant agencies
    - ▪ Foster worldwide PDC education community, addressing local constraints (computing resources, local requirements, etc.)
      - • Initiate regional Edu* workshops
      - • collaborate on curriculum development and refinement
      - • Have a CDER-worldwide membership that would perform interaction with local actors -International affiliates
      - • CDER could encourage US federal agency to develop joint calls with EU funding agency (or others)
      - • Continue discussions after workshops to build community
    - ▪ Enable more virtual conferences to foster easier international collaboration on PDC.
    - ▪ Involve industry partners with international presence to fund international efforts
    - ▪ Coordinate/use international campuses of US/NA universities
  - o Be able to reuse international efforts and adapt it to local context in PDC
    - ▪ And likewise provide inputs on new strategies that worked in a particular country/geography and which can then be adopted elsewhere.
    - ▪ A search mechanism to find PDC education research papers, curriculum, activities, etc., by region of the world and type of institution
  - o Know whether what they are currently doing needs to be adapted
  - o Shine internationally by showing that they are doing it right
  - o Tele-education in PDC (prerecorded lectures, problems, solutions, applications).
    - ▪ Open-courseware kind of strategy with online modules and workbooks
    - ▪ Enable virtual conferences to enable a broader participation.
  - o Share knowledge on curriculum
    - ▪ Share curriculum and also textbooks and tools across countries.
      - • Seek authors from diverse countries
    - ▪ Have a platform to share local best strategy
    - ▪ Collaborative platform
      - • There are several online/remote learning tools that have evolved during COVID which can be a cost effective way to accomplish this.
      - • Develop interactive online tools like Google Collab Books and Jupyter notebooks.
  - o Be able to reuse/adapt the work done by CDER in their local curriculum
    - ▪ And likewise provide inputs on new strategies that worked in a particular country/geography and which can then be adopted elsewhere.
    - ▪ A search mechanism to find PDC education research papers, curriculum, activities, etc., by region of the world and type of institution
  - o Democratize/enable more virtual participation in PDC conferences, competitions, hackathons, etc., to enable larger participation worldwide. E.g.: ACM Programming 2021.
  - o Conferences allow discussion of ideas, so create BOFs or workshops in conferences to discuss PDC concepts and coursework prescribed and followed by different countries/institutes/educational boards around the world (from high schools to colleges).
  - o Form international partnerships- something like an ITiCSE working group to hear what people are doing outside the US