2021 PICUP Virtual Capstone Conference Report

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PICUP

PARTNERSHIP FOR INTEGRATION OF COMPUTATION INTO UNDERGRADUATE PHYSICS

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I. Executive Summary

Using a computer to model, simulate, and analyze physical systems is central to the enterprise of physics. Physicists rely on computation to develop models of physical systems, to run experiments, and to analyze the resulting data from these theoretical and experimental endeavors. Computation is used widely in physics in both industrial and academic settings. How we understand the physical world is increasingly being shaped by our use of computation in physics. As computation has become central to physics, educators must reflect on the role of computation in their students' physics education.

We report on the activities of the Partnership for the Integration of Computation in Undergraduate Physics (PICUP, gopicup.org)—an organization devoted to supporting a community of physics educators who are working to incorporate computational physics learning opportunities into their classrooms. Started in 2007, PICUP worked over several years with small amounts of external support to build up capacity and develop strategies. In 2016, five members of PICUP were awarded a set of National Science Foundation (NSF) grants to grow PICUP's nascent community. Over the last 6 years, PICUP has developed into a much larger community of physics educators who share a variety of professional development resources. As of this writing, PICUP claims 1442 members across the world who are supported by a growing, virtual community of physics educators.

To celebrate the end of this initial NSF support, we hosted (virtual due to COVID-19) the 2021 PICUP Capstone Conference from August 11th to August 13th. 123 physics educators joined, over ZOOM, a series of plenaries, presentation sessions, workshops, and discussions covering the history, achievements, and lessons learned from the last six years of PICUP work. In this report, we organize, summarize, and discuss the ideas and conversations from the Capstone Conference.

This conference report aims to:

- Provide a record of the efforts of a large, disciplinary-specific, community-driven effort to integrate computation into science courses,
- Summarize important ideas and lessons from the PICUP community for the broader physics educator community, and
- Collect the many efforts to introduce computation into physics coursework (as of the writing of this report) in one document.

This report is organized as follows. We first describe the PICUP project in detail including a timeline of events since support was received from NSF. We then summarize the current state of computational integration into physics courses—reaching back into history as well as presenting the current state. We then discuss several emergent themes that appeared across the conference presentations and discussion.

As part of attending this conference, some PICUP members provided narrative histories of their work to integrate computation at their home institutions. We summarize these cases before providing the conference evaluation based on feedback from the participants. We finish with recommendations for future directions that stemmed from discussions at the conference. Appendices follow the main report and include resources for adopters, schedules for workshops, and details about the Capstone Conference, including presentation abstracts.

II. Project Background

The 2021 PICUP Virtual Capstone Conference is the culmination of a 6-year, $1.2 million, NSF-funded project that began in November 2015. The American Association of Physics Teachers (AAPT), Bradley University, Michigan State University, the University of St. Thomas, and Francis-Marion University received awards under the title "Collaborative Research: Integrating Computation into Undergraduate Physics—A Faculty Development Approach to Community Transformation." The main goals of the project as stated in the proposal were:

1. To establish and maintain a uniquely usable and effective repository of educational materials that lower barriers to integrating computation into undergraduate physics courses.
2. To foster the integration of computation into the undergraduate physics curriculum on a national scale through (i) engaging physics faculty in a variety of interest building workshops at national and regional American Physical Society (APS) and American Association of Physics Teachers (AAPT) meetings, (ii) conducting a large scale week-long faculty development workshop each summer of the project period, and (iii) supporting workshop participants and other interested persons through post-workshop online programs and activities.
3. To build a community of like-minded physics faculty who are dedicated to integrating computation into undergraduate physics, towards the eventual creation of a formal organization.
4. To understand the factors surrounding how faculty choose to adopt, adapt, or abandon changes to their teaching using computational instruction as the exemplar.

Each of these goals was addressed as follows:

1. Creation of an online repository, gopicup.org. This repository contains peer-reviewed Exercise Sets, a place for faculty to share computational activities (Faculty Commons), Resources for integrating computation, and a list of past and upcoming Events. The Community tab highlights a member of the month and connects to the PICUP's Slack channel. As of 21 July 2021, there were 1,405 verified educators registered to access the site.

2. (i) Half-day and full-day workshops were offered in a variety of venues listed below in the "Project Timeline." These included workshops at national and regional meetings of the APS and AAPT, regional workshops at selected locations, institutional workshops, and virtual workshops. Workshops marked with * represent those that were offered as part of the associated NSF-funded project "Collaborative Research: Fostering integration of computational practices into physics courses, a local communities approach." Project principal investigators also gave invited and contributed talks, presented posters, and organized PICUP-related sessions at APS and AAPT national and regional meetings.

A big change in the project plan was the pandemic-induced delay of the PICUP Capstone Conference originally scheduled for Summer 2020. Instead, virtual workshops and a virtual conference were organized that summer. The "PICUP Virtual Conference: Tips, Tricks, and Best Practices for Teaching Physics Online" emphasized teaching physics online to address the pandemic-related challenges facing not only computational physics education, but all of undergraduate education. These virtual offerings were successful—helping PICUP to reach a broader audience. A virtual workshop was also offered in Summer 2021, and other virtual offerings will be part of PICUP plans going forward.

(ii) Four week-long faculty development and community-building workshops (FDWs) took place during the summers of 2016–2019 at the University of Wisconsin–River Falls. Originally proposed for 24 participants, increasing interest and careful budgeting allowed the project to host up to 70 faculty members with 11 coordinators, a project evaluator, and 5 principal investigators as staff at each FDW. The week's schedule for the 2019 FDW is included in Appendix A.

The 2018 and 2019 FDWs included a day-long "Computational Basics" boot camp experience that we offered the day before the week-long FDW formally began. The day-long bootcamp provided a basic introduction and/or refresher for faculty who did not have extensive experience with programming and numerical methods. The bootcamp helped participating faculty get up to speed with computational basics so that they were able to participate productively in the rest of the FDW.

In collaboration with the Advanced Laboratory Physics Association (ALPhA), the 2019 FDW also included a group of 10 faculty who participated in a hybrid workshop that combined the computational emphasis of the PICUP workshop with the experimental experience of ALPhA's immersion program. These 10 faculty members attended select sessions of the PICUP workshop and also spent time working on an advanced physics experiment with a mentor. This hybrid experience emphasized the integration of analytical theory, computation, and experiment. The initial assessment of the experiences of the participants and the workshop facilitators was very positive.

(iii) PICUP workshop participants received continuing support through several mechanisms: monthly webinars, a community of faculty in the PICUP Slack channel, further opportunities to attend workshops, and PICUP Stipends to Support Computation-Based Curricular Changes. This last program made 12 awards of $5,000 each to individual faculty or teams of faculty whose application effectively addressed barriers to integrating computation into the physics curriculum. Workshop participants were invited to get involved in the PICUP and many did, becoming workshop facilitators, organizers of online webinars, reviewers of exercise sets, editors of exercise sets, and organizers of sessions and report writers for the PICUP Capstone Conference.

3. In addition to the 1,405 verified educators that have registered on the PICUP website, 511 faculty members have joined the PICUP Slack channel. The Slack channel allows members to participate in discussions on particular topics, or to message each other directly. PICUP organized sessions at APS and AAPT meetings and PICUP online webinars and virtual conferences provide opportunities for members to network and share their work.

4. We have conducted research in several key areas to better understand how physics faculty choose to adopt (or not) computation and what factors might contribute to those outcomes. In particular we have:

- ***A.*** Conducted a national survey of physics faculty across the United States to understand the prevalence of computational instruction in physics departments (Caballero and Merner, 2018).
- ***B.*** Determined several factors that might contribute to adoption of computational instruction in physics departments (Young, Allen, Aiken, Henderson, and Caballero, 2019).
- ***C.*** Identified barriers to the adoption of computational instruction, which include several that are beyond those identified in the known literature of instructional change in physics (Leary, Irving, and Caballero, 2018).
- ***D.*** Followed PICUP workshop participants to understand how the broader PICUP community is developing (Irving and Caballero, 2017). This follow-up work is ongoing.

Project Timeline

Figure 1. A complete timeline of PICUP's efforts conducted under the NSF awards.

2016	1	2	3	4	5	6	7	8	9	10	11	12
Package Development and Organizational Workshop	Remote package development period					Package Development/ Organizational Workshop						
Half-day and Full-day Demonstration Workshops	AAPT Winter Meeting		APS March Meeting	APS April and AAPT-SACS*			AAPT Summer Meeting			AAPT-SACS, AAPT-WA* and AAPT-Northeastern*		
In Person Week-Long Workshop and Community Building (FDW)								FDW				
Virtual Community Building				Global Physics Department Webinar				Launch of gopicup.org		Online Meeting		Online Meeting
	Faculty supported by PICUP and growing community through web-based resources such as email, Zoom, and Slack											

2017	1	2	3	4	5	6	7	8	9	10	11	12
Half-day and Full-day Demonstration Workshops	APS April Meeting	AAPT Winter Meeting	APS March and AAPT-TX*	AAPT-Illinois, AAPT-SACS, and AAPT-ND and MN*	AAPT-Ohio		AAPT Summer Meeting			AAPT-NE OH*, AAPT-NC*, and AAPT-IL and WI	AAPT-AZ*	
Departmental Workshops											Northwestern University	
In Person Week-Long Workshop and Community Building							FDW					
Virtual Community Building		Online Meeting	Online Meeting	Online Meeting	Online Meeting					Online Meeting	Online Meeting	
	Faculty supported by PICUP and growing community through web-based resources such as email, Zoom, and Slack											

2018	1	2	3	4	5	6	7	8	9	10	11	12
Half-day and Full-day Demonstration Workshops	AAPT Winter Meeting		AAPT-SACS				AAPT Summer Meeting		Greater Chicagoland Workshop	AAPT-SACS and APS-Far West		
Departmental Workshops				IUPUI								
In Person Week-Long Workshop and Community Building							FDW					
Virtual Community Building	Online Meeting	Online Meeting					Online Meeting		Online Meeting	Online Meeting		Online Meeting (x2)
	Faculty supported by PICUP and growing community through web-based resources such as email, Zoom, and Slack											

2019	1	2	3	4	5	6	7	8	9	10	11	12
Half-day and Full-day Demonstration Workshops	AAPT Winter Meeting (x2)			APS April			AAPT Summer Meeting (x2)		Greater Chicagoland Workshop			
Departmental Workshops				Kansas State								
In Person Week-Long Workshop and Community Building							FDW					
Virtual Community Building										Online Meeting (x2)	Online Meeting	Online Meeting
	Faculty supported by PICUP and growing community through web-based resources such as email, Zoom, and Slack											

2020	1	2	3	4	5	6	7	8	9	10	11	12
Half-day and Full-day Demonstration Workshops	AAPT Winter Meeting (x2)											
Virtual Conferences and Workshops						Virtual Conference	Virtual Workshop	Virtual Workshop	Virtual Workshops (x5)			
Virtual Community Building			Online Meeting	Online Meeting (x2)	Online Meeting			Online Meeting				AAPT Virtual Coffee Hour
	Faculty supported by PICUP and growing community through web-based resources such as email, Zoom, and Slack											

2021	1	2	3	4	5	6	7	8	9
Virtual Conferences and Workshops				Workshop on Assessment				Virtual Workshop	Capstone Conference
Stipends to Support Integration of Computation				12 stipends awarded		Progress reports submitted		Final reports submitted	
Virtual Community Building	Online Meeting	Online Meeting			Online Meeting	Online Meeting			
	Faculty supported by PICUP and growing community through web-based resources such as email and Slack								

PICUP Capstone Conference Participants

The PICUP Virtual Capstone Conference had 123 registrants. These people attended from all over the country, as shown in the map below (Fig. 2). There were also 12 people who attended from outside the US, including 5 attendees from Canada.

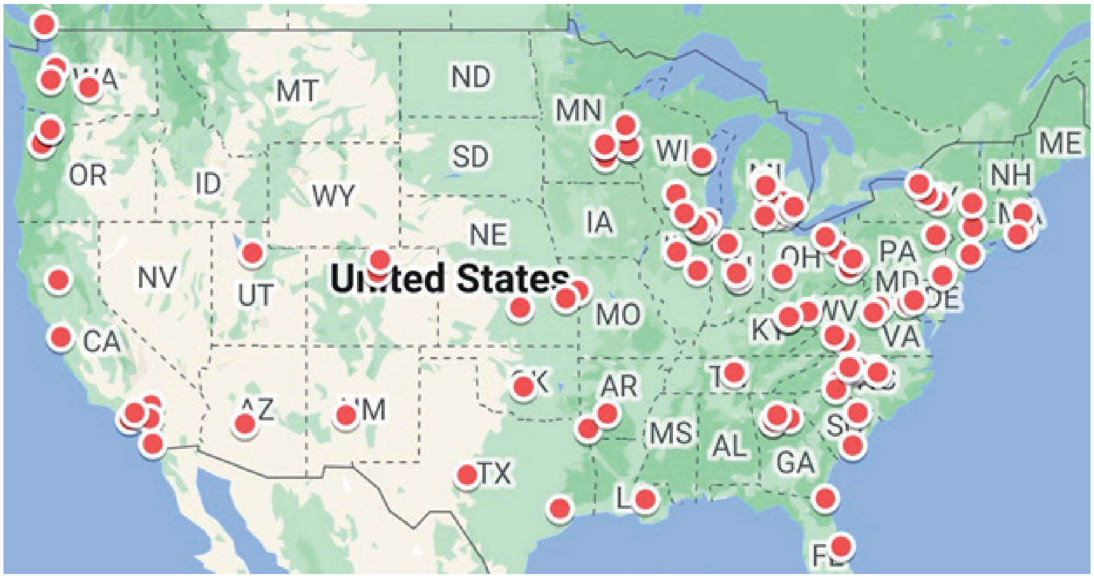

Fig. 2. Locations of the PICUP Virtual Capstone Conference attendees. Map data © 2021 Google

Registration for the Capstone Conference was restricted to those who had attended PICUP workshops during the past 5 years, as an opportunity to bring together the PICUP community. This recruitment targeted participants starting with our first Faculty Development Workshop (FDW) in Summer 2016 continuing though summer 2020's virtual conference and workshop. In August 2016, we began using Slack for engaging the PICUP community online. The size of the PICUP Slack team is shown below as a function of time (Fig. 3). Our largest jump in Slack membership was in Summer 2019, which corresponded to our largest FDW. By late 2019, we had 400 Slack members.

Due to the pandemic, we were not able to hold any in-person workshops in 2020 and 2021. As a result, we did not have big jumps in Slack membership in 2020 and 2021. New people did continue to join the PICUP community during the pandemic, but in smaller numbers.

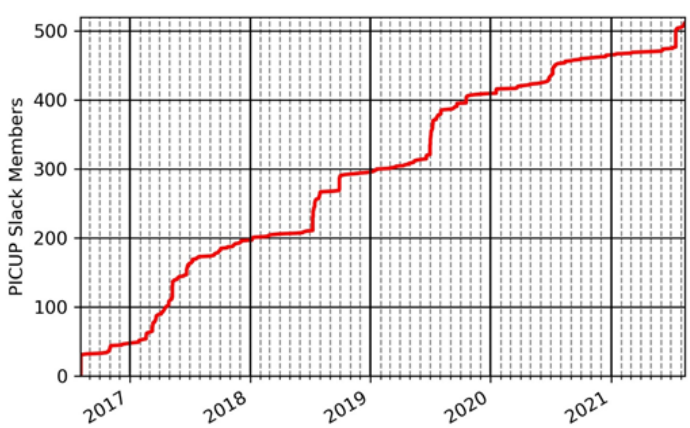

Fig. 3 PICUP Slack membership over time.

Membership in the PICUP Slack team is one direct indicator of involvement in the PICUP community. Namely, each of these 500+ people has chosen to join this platform devoted exclusively to facilitating interaction among the members of the PICUP community; so these tend to be people who have a relatively strong connection to PICUP, most notably the faculty who have attended in-person PICUP workshops.

Another indicator of the impact of PICUP is the recruitment of new “Verified Educators”. A PICUP Verified Educator is a faculty member who has gone to the PICUP website and chosen to register to access the curricular materials from the PICUP Collection. These faculty might not necessarily be members of the PICUP “community” in the same way as the Slack members, but they are at least “consumers” of PICUP materials.

The plot below (Fig. 4) shows the number of PICUP Verified Educators as a function of time. By late 2019, we surpassed 1,000 Verified Educators, including 359 new Verified Educators in 2019 alone. During the pandemic the number of Verified Educators has grown somewhat more slowly with 276 new Verified Educators in 2020. However, we did see a significant jump in Verified Educators in Summer 2020, corresponding to our 2020 “PICUP Virtual Conference: Tips, Tricks, and Best Practices for Teaching Physics Online”.

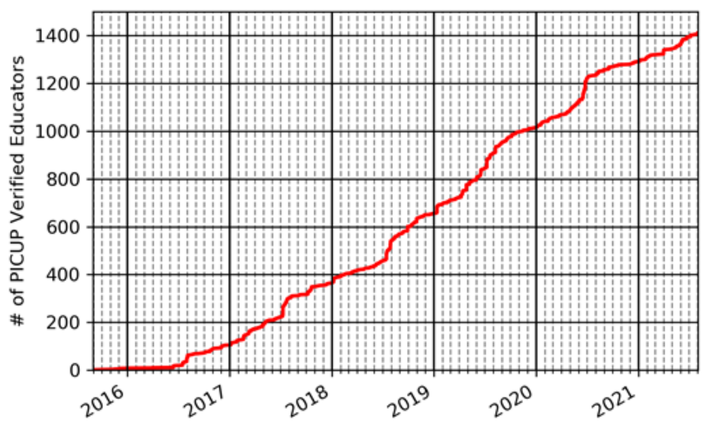

Fig. 4. PICUP Verified Educators over time.

Figure 5 shows the geographic locations of PICUP Verified Educators. They are from all over the US, as well as a significant number of international faculty, especially from Europe.

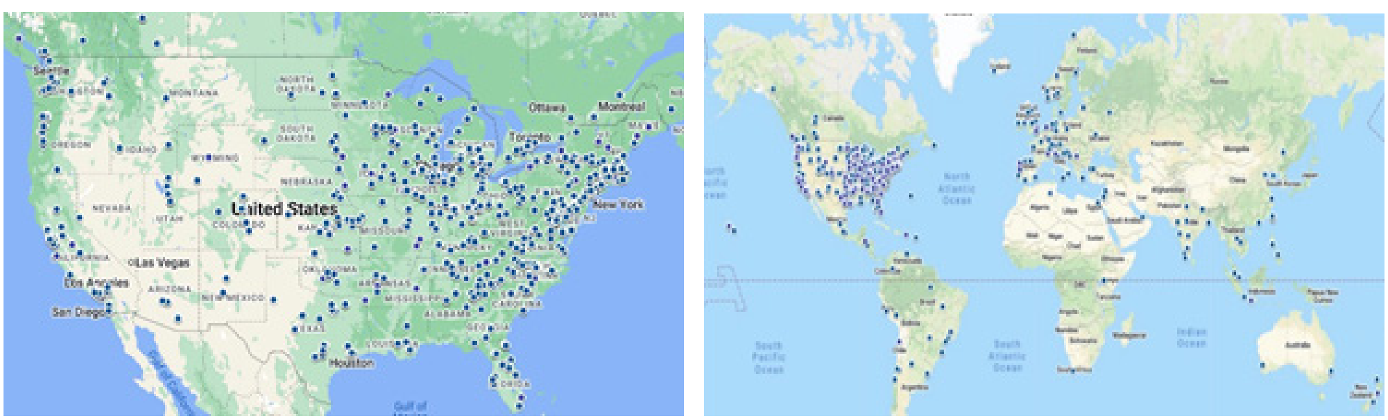

Fig. 5. Distribution of PICUP verified educators. Left panel: in the U.S. Right panel: world-wide. Map data © 2021 Google

III. Integrating Computation

The Contemporary Need

Computation is a critical component of 21st century physics and the STEM enterprise more broadly; within the past decade alone, the use of computation has facilitated the important and celebrated imaging of black holes (Event Horizon Telescope Collaboration, 2019 Astrophys J. Letters), the detection of black hole mergers (Abbott, B. et al. 2016 Phys Rev Letters), and the discovery of the Higgs boson (Aad, G. et al. 2015 Phys Rev Letters). Indeed, computation is widely considered to be the third pillar of contemporary physics, drastically expanding our ability to test theoretical models and to analyze experimental data. According to the 2016 joint APS and AAPT Phys21 report: "virtually all [physics] graduate students are likely to … use programming to solve problems, …, and develop apparatus and computational tools for their research" (Heron and McNeil, 2016).

Looking more broadly at post-graduate careers, the American Institute of Physics (AIP) reports that, as of 2017, 75%-90% of physics bachelor's degree recipients will engage in programming in their post graduate positions while 50%-60% will engage in some form of simulation or modeling (Mulvey and Pold, 2017). As Mark Guzdial argues in his 2015 book Learner-Centered Design for Computing Education, "the goal of a computationally literate society is to be able to use computing as a form of expression and a way to think about domains other than computing. In many fields, computing allows people to do things that they could not without computing."

With the clear need for computational literacy within scientific and technical professions, the Phys21 report stresses that "if undergraduate physics programs are to enhance their graduates' prospects for employment in diverse careers that are not normally described as 'physics jobs,' it is critical that they explicitly include opportunities to acquire the skills and knowledge needed in these jobs." The report explicitly includes both software competency and coding literacy as fundamental skills that will be needed in our technologically driven society. The 2016 AAPT report on Recommendations for Computation in Undergraduate Physics Curriculum further emphasizes the need to introduce computation into the physics curriculum. Reemphasizing the 2011 AAPT statement "that every physics and astronomy department provide its majors and potential majors with appropriate instruction in computational physics," the 2016 AAPT report adds that "to be relevant, curricula must facilitate the development of skills that are useful to physics majors in their post baccalaureate careers" while explicitly identifying the use of a computer to solve physics problems as such a skill. Despite these calls for action, however, most contemporary physics curricula still do not fulfill the needs of contemporary science and industry, presenting physics largely as it was half a century ago (Phys21 report 2016, AAPT report 2016).

A Brief History of Computation in Physics Education

For much of the early history of the computer, price, size, and processing power proved to be prohibitive factors in their use as classroom tools. The development of the modern PC in the mid 1970's significantly increased access to computers—especially in research and classroom environments (see, for example, the work of Seymour Papert or Andrea DiSessa)—and led to the design of many early pedagogically oriented programming languages such as PASCAL and BOXER (diSessa and Abelson 1986) and modeling environments such as STELLA (Costanza 1987). Hardware and software limitations, however, continued to prove challenging for those wishing to integrate programming and computational modeling into their science classrooms. As an example, the faculty who ran the M.U.P.P.E.T. project at the University of Maryland throughout most of the 1980's had to expend considerable effort instructing students how to render simple graphs and introducing them to sophisticated Runge-Kutta algorithms just to reduce the runtime to something appropriate for classroom use while also minimizing numerical error (MacDonald, et al. 1988, Redish and Wilson 1993).

Advances in hardware and software—not to mention the development and growth of the internet—over the next few decades drastically increased the processing power, accessibility, and portability of computers leading to widespread use in contemporary physics research and the tech industry as well as an increasing prevalence of personal computers and smart devices among the general public. A number of attempts were made during this time to more formally integrate computational modeling into physics and other science curricula; a 2008 AJP theme issue (Christian & Ambrose 2008) highlights a number of these efforts. However, most of these activities were largely sustained by faculty who already used computation in their own research. In a 2008 survey, Chonacky and Winch found that of those who responded (~33% of survey recipients) most (~80%) agreed that computational physics should be taught alongside analytical approaches however less than 20% of respondents reported that computation was a part of their coursework (Chonacky & Winch, 2008). While some of these efforts led to continued lasting impact—including the development of the PICUP project (Chonacky & Winch 2008, Caballero, et al. 2019), the authoring of a computation-focused introductory physics textbook (Chabay & Sherwood 2008; Matter & Interactions 4th ed. 2015) as well as a variety of other undergraduate-focused computational physics texts (e.g., Giordano 1997; Gould & Tobochnick 1996), and an increased emphasis on computation by both professional development and education research communities—widespread computational integration remained elusive. According to the 2016 AAPT report, much of this reticence was due to the conservative nature of academic institutions and their faculty members who tend to value established curricula and pedagogies over novel practices.

The Current State of Computation in the Physics Classroom

Since the 2016 Phys21 and AAPT reports came out, there has been increased attention by the community of physics educators towards integrating computation into physics courses across the curriculum. This includes department-level efforts to create comprehensive curricula that continuously engage students in computation throughout the major. Since 2016 the number of examples of computational teaching and learning in physics has grown, as have both educational research and professional development efforts. Indeed, it appears that physics educators are regularly using professional development for computation instruction and working alongside the education research community to enhance both by iteratively designing classroom activities, courses, and, in the future perhaps, whole curricula that integrate computation instruction effectively.

As attention has increasingly turned towards computational instruction, the number and variety of efforts to integrate computation into physics courses has grown. At the introductory level, a number of departments have adopted the Matter & Interactions curriculum (matterandinteractions.org) with the specifics of each implementation adapted to fit the local contexts. Beyond using an established curriculum, others have developed courses with integrated computational activities—often as labs and project-based experiences (Buffler, Pillay, Luben, & Fearick 2008; Beichner, Chabay, & Sherwood 2010; Caballero, Kohlymer, & Schatz 2012; Orban et al. 2018). As the software and hardware have continued to develop, more faculty are making use of web-based tools for computational instruction such as Glowscript, trinket.io, and p5.js. In addition, the specific programming languages used in introductory physics courses have become increasingly diverse (Python, Javascript, MATLAB, etc.). We have seen even more diverse examples in so-called "beyond the first-year" (BFY) courses for physics majors. In these BFY courses, there appears to be a wide belief that computational knowledge and skills are needed by physics majors and, thus, most include a deeper understanding of the algorithms and tools that are used to model physical phenomena. Examples from core physics courses such as Classical Mechanics, Electricity and Magnetism, Quantum Mechanics, and Statistical and Thermal Physics are common (e.g., Timberlake & Hasbun 2008; Caballero & Pollock 2014). Examples from laboratory and elective courses are also growing. In each of these examples, the specific context for integration and the motivations of the teaching faculty were key in the implementation. In some cases, national reports, research efforts in fields like computer science education, and other external guiding documents have helped faculty with integration. As those faculty have developed course materials and activities, some have contributed them to the PICUP open-access repository (gopicup.org).

Physics Education Research

With more examples of these computational integration efforts, education researchers have had a greater opportunity to investigate integrated computational learning environments. Early in the history of physics education research (PER), researchers i were somewhat limited in the contexts they could study. Typically, studies occurred within one's home institution. As both the field of PER has grown into more departments and the efforts to integrate computation into physics departments have expanded, physics education researchers have had more opportunities to conduct studies. PER researchers have studied environments where computation has been taught with several goals in mind:

1. To understand student learning and engagement (Sherin 2001; Kohlmyer 2005; Weatherford 2011; Lunk 2012; Caballero, Kohlmyer, & Schatz 2012; Obsniuk, Irving, & Caballero 2015; Sand, Odden, Lindstrøm, & Caballero 2018; Odden, Lockwood, & Caballero 2019, Lunk 2019),
2. To investigate instructor teaching practices (Young, Allen, Aiken, Henderson, & Caballero 2019; Pawlak, Irving, & Caballero 2020),
3. To make sense of student perspectives (Lunk & Beichner 2016; Bumler, Hamerski, Caballero, & Irving 2020), and
4. To investigate departmental integration efforts (Leary, Irving, & Caballero 2018).

Much of this work has been at the introductory level, with some efforts occurring in BFY courses. By and large, these efforts have been organic and steeped in local contexts and conditions. In many cases, physics education researchers have worked to connect existing perspectives on physics education research such as conceptual learning to the study of classrooms where computation is taught (Kohlmyer et al 2009; Caballero et al 2012).

As these research efforts have grown, so have the efforts to develop frameworks that guide this research. Many of these framework efforts stem from the notion of "computational thinking" (Wing 2008). This term has come to encompass many of the efforts in physics and elsewhere to introduce computational tools, methods, and concepts to students. The challenge with the term "computational thinking" is it remains somewhat ill-defined (Orban & Teeling-Smith 2020). Recently, researchers in computer science education have begun to develop frameworks that attempt to define computational thinking in more practical terms that can be used by educators and researchers alike (Barr & Stephenson 2011; Berland & Lee 2011; Brennan & Resnick 2012; Shute et al. 2017). In addition, efforts in science and mathematics education research have further attempted to refine "computational thinking" in the context of modeling natural systems. One of the more notable of these is the framework developed by Weintrop et al. (2016), which works to define practices (specific actions or activities) that students might use when engaged in computational thinking. While useful in framing computational thinking in terms of the practices that underlie it, the Weintrop framework is relatively context-free and provides few specific examples of students engaged in those practices. This can make it challenging for physics educators and physics education researchers to draw from this framework for integration efforts or research studies.

Recently, two potentially useful frameworks have been developed to address both of these issues. In the work of Odden et al, the notion of physics computational literacy is defined in terms of cognitive, material, and social domains (Odden, Lockwood, & Caballero 2019). Here, the idea is that we aim to develop physics computational literacy in our students in the same ways we want to develop reading literacy in children. That is working with computation and thinking computationally are part and parcel of the way people live in the world. Odden et al. provide examples of how different aspects of physics computational literacy can be manifested in physics courses and how we might design course materials (i.e., computational essays) to develop and strengthen that literacy. In other work, Weller et al. have developed a framework for computational practices within introductory physics courses (Weller, Bott, Caballero, & Irving 2021). Here, the work was conducted as part of an effort to support high school physics teachers in integrating computation into their courses. As such, the framework is focused on introductory courses, but is couched in terms of observable computational practices such as decomposing problems, algorithm building, intentionally generating data, and debugging. In addition, Weller et al. provide examples from high school physics courses where these practices can be implemented and demonstrate that their framework can potentially distinguish computational learning opportunities appropriate for different classrooms, course activities, and groups of students.

Each of these components (more computational examples, increased research efforts, and newly developed frameworks) have helped inform and grow professional development opportunities for faculty looking to bring computation into their courses. The AAPT and APS allow interested folks to design and offer workshops that support physics educators. The computational physics education community has been a frequent user of these venues to help faculty learn about computation in the classroom and to support their efforts to include computation as part of their courses. A recent series of projects have examined these efforts across many spaces. Some of the more notable efforts are PICUP, the STEM Coding project, the Bootstrap Physics project, and the Integrating Computation in Science across Michigan (ICSAM) project. Of these, PICUP is the one that is uniquely focused on physics majors and university physics departments. Extensive efforts by STEM Coding, Bootstrap, and ICSAM are offering lessons and information about integrating computation in high school and other introductory courses (Weller, Caballero & Irving 2019; Bott, Weller, Caballero, & Irving 2019). Much of the work to support physics faculty to integrate computation into their undergraduate courses, and, in particular, BFY courses, has been driven largely by PICUP.

These integration efforts now appear more sustainable and more deeply connected to each other across the US, such that they have allowed researchers to study integration efforts broadly; that is, not only in the classroom. As more faculty have begun the work of integrating computation into their physics courses with many connected to the PICUP project, researchers have been able to investigate the specifics of integration efforts and how those efforts relate to what faculty experience. Studies have included documenting the current state of computational instruction across the US (Caballero & Merner 2018) and what potential factors indicate that a faculty member is likely to have taught computation to their students (Young et al 2019). This work has shown that while the instructional efforts have grown, they still appear, at the moment, limited to the "coalition of the willing." In addition, this work has demonstrated a great opportunity to support two-year college faculty who report with less frequency teaching computation to their physics students. More detailed studies of members of the PICUP community have shown how challenging these efforts can be (Leary, Irving, & Caballero 2018)—reflecting some of the known barriers to change (Dancy & Henderson 2008) while also highlighting new ones like choosing a particular computational platform. These efforts to study the work of integration itself helps to communicate the lessons learned from faculty who are actively teaching computation in their courses to the broader physics education community. All this work has led to the growth of a community of physics educators who are actively teaching computation in their classrooms and a smaller community of physics education researchers devoted to understanding those efforts.

Looking ahead

With the widespread use and importance of computation in both the academic and business/industry sectors, as well as the push from professional societies to integrate computation into the physics curriculum, our priorities must shift toward identifying and lowering the barriers associated with using these new tools and new pedagogies. The 2016 AAPT report identifies a number of challenges to integrating computation, including managing curricular and class time, negotiating a variety of student and instructor backgrounds, and a lack of community support as well a dearth of appropriate computational resources—challenges that reflect the broader reticence in adopting pedagogical innovations (Dancy & Henderson 2008). Young, et al. (2019) and Caballero and Merner (2018) specifically highlight faculty experience (or lack thereof) as being one of the main predictive factors for whether or not computation is used in the classroom and they suggest that helping to support individual instructors might be the most effective way to expand the instruction of computation in the physics curriculum. It is in this context that the PICUP project can continue to push for the increased adoption of computation in the physics classroom by providing access to instructional materials, leading extensive week-long professional development workshops, and cultivating supportive communities of adopters.

IV. Capstone Conference Themes

The PICUP virtual capstone conference was held over three days: August 11-13, 2021. The details of the conference schedule appear in Appendix C. Members of the PICUP leadership took contemporaneous notes during the conference to synthesize the presentations and resulting discussions into recurring themes. Below, we present the themes we have extracted from the conference along with a brief presentation of how conference participants discussed each theme. Section 5 provides a summary of reflections from conference participants.

Theme 1: How to Create an Effective Computational Learning Environment for Students

Across the Capstone conference, instructors focused on creating a positive, inclusive learning environment for students who are using computation within their physics courses. Invited speakers outlined approaches to combat inequities in student preparation, while participants in the workshop sessions noted pedagogical tools implemented in their classes to create an equitable, productive environment, and highlighted concerns that arose about these topics.

Courtney Lannert's talk outlined the Computational Skills recommendations in the newly released guide of "Effective Practices For Physics Programs" (EP3) (APS/AAPT, 2021)). This guide provides concrete suggestions that departments "include strategies for supporting students from marginalized groups, while not singling out such students" (EP3 Guide for Computational Skills, available at https://ep3guide.org/), among other suggestions that reduce barriers for students learning computation. In addition, the guide covers topics that range from recruiting and retaining students, to creating an environment of inclusivity, to course offerings, to how to be an effective chair. The section on computational skills discusses steps for determining departmental computational goals.

Ruth Chabay noted the pedagogical challenges in incorporating computation in physics courses. These include varying degrees of prior exposure, inequitable access to computational resources, and student sentiment towards programming. She highlighted that the payoffs are worth the efforts of addressing these challenges, and cited scaffolded activities, working in a tutorial setting with access to help, and graphical visualization as methods to address barriers to the integration of computation.

Michelle Kuchera and Evan Peck led a workshop entitled "Lessons from Computer Science Pedagogy", in which results from computer science education research found that most students inaccurately self-assess themselves at a lower performance level than their peers, which affects their sense of belonging in computation-based courses (Barker, L. J., et.al 2002 SIGCSE). In addition, research demonstrates significant gender inequities when self-evaluating computational ability. Kuchera and Peck introduced methods to address these student sentiments by demonstrating that failure is a path to learning and providing highly-scaffolded activities and assignments (Margulieux, L. et. al, 2020 International Journal of STEM Education 7, Xie, B. et. al 2019 Computer Science Education, K. Cunningham, et.al. 2021 CHI). Participants highlighted additional challenges in a physics class environment, including barriers due to a lack of student buy-in and creating an effective environment in classes with students of vastly varying computational backgrounds.

Similar challenges were discussed in the workshop: "The Computational Physics Course: Objectives, Design, and Assessment", organized by Gillian Ryan and Walter Freeman. This workshop focused on dedicated computational physics courses. Addressing inequities in student preparation was a theme that arose from discussions in this workshop. Ryan and Freeman stressed communicating the importance of the computational tools that students learn to use. These tools are essential in both physics research and industry positions outside of physics, making the skills learned in a physics course valuable far beyond that individual course.

Another topic that was brought up across workshops and talks was careful group and pairing practices to enhance learning. Discussions about how to best pair students was engaging but but there is little consensus in the physics education community about the most effective way to structure student groups. Computer science education pedagogy often advocates for pairing students with similar computational expertise so that both students are able to take ownership of the work and feel more comfortable with being both a learner and teacher in the paired environment. On the other hand, proponents of physics group work often advocate for grouping students of different expertise with well-defined roles within the group. These discussions point out the need for continued studies of group work in computational physics and in other areas of STEM education.

Theme 2: How to Support Faculty Looking to Integrate Computation

Many instructors are aware of the importance of computational skills for physics graduates. For example, the Phys21 report, ***"Preparing Physics Students for the 21st Century Careers"***, states "[b]oth graduates and their employers report that preparation for positions available to those with physics training could be significantly improved. Studies of physics graduates conclude that their technical skills should be expanded to address a wider and deeper knowledge of computational analysis tools." However, not all instructors have the resources and support to make the changes necessary to incorporate computation into their physics curriculum. Discussing ways to support faculty who would like to integrate computation in their courses was a common theme of the conference. Nick Young's talk "Why physics instructors choose to include computation in their courses" presented survey results from 1257 physics faculty in which he explored the barriers to incorporating computation for instructors.

Many instructors struggle to find course time to add computational activities. Adding in something new usually means something else needs to be taken out. At present there is no consensus of what aspects of computation in physics are most important, nor is there consensus about which topics should be removed from the course. Ruth Chabay's talk "Computation in the Introductory Physics Course" and Todd Zimmerman's workshop, "Department-Wide Computational Integration" also touched upon this topic.

A lack of consensus on learning objectives for computation in physics is part of what makes determining what material to leave out of the course a challenge. By and large, physics undergraduate programs have developed a canon for physics instruction—emphasizing the same theoretical (non-computational) topics in commonly taken courses such as modern physics, classical mechanics, electrodynamics, quantum and statistical mechanics. PICUP is in a strong position to lead the conversation on developing some consensus of what these learning objectives should be like in the "age of computation."

Instructors sought advice on how to combat student resistance to computation in physics courses. Some instructors are nervous that this resistance can show up in student evaluations, which can be a concern for instructors not protected by tenure. Conference attendees mentioned that students are sometimes afraid of not being good at computation, which is a similar sentiment expressed by students taking introductory courses in computer science. This can be especially problematic for students who regularly experience marginalization (e.g., women, racial and ethnic minorities, LGBTQA+ students). Some students have expressed that they feel programming is "just one more thing" they need to learn, on top of math and physics. The EP3 Guide presents ways to address student hesitancy. Workshop discussions suggested that framing the activities in terms of computational modeling, rather than programming may help with this concern. Also, referring to documents from APS and AAPT on the importance of computing may help.

PICUP has offered workshops to assist instructors in integrating computation into their courses. These efforts have inspired additional efforts in other educational spaces. For example, Paul Irving presented a talk "Integrating Computation in Science Across Michigan", which outlines the ICSAM program for supporting Michigan high school teachers in integrating computation into their classrooms.

Instructors also sought guidance on assessment tools for computation. Tor Ole Odden's rubric "Using Computational Essays to Support Student Creativity and Agency in Physics" provided some help to instructors. Several instructors asked for his rubric during his talk. Additionally, Daniel Weller's talk "Learning Goal Framework for Computational Thinking in Computationally Integrated Physics Classrooms" provided another way to think about computational assessment in physics.

Theme 3: Considerations for Integrating Computation Across the Curriculum

One major theme that emerged from the conference focused on how to integrate computation in a coherent fashion across the curriculum in a physics department. The goal of an integrated curriculum is to allow courses to build on skills developed in earlier courses as well as to provide a greater depth of experience in computation over a longer period of time. Many conference attendees were from departments situated in various stages of implementing curricular integration of computation. The attendees discussed hurdles they encountered and suggestions on how to overcome hurdles. These topics also came up in

Courtney Lannert's plenary, in some of the contributed talks, as well as in the workshop on departmental integration run by Andy Gavrin and Todd Zimmerman.

The lack of consensus on computational learning objectives at the department-level is an area the PICUP community can tackle. As mentioned earlier there is no consensus of the computational learning objectives even within given courses. This is likely because we are only beginning to form a clear vision of what skills a student should have mastered in their physics courses (APS, 2021). In discussions, the question arose as to whether students should be learning programming in computer science courses or should they pick up those skills in the context of physics courses.

Without clear learning objectives, it will be difficult to figure out what material to keep and what to take out of the existing curriculum. Attendees at the departmental integration workshop were not sure if there are specific topics that could be removed at the department level. Topics like separation of variables or complex numbers that show up in multiple classes was given as an example. Clear learning objectives for both computational and non-computational physics learning will help with this question.

Maria Hamilton of Marshall University discussed how adding a specialization and a minor in computational physics aided in integrating computation across her department's courses. In her talk she provided examples of the outcomes of each of three computational physics courses along with the desired outcomes for the set of courses collectively.

Many smaller schools offer upper-level classes on a two-year rotation, which makes it harder to ensure students follow a specific path through the classes. This complicates which skills in one class can build on skills from previous classes. One workshop attendee pointed out that we encounter the same issue with analytical skills and what we end up doing is teaching the same skill more than once. For example, many instructors end up teaching separation of variables in electricity and magnetism courses and again in quantum mechanics. Some repetition is beneficial, but the department should take a holistic view of its curriculum, including computational work, to remove unnecessary redundancies.

Colleague resistance can also be a major barrier to adding computational modeling across all courses. Many colleagues might not see the value of adding computation, while others might not know how to teach coding. Even in the case where everyone agrees to add more computation, there is frequently no agreement about what that will look like. Developing a recommended scaffolding for computation in physics might be an opportunity for PICUP to support the physics community. Several attendees stated that some of their colleagues did not see the benefits of computation or at least they didn't think it was worth the time taken away from analytical approaches. The AAPT statement on the importance of computation as well as the Phys21 report are useful resources to provide evidence for the need for more computational modeling. The EP3 Guide also provides tips on how to promote the importance of computation to instructors, current students, prospective students, and possible employers.

Introducing computation into the physics curriculum is a substantial change effort. The challenges with these kinds of efforts are well documented (Dancy and Henderson, 2008). Two problems that are specific to computation are the issue of choosing a common programming platform and ensuring students have access to hardware (Leary, Irving, and Caballero, 2018). When considering what program or language to use, some of the factors include familiarity of instructors with a platform, costs associated with the platform, and usefulness of proficiency to students in their careers. Assuring that computers are available to the students can be a problem, especially in situations where computers are housed in labs on campus. This can be an even larger hurdle for students from underrepresented groups or students with disabilities.

J. Kevin Adkins gave a talk on how he, Jennifer Birriel, and Ignacio Birriel of Morehead State University successfully added a computational component to the courses for first- and second-year students. They chose Excel as their platform and explained how they used spreadsheets for some activities as well as for analyzing data. They provided a useful roadmap of what this curriculum could look like. Martin Connors discussed the benefits of adopting Octave, an open-source Matlab clone. Matlab is a fairly common tool for engineers.

V. Reflections from Participants

One of the main barriers to widespread implementation of computation in the physics curriculum is the instructor's lack of computational experience and lack of experience teaching computation. Indeed, Caballero and Merner (2018) and Young et. al (2019) highlighted faculty experience (or lack thereof) as being one of the main predictive factors for whether or not computation is used in the classroom. The PICUP project was founded in part to help provide direct experience to instructors in using computational tools and in developing instructional activities through faculty development workshops. It is also useful to examine reflections of faculty who have led successful implementation efforts to produce models for instructors who need some sense of what computational integration could look like in a classroom setting. As part of the PICUP Capstone Conference, we invited presenters, panelists, and workshop organizers to complete a comprehensive survey to share their narratives and experiences incorporating computation into their own classrooms and departments. Eleven capstone presenters, including instructors from two-year colleges, liberal arts colleges, and graduate degree-granting institutions, completed the survey. Some of these contributors have largely had to forge ahead alone and others have been able to change their departmental culture from positions of leadership. While we recognize that these responses reflect only a few of the many implementation efforts discussed at the PICUP Capstone Conference, we hope that they provide a diverse enough set of experiences and perspectives that they can serve as examples for the benefit of anyone who wishes to make use of them. In order to protect the identity of the respondents, we will refer to them with pseudonyms that indicate their university context: TYC (two-year and community colleges), LAC (liberal arts colleges), and RU (research universities).

Bottom-Up Change

We understand bottom-up change to be those efforts led by an individual or small teams of instructors and limited largely to the courses that they teach—this is probably the mode of course change that most instructors will experience.

We asked our survey participants to identify an individual class and to describe the ways in which computation was incorporated into the coursework focusing especially on the course goals, challenges encountered, platforms used, and efforts to sustain these changes. Most of our participants discussed introductory courses, but a few highlighted mid- and upper-level courses. Most everyone agreed that when incorporating computation, it's important to consider:

- The classroom instructional and pedagogical context. We recommend that instructors follow contemporary best practices of interactive-engagement and inclusive pedagogy, but class size, instructional model, and the use of peer instructors can all impact decisions in how to best incorporate computation in the physics classroom.
- The specific course goals. Articulate how these support the use of computation, whether these need to be adjusted, and how they are communicated to the students.
- The avenues through which computation will be integrated into the course. Will it be in class activities? Graded homework assignments? Assessments? Projects?
- Student perspectives and how students will interact with and accept computational tools, and
- Departmental support, especially teaching assignments and funding considerations.

Classroom Pedagogical Models

Before considering the specifics of incorporating computation into coursework, instructors need to consider the classroom environments and pedagogical models they currently use or plan on using in the future. While not all participants shared the details of their specific pedagogical approaches, those who did highlighted their use of studio classrooms and interactive engagement techniques like "flipped" or "project-based" instruction. TYC-1, for example, noted that their "class size is restricted to no more than 35 students" and that "most classes are completely or partially flipped." TYC-1 continues, "the instructor does use a few slides to organize and guide the class, but much of the work is based on discussion among students and questions that students ask each other and the instructor. Discussions are started with multiple-choice questions or open-ended questions." TYC-2 similarly mentions that their "classes are all studio style (integrated lecture-lab)."

Two of the respondents from liberal arts colleges mentioned that they are in the process of switching over to flipped or studio-based instruction. "During the pandemic," LAC-3 wrote "we went to a mostly flipped format and plan to keep that this year as we go back in person." And LAC-5 noted that "this year I am going to begin a flipped pedagogy in the lecture as well, building on a framework of modeling systems in groups." Classroom models like this can help inform how students engage in computational activities.

These examples show that a variety of pedagogical approaches are compatible with bringing more computational work into the classroom.

Course Goals

An important component of establishing the structure and content of a course is to enumerate a set of learning goals or standards for the students. Most courses, we imagine, have a set of learning goals not dissimilar to those highlighted by TYC-1 for their introductory mechanics course: "1) Demonstrate an open and inquiring attitude toward physical phenomena and scientific investigation of them, 2) Demonstrate a deep mathematical understanding of classical Newtonian mechanics, 3) Employ analytical problem-solving skills and extend them to a wider range of physical phenomena, 4) Employ basic laboratory and report writing skills necessary for further work in science and engineering, and 5) Employ the interpersonal skills needed to function effectively as a member of a working team."

Similarly, a successful integration of computation will follow from a set of well-articulated learning goals. For example, LAC-3's introductory calculus-based course now includes the learning goal "students will construct (or modify) and interpret computer models to extract information about the physical world." Meanwhile LAC-4's introductory course added multiple learning goals: "reading a computational model written in VPython, answering questions about the system, editing it as needed (in particular, being able to write expressions in the loop for calculating a field or calculating a force and updating momentum and position, if predicting motion), and explaining what expressions must be inside a loop and what expressions can be outside the loop." At the more comprehensive end, LAC-5 mentioned their department will soon be adding a set of learning outcomes "specific to computation, which will include a piece on data processing and visualization, a piece on translating models into code, and a piece on extracting physical insight from computational approaches." Articulating course goals is also critical in upper-level courses. As an example, LAC-6 mentioned that "comfort with numerical methods became an implicit goal" when introducing computation into their quantum mechanics course.

Avenues of Computational Integration

Our survey participants highlighted multiple avenues for integrating computation into the physics classroom including:

- In-class activities
- Lab activities
- Homework assignments
- Demonstrations
- Assessments, and
- Textbook/curricular selection

They also highlighted a variety of software platforms including spreadsheets like Excel, online platforms such as Glowscript, and more formal scientific computing packages such as Jupyter and Mathematica.

Both LAC-3 and LAC-4 make use of Matter & Interactions in their introductory courses and use VPython and Glowscript in both lecture and lab. LAC-4 adds that "computational modeling is taught during approximately 40% of the 13 or 14 lab meetings during the semester. Students take a lab practicum, of which one-half is computational and has two sections: (1) reading, interpreting, and answering questions about a program; (2) editing and running a program. The response was overwhelmingly positive, led to growth in our major and program, and led faculty to implement computational modeling into every physics course for majors in the curriculum."

LAC-5 integrated computation into both the calculus and algebra-based introductory sequences with only a discussion of integration and Riemann sums separating the calculus-based use of computation from the algebra-based. "We have integrated computation in the intro sequence primarily through the weekly, three-hour lab. Enrollment is typically 10-15 students, and they work in groups of around 3… in about the third week we begin by plotting and presenting data on spreadsheets. We progress through brute-force error propagation, extracting kinematics from data and modeling constant acceleration systems, to modeling energy loss as balls move through water, all on spreadsheets." Looking ahead, LAC-5 will "begin … building on a framework of modeling systems in groups. Every two weeks there will be a computational activity…The idea is to immerse the students in computational work and programming, and to get them comfortable using computational tools." In addressing student opinions, LAC-5 mentioned that "in this sequence, few of the students seem to appreciate the computational approach" however "opinions seem to shift when we get to the second semester…I have had the impression twice now that students begin to appreciate computation after the electric potential computation."

Some participants briefly discussed other alterations to their introductory courses in order to better incorporate computation. LAC-1 mentioned that their introductory course was "problem/project based" and made use of "Glowscript for modeling in lecture, collaborative notebooks, and the use of numpy, scipy, etc in lab." TYC-3 focused on their labs, noting that "we replaced two labs with computation using Excel: Projectile Motion and Simple Harmonic Motion… So far the response is mostly positive." And for TYC-1, "the instructor uses Excel as the platform for computation, sometimes as a form of classroom demonstration and sometimes to enhance laboratory experiments."

Both LAC-2 and LAC-6 described an upper-level quantum mechanics course with LAC-2 using Griffiths & Schroeter (Griffiths & Schroeter 2018) and LAC-6 switching to the Mathematica-based Schroeder text (Schroeder 2020). According to LAC-2, this course was altered "to include approximately 8 weeks of computational exercises, centered on the NxN eigenvalue problem and utilizing two PICUP exercise sets: *Using the Finite-Difference Approximation and Hamiltonians to solve 1D Quantum Mechanics Problems* and *Quantum Dynamics in 1D with a Series Solution*. Along with completing the exercise sets as written, the students created adaptations and extensions to the exercises, including a new animation technique and a code to calculate a delta function perturbation to the infinite square well, which was compared to the numerical solution using the finite difference approximation. All coding was performed in Python (Spyder) and the students in general reacted favorably to the exercises." LAC-6 mentioned that their students had already been introduced to Mathematica in their math methods course and readily used computation at various points in the course, including on final projects.

RU-1 teaches at a masters granting institution and described an intermediate mechanics course that "[includes] spreadsheets and GlowScript (and occasional straight Python) to model and visually represent dynamics (including collisions). It is a small class (<= 12) and so I am the sole instructor. We take class time to do computation—literally, in-class assignments where people work in groups to perform computational tasks, typically starting from a minimally working code that needs the correct physics to be included….The students like (being able to make) the visualizations."

Challenges

In addition to highlighting their success in introducing computation into their classrooms, we invited our participants to share some of the challenges they've faced. Some of these are specific to the challenges of online instruction forced upon us by the COVID pandemic, and some are more general. Among the most common challenges were:

- Student access to technology, including computers and the internet
- Instructional support among faculty who have limited experience with computers
- Making time in already packed course schedules, and
- Student buy-in

TYC-1, for example, notes that "the greatest barriers are student access and time…Many do not have a computer beyond the Chromebook provided by their high schools. Most have smartphones, but these don't have screens large enough to see much of a spreadsheet at one time. Homes do not have much bandwidth. Many students park outside buildings such as coffee shops in order to do online homework." LAC-5 also mentions the challenges of students' access to computers, but their department was able to purchase "four laptops for students to use in the lab, to address technological equity." In this effort, LAC-5 has also "purchased Arduino boards and sensor kits, and we will begin pasting together sketches from the Arduino

Programming Language. The idea is to immerse the students into computation and programming, and to get them comfortable using computational tools." Obviously, the option to purchase equipment is not available to all departments due to limited financial resources.

LAC-3 noted that "[t]he biggest challenge has been staffing the classes and labs. Everyone says they are on board with adding computation, but, in practice, only 2-3 faculty members actually do it. So these few faculty have been covering these courses and labs and sometimes taking overloads." TYC-1 and TYC-3 shared similar concerns, with TYC-1 noting that "our physics department is really only two professors" and TYC-3 adding that "I am the only full-time physics instructor… I am the only one instigating and maintaining these changes."

Multiple participants point to the challenge of making time in their schedule to introduce computation. "The main challenge, as always, is finding the class time to do in class computation" says LAC-6. RU-1 agreed: "The challenge: making the time during the pandemic, and department leadership which has been neutral but is in the process of changing."

Finally, student pushback was brought up by multiple participants. LAC-1 simply noted that "some students [were] positive; some not so much" and according to LAC-3, "Student response has been mixed." LAC-5 points out that even after adjusting pedagogical approaches to include first iterating a calculation by hand, "few of the students seem to appreciate the computational approach. Most seem to find it an added burden." However, despite the challenges associated with making time in their schedules, multiple participants agreed that increased exposure and experience could help support students and mitigate push back. Both participants who described their upper-level quantum mechanics course noted this, with LAC-2 adding that their department was working on increasing the scaffolding in the intro sequence; TYC-3 has gotten mileage out of simply telling their students "that I am trying to prep them for career and transferring;" and, again, LAC-5 observed that "opinions seem to shift when we get to the second semester" and added that they will start increasing the frequency of computational activities in the hope that this will "accelerate [the students'] comfort with and acceptance of computation." There were also observations that even novice students appreciated the visualization that comes with packages like VPython and Glowscript. According to RU-1 "the students like (being able to make) the visualizations" and TYC-1 mentioned that students "also tell me that watching graphs change as parameters are changed is helpful in following simulations such as PhET."

Top-Down Change

In addition to asking participants about successful instances of computational integration within single courses, we also asked participants to share successful departmental-wide efforts. Fewer respondents provided detailed answers to this question, suggesting the relative challenge in implementing department-wide change. Indeed, LAC-3 noted that "as department chair, it's frustrating that I've been able to get the faculty on board philosophically but not in practice."

Still, those who reported successful instances of department-wide change highlighted two principal aspects of this change:

- Explicitly codifying departmental values which can then feed into hiring decisions, teaching assignments,
  and support for faculty who implement computation in their classrooms, and
- Creating an explicit computational component to the major such as creating a numerical methods course or requiring students to take a CS course can help scaffold students' learning.

LAC-4 noted that "our department has written a small set of core values which includes computation. Thus when hiring, we expect faculty to use and integrate computation into courses…Computation was part of the DNA of our department from the beginning since we are a new department and were established with relevance and career preparation being essential to preparing physics majors for diverse careers." And LAC-5 said "I plan to stress a computational background for candidates in faculty searches, though I do not know how much effect I will have." LAC-3 mentioned that their department has been deliberate about "staffing [the introductory sequence] with those instructors willing to implement [computation]" and that "at the upper level, instructors are encouraged to include computation in their courses (though in practice only a couple do.)" And regarding other aspects of departmental support, and LAC-6 commented that "we also made computational integration our departmental assessment goal."

As mentioned above, departments could also require students to take numerical methods courses, either in-house or through the CS department. For example, LAC-6 notes that as department chair, "my department changed our Applied Physics and Physics majors to mandate Intro to Programming, Math Methods in Mathematica, and to introduce a computational physics elective. We also made Computational integration our departmental assessment goal." RU-1 commented that they "added two numerical methods courses several years ago: a one-credit intro course focusing on spreadsheets and intro to Python; and a numerical methods course. We have a computational atmospheric physicist who created these courses. It seemed to take his hiring to make it happen although I had pushed for this earlier." Similarly, LAC-5 commented that "at the department level, we are creating a numerical methods class, which will be a required course to follow the 'Intro to Programming' course that Pre-engineering majors and Physics minors are already required to take. We are in the first steps of these changes, which are being driven by myself (Physics Professor) and by a Math Professor who has a background in Computational Physics and will also teach the class." LAC-3 adds that "students are required to take a programming course in the CS Department and a computational physics course in the major."

Summary

The participants' reflections can provide a starting point for thinking about how other faculty or other departments might integrate computation into their courses. We recognize that the advice and experiences of these participants may not fit the specific contexts of every potential adopter—not everyone has the resources of a R1 research institution or a Liberal Arts College and not everyone has the leadership capital to steer the culture and expectations of a whole department. However, we hope that these perspectives can provide aspirational examples that potential adopters can share with their departments or use in their own courses.

VI. Summary of Pre/Post Conference Surveys

This part of the report was prepared by the external evaluator for this project, Dr. Alexis Knaub. There were 112 registrants for the Capstone Conference when the pre-Capstone survey was sent out. A total of 65 (58%) completed at least part of the pre-Capstone survey. For the post-Capstone survey, the response rate is 49% with a maximum of 54 respondents per question. Note that none of the survey questions was required and some questions were not applicable (e.g., some respondents did not attend a workshop). Qualitative survey data were analyzed thematically. Quantitative data are presented as percentages, rounded to two significant figures.

Why Respondents Signed up for the Capstone

The most popular reason respondents (N = 25, 43%) signed up for the Capstone was to learn more about how to integrate computation. Some were seeking simply to learn more or how to get started. Some saw the Capstone as a means to "…to keep moving forward and include more computation throughout the curriculum." The second most popular (N = 15, 26%) reason was to connect with the community. This was often stated as "to see what others are doing," suggesting a general curiosity. A few (N = 4) also wanted to share what they were doing regarding computational integration.

Connections to and investment in PICUP itself were also reasons respondents gave for signing up. These reasons include: prior good experiences (N = 11); already involved with PICUP (N = 10); and updates on PICUP itself (N = 4). Respondents mentioned the Faculty Development Workshop (FDW) as a reason they chose to sign up for the Capstone, remembering the FDW fondly. Respondents who were already involved with PICUP were invited to participate in the Capstone (e.g., by delivering a workshop or giving an invited talk). One respondent who was interested in updates on PICUP thought the Capstone would be the simplest way to see where the project currently is: "I want to see where things have ended up. I know Slack provides information, but I don't have time to access the various PICUP Slack pages every day." These responses were separated from "connect with the community" responses, because these are more programmatic and within the purview of the PICUP leadership. Although the PICUP leadership sets up structures and influences how the community is created and sustained, some of the community participation is left to chance as individuals may not wish to be active in the community regardless of how well-designed it is. Respondents appear to be both invested in the broader community as well as have positive associations with the PICUP brand and its programmatic efforts.

Workshop Responses

Thirty-six respondents shared positive aspects about the Capstone workshops. The most often (N = 17, 47%) mentioned positive aspect was how interactive the workshops were. Although the workshop facilitators (N = 6) were specifically mentioned favorably, the respondents felt that the overall interactivity among participants was positive as they could learn from one another. One respondent commented "[I liked the] exchange of ideas both with other participants and with the leaders who are a bit further ahead than most of us."

The workshops' content was favorably noted by many (N = 17, 42%) as being useful because it supported the respondents in having plans on what to do next. Below are four sample quotes that illustrate this:

- I appreciated that the Integrating Computation into the Curriculum asked us to consider some of the same issues, concerns, and strategies from slightly different angles, so that by the end you had a more coherent idea of what to do.
- Learning what others are doing in labs was great! I am going to use a couple of computational lab exercises and ideas I learned!
- I came away with a good plan and ability to discuss an action plan with my department.
- The computer science pedagogy workshop I thought was really nicely organized and well done. I was introduced to several new tools/applications to potentially play around with and got some good ideas about how to better motivate collaborative group work.

A few respondents commented on logistical aspects of the workshops. Some (N = 6, 17%) felt the workshops were well-organized. Others (N = 4, 11%) appreciated that the material covered the "right" number of topics.

Twenty-nine respondents provided suggestions on how to improve the workshops. There were few common themes. Some respondents (N = 7, 24%) felt there was nothing to improve upon and some respondents (N = 6, 21%) would like to have had technical difficulties, namely with Gather.town, worked out. Regarding the latter, these respondents did not appear to have much if any experience with Gather.town. Respondents also noted that they needed to have "share the screen" options available to be able to communicate effectively.

Some respondents (N = 6, 21%) wished for more interactivity in some of the workshops, which parallels how that is seen as a positive aspect. Two respondents noted that more general interactivity and discussion would have been helpful. Four respondents would have liked having time set aside to work on their own materials, similar to what participants do at the FDW.

Plenaries, Invited Sessions, and Contributed Sessions Feedback from Participants

Thirty-four respondents provided some insight into what was most useful regarding the plenaries, invited sessions, and contributed sessions. Most (N = 19, 56%) found that getting new ideas and resources was important. The general emphasis was on specific items, e.g., one respondent stated: "I really enjoyed hearing about particular implementations, with details. Most of which came from the contributed sessions." Respondents (N = 11, 32%) also liked just hearing what others were doing, either for details on how to do something in particular or just new insights. Lastly, a few (N = 4, 12%) liked hearing about the overall big picture regarding computational integration in undergraduate physics.

Interestingly, respondents wrote about either contributed or invited (or both) sessions. This was split almost evenly, with 4 respondents noting contributed sessions were useful and 5 noting invited sessions or plenaries. Two respondents wrote about both. The general trend with responses favoring contributed sessions was that respondents could see a lot of practical matters and implementations. The plenaries and the invited sessions were seen more as big idea sessions.

Conclusion

Overall, the Capstone served its purpose. The event provided an opportunity for the PICUP community to reconnect. The individuals who attended and filled out the survey had overall positive experiences. The community is quite diverse in the types of institutions, occupations, interests, etc., yet the Capstone did a reasonable job in serving most attendees. The post-Capstone survey also suggests that the Capstone delivered much of what the pre-Capstone survey respondents were seeking.

VII. Future Directions

Although PICUP has supported faculty in making major strides in integrating computation in their undergraduate physics courses, there is still work to be done as indicated through the talks, workshops, and informal discussions throughout the Capstone. Some of the more significant challenges that need to be addressed are:

A. Better defined learning goals for computation in each course. PICUP's approach has been to meet faculty and the students where they are, which has allowed for varying types and levels of integrating computation. This approach is flexible and freeing, yet there exists interest in articulating fundamental learning goals for computation in different physics courses. This was brought up during the workshop on departmental integration in the context of course-level goals and program-level goals. Although most instructors can agree on what general physics topics should be in a particular type of course, there is no clear vision on how to use computation in those courses. We see this as similar to how there are some core areas of study and skills, such as some understanding of classical mechanics or being able to create a plot, that are assumed with a physics bachelor's degree program.

This is not a call to prescribe an overbearing, detailed set of mandates, but to focus on broad goals and ideas. Computation is new enough to most instructors that they don't have a clear sense of what it should look like in their courses. Providing field-tested examples of learning goals would help instructors. The section on computation in physics courses in the EP3 guide is a good example for what kinds of learning might be useful.

B. Student Assessment. This topic was a common thread in many talks. Some of the examples are as follows. Danny Caballero's talk on assessing computational knowledge discussed the need for evidence-based assessment of computational skills. He called on the PICUP community to take the lead in figuring out what should be assessed. Daniel Weller shared a possible framework for computational thinking that can guide how we think about assessing students. Workshop attendees brought up this question in the departmental integration workshop and in the computational physics course workshop. Core questions remain regarding what we are assessing about computational work and through which means we are assessing students. Because different departments and even instructors have varying learning goals, as well as constraints and understanding regarding assessment, there are questions remaining about to what extent should assessment instruments and tools be used for large-scale studies and what might be best for more local use or in particular contexts.

We are not making an argument for one type of assessment or one approach; different approaches have considerable strengths, as well as considerable limitations. Rather, we are noting a complicated challenge where decisions should be made carefully and thoughtfully.

C. Department-wide integration. Based on the *Reflections from Practitioners* section, we know that departments are integrating computation in multiple courses. This is promising and provides a good foundation for computation integration in all physics courses. Still, there is work to be done to encourage departments to keep focused on this goal. Departmental constraints, including time and faculty resistance, exist and challenge whether the department can integrate computation in all courses. Some departments might have faculty buy-in and time, but they might be unsure what would be good learning goals for some courses. One of the themes that emerged from the conference relates to the hurdles that faculty face in trying to create a cohesive curriculum involving computation (see Sec. 5). The workshop on department-wide integration was run twice so there is a clear interest in this topic.

D. Expanding the number and diversity of departments involved with PICUP. Figure 5 shows that PICUP has reached many departments across the US and even internationally. However, there are many departments which are not part of the community. While participating in the PICUP community is not the only way for departments to work towards the goal of integrating computation in undergraduate physics, our work (Secs. 3-6) indicates that the PICUP community is often a useful means and has been the catalyst for faculty and departments who were on the cusp of integrating computation but needed one or more key elements to actually implement the integration. Increasing the number of departments would ideally involve increasing the diversity of departments. The overarching goal of PICUP is for all undergraduate physics courses to integrate some computation. Having a diverse group of departments actively participating in PICUP would not only support the overall goal but also improve the PICUP community's understanding of the constraints, challenges, and opportunities when integrating computation. This understanding can help the community learn novel approaches that work at other institutions and spark news ideas.

E. Pandemic. The COVID-19 pandemic has been a consistent presence in everyone's lives since at least March 2020. While increasing vaccination rates and life slowly transitioning from primarily virtual to in-person are providing glimmers of hope and signs the pandemic will end, we would be remiss not to mention the pandemic's impact on the PICUP community. These include but are not limited to: multiple forms of grieving and mourning; the exacerbated stress from living during a pandemic; health impacts on many people; institutional financial austerity and other professional stress; and differences between what students learned pre-pandemic and what they learned during the pandemic. This context is a challenge that may not seem to be directly connected to PICUP or its overarching goals, but faculty, students, and staff are all impacted by the pandemic. Understandably, they may not be able to take on new teaching challenges when handling significant personal and professional challenges.

Although these challenges are listed separately above, they are part of the educational ecosystem. For example, learning goals and student assessment should work in conjunction. These issues are not trivial and require careful deliberation about how PICUP should move forward.

We offer the following recommendations to help the PICUP community overcome these challenges.

- ***Sustain and expand PICUP's current offerings [Addresses challenges A, B, C, D, and E].*** The Capstone attendees were asked about what could PICUP do to help them overcome challenges they face (Sec. 5). Remarkably, many said PICUP was already helpful enough or that PICUP should simply keep doing the same thing, perhaps with more exercises, events, etc. Much of the PICUP community is remarkably dedicated to improving physics education at their own institutions but the members are also invested in supporting the community at other institutions. Encouraging and supporting others to contribute and participate in PICUP offerings can help. In terms of expanding its programs and community, PICUP introduced new offerings during the pandemic. These included a virtual version of the FDW and a virtual conference to share teaching practices during the pandemic. Although in-person offerings are preferred by most faculty members, there are considerable barriers to attending in-person events. People cannot travel for many financial and health reasons. Many institutional or departmental budgets have been frozen during the pandemic. The virtual offerings can be a low-cost way to reach more people.

- ***Provide more scaffolding on the fundamentals of integrating computation across the curriculum [Addresses challenges B and C].*** These include both how to teach computation and how to make changes in their department. For how to teach computation, some educators might be enthusiastic about PICUP's goals but have never taught computation. Guidance on where to begin with students would support these educators by setting them and their students up for success and minimizing unnecessary frustration. Departmental change can be difficult if one has little or no experience with successful change initiatives. Understanding what practices and approaches have been useful will help integrate computation across the curriculum, because this is ultimately a departmental-level change initiative. Knowing how to create an effective change team and what arguments have been compelling to foster change, as well as how to avoid potential pitfalls, will support change agents.

- ***Be more informed by best practices from computer science education research [Addresses challenges B and C]*** The workshop called "Lessons from Computer Science Pedagogy" demonstrated some of the things that computer science education researchers (CSER) have looked at that might not occur to physics instructors or might be different in a physics context. For example, programming in groups of two (pair programming) has been shown to be more effective for computer-related tasks while physics education research has focused on the benefits of three- and four-person groups for traditional problem-solving. How to scaffold coding is also something that has been researched but is not widely known to physics educators. Ethical considerations of programming are another area of research that might not occur to physics instructors. There is a wealth of information in CSER and there is no reason for physicists to reinvent the wheel.

- ***Develop intentional outreach and inclusion efforts for particular populations [Addresses challenge D].*** The PICUP community has grown considerably since its inception. Still, there are many departments that have no faculty participating in PICUP, as well as some types of departments with little or no participation. Not only do we believe that the PICUP community could be useful for these departments if they are interested in integrating computation but we also believe that the PICUP would benefit from having diverse perspectives. This can inform the work, perhaps helping the community devise novel solutions or understand potential issues with current work such as promoting learning goals that are overly ambitious, impractical, or exclusionary.

- ***Support individual members in PICUP in obtaining funding to work related computation integration efforts [Addresses challenges A, B, and C].*** Some faculty members at one department in PICUP have grant funding to work on integrating computation across their curriculum. Although the project is still developing, this project demonstrates how grant funding can solve or decrease the impact of many issues. Faculty can hire staff to help with some of the work, mitigating the issues with time and expertise. Funding can create professional value for those doing this work. Although a grant does not have to address the learning goals and student self-assessment issues, it can help because articulating these features is necessary for a successful grant proposal.

  We envision PICUP playing a supporting role in guiding interested PICUP members in obtaining funding to support their integration of computation across the curriculum. Some faculty might not have experience with writing education grants. Even if they do, having some insight into how PICUP can support their departmental goals and how their projects could fit into the broader goal of integrating computation into all undergraduate physics curricula would likely help create a competitive grant.

- ***Promote diversity and inclusion in the community [Addresses challenge D]***. The PICUP community guides PICUP and has considerable influence over the broader effort to integrate computation in undergraduate physics courses. To ensure that PICUP is truly serving all departments and faculty, diversity, equity, and inclusion must be part of PICUP in many ways.

PICUP should devise low-cost ways to provide an on-ramp to its community. Regional workshops and participating in conferences where underrepresented or traditionally marginalized are present are good ways to "meet people where they are" so that they do not have to go out of their way to attend a PICUP event. The PICUP leadership team should work with a diverse PICUP community to generate ideas about what would help attract members from diverse populations.

Enhancing the diversity of the PICUP leadership can also support this goal by ensuring the PICUP offerings are accessible to and appropriate for a diverse audience, and the PICUP community is welcoming to everyone. For example, two-year colleges have different constraints and goals than four-year institutions. Having that perspective present in the leadership team would help inform offerings.

The leadership plays a major role in decision making around PICUP's work, such as embarking on new directions, and running already existing areas, by showcasing particular workshops or exercise sets, for example. Continuing to have a diverse group in the PICUP leadership team supports the community so it has the capabilities and materials to support a diverse group of educators and contexts. This in turn will demonstrate PICUP's value for and interest in educators in different contexts, attracting yet more faculty.

Another step that the leadership could take is reflecting on what perspectives and work have been promoted and publicized, and which have less visibility. The leadership can work to rectify anything missing by reaching out and engaging with the community. Likewise, if community members observe important perspectives and content that are missing or overlooked, there should be mechanisms for them to share their concerns with the PICUP leadership team and the PICUP community.

We have seen considerable success with PICUP over the past 6 years, but there is still work to be done for the next era of PICUP activities. We anticipate that in an ever-changing world, new societal and educational challenges will arise. We are optimistic that the PICUP model's flexibility and vibrant community can meet those challenges and enhance physics education for tomorrow's students.

Appendix A: Resources for Adopters

This section provides a detailed listing of many resources that may be of value to those who want to incorporate computational modeling into their classrooms and/or departments. All of the urls were checked in late September 2021.

A. PICUP

a. *PICUP exercise collection*. This resource offers a continuously growing collection of computational resources including ready-made, peer-reviewed, open-source classroom activities, curricular resources, community engagement, and expert recommendations. www.gopicup.org

B. Policy and Supporting Documents

a. *EP3 Guide.* A joint APS/AAPT guide for supporting the development of effective practices in undergraduate physics programs including the integration of computation. https://ep3guide.org/guide-overview/computational-skills

b. *Advancing Interdisciplinary Integration of Computational Thinking in Science*. AAPT sponsored conference report that provides recommendations on integrating computational thinking in science courses. (2020) https://www.aapt.org/Resources/upload/Computational_Thinking_Conference_R eport_Final_200212.pdf

c. *AIP Focus On* report on physics bachelors initial employment. These data include use of computation. Mulvey, P. and Pold, J. (2017) https://www.aip.org/statistics/reports/physics-bachelors-initial-employment2014

d. *AAPT Recommendations for Computational Physics in the Undergraduate Physics Curriculum.* AAPT sponsored report by the Undergraduate Curriculum Taskforce on the need to incorporate elements of computation in the undergraduate physics classroom. (2016) https://www.aapt.org/resources/upload/aapt_uctf_compphysreport_final_b.pdf

e. *Phys21 Report: Preparing Physics Students for 21st Century Careers.* A joint APS-AAPT report on improving the undergraduate education of physics majors. Computational literacy is one of the report's central recommendations. (2016) https://www.compadre.org/JTUPP/docs/J-Tupp_Report.pdf

f. *AAPT 2011 Statement on Computation.* The AAPT's original statement of recommendation for the inclusion of computation in the physics classroom. (2011) https://www.aapt.org/resources/policy/statement-on-computational physics.cfm

C. Resource Letters from the American Journal of Physics

a. "Resource Letter CP-2: Computational Physics" Rubin Landau, *Am. J. Phys.* **76**, 206, (2008)

b. "Resource Letter CP-1: Computational Physics" Paul DeVries, *Am. J. Phys.* **64**, 364, (1996)

c. "Resource Letter CPE-1: Computers in Physics Education" Robert Fuller, *Am. J. Phys.* **54**, 782, (1986)

D. Computation-themed AJP issues

a. *American Journal of Physics,* April 2008 issue, *Computation and Computer Based Instruction,* Wollfgang Christian and Bradley Ambrose, editors. https://aapt.scitation.org/toc/ajp/76/4?expanded=67

E. Articles about integrating computation in the physics classroom

a. Apple, L. et al. "Computational Modeling in High School Physics First: Postcards from the Edge," *Phys. Teach.* **59**, 535 (2021); doi.org/10.1119/10.0006458

b. Sachmpazidi, D. et al., "Integrating numerical modeling into an introductory physics laboratory," *Am. J. Phys* **89,** 713, (2021); doi.org/10.1119.10.0003899

c. Caballero, M.D., et al., "PICUP: A Community of Teachers Integrating Computation into Undergraduate Physics Courses," *Phys. Teach.* **57**, 397, (2019); doi 10.1119/1.5124281

d. Orban, C. and Teeling-Smith, R.M. "A hybrid approach for using programming exercises in introductory physics," *Am. J. Phys* **86**, 831 (2018); doi.org/10.1119/1.5058449

e. Leary, A., Irving, P. and Caballero, M.D., "The difficulties associated with integrating computation into undergraduate physics," 2018 PERC proceedings (2018); doi.org/10.1119/perc.2018.pr.Leary

f. Burke, C.J. and Atherton, C.J. "Developing a project-based computational physics course grounded in expert practice" *Am. J. Phys***. 85**, 301 (2017); doi.org/10.1119/1.4975381

g. Caballero, M.D., et al., "Integrating Numerical Computation into the Modeling Instruction Curriculum," *Phys. Teach.* **52**, 38 (2014); doi.org/10.1119/1.4849153

h. Caballero, M.D, and Pollock, S. "A model for incorporating computation without changing the course: An example from middle-division classical mechanics"*Am. J. Phys.* **82**, 231 (2014); doi.org/10.1119/1.4837437

i. Caballero, M.D., et al. "Implementing and assessing computational modeling in introductory mechanics," *Physical Review ST: PER,* **8**, 020106 (2012); doi.org/10.1103

j. Cox, A. et al. "Teaching physics (and some computation) using intentionally incorrect simulations" *Phys. Teach.* **49**, 273 (2011); doi.org/10.1119/1.3578417

k. Beichner, R. et al. "Labs for the Matter & Interactions curriculum," *Am. J. Phys.* **78**, 456 (2010); doi.org/10.1119/1.3266163

l. Chonacky, N. and Winch, D., *Am. J. Phys.* **76**, 327 (2008); doi: 10.1119/1.2837811

m. Chabay, R.W. and Sherwood, B. "Computational physics in the introductory calculus-based course" *Am. J. Phys.* **76**, 307, (2008); doi: 10.1119/1.2835054

n. Buffler, A. et al. "A model-based view of physics for computational activities in the introductory physics course," *Am. J. Phys.* **76**, 431 (2008); doi.org/10.1119/1.2835045

o. Timberlake, T. and Hasbun, J. "Computation in classical mechanics," *Am. J. Phys.* **76**, 334 (2008); doi.org/10.1119/1.2870575

p. Redish, E.F. and Wilson, J.M., "Student programming in the introductory physics course: M.U.P.P.E.T." *Am. J. Phys.* **61**, 222–232 (1993)

F. Articles on Computational Thinking (in physics)

a. Weller, et al. "Developing a learning goal framework for computational thinking in computationally integrated physics classrooms" arXiv:2105.07981 (2021)

b. Orban, C.M. and Teeling-Smith, R.M. "Computational Thinking in Introductory Physics," *Phys. Teach.* **58**, 247 (2020); doi.org/10.1119/1.5145470

c. Pawlak, A., Irving, P.W., and Caballero, M.D., "Learning assistant approaches to teaching computational physics problems in a problem-based learning course," *Phys. Rev. Phys. Educ. Res.* **16,** 010139 (2020); doi.org/10.1103/16.010139

d. Bumler, J.N. et al. "How do previous coding experiences influence undergraduate physics students?" *2019 PERC Conference Proceedings* (2020); doi.org/10.1119/perc.2019.pr.Bumler

e. Odden, T.O.B., Lockwood, E., and Caballero, M.D., ''Physics computational literacy: An exploratory case study using computational essays," *Physical Review: PER* 15, 020152 (2019); doi.org/10.1103

f. Lunk, B.R. "Using Conceptual Blending to model how we interpret computational models," *2019 PERC Proceedings;* doi.org/10.1119/perc.2019.pr.Lunk

g. Sand, O.P., et al. "How computation can facilitate sensemaking about physics: A case study" *2019 PERC Proceedings;* doi.org/10.1119/perc.2018.pr.Sand

h. Bott, T.E., et al. "Student-identified themes around computation in high school physics" *2019 PERC Proceedings*; 10.1119/perc.2019.pr.Bott

i. Lunk, B.R. and Beichner, R. "Attitudes of Life Science Majors Towards Computational Modeling in Introductory Physics," *2016 PERC Proceedings* (2016); doi.org/10.1119/perc.2016.pr.047

j. Obsniuk, M.J., Irving, P.A., and Caballero, M.D. "A Case Study: Novel Group Interactions through Introductory Computational Physics" *2015 PERC proceedings* (2015); doi.org/10.1119/perc.2015.pr.055

k. Lunk, B.R., "A Framework for Understanding Physics Students' Computational Modeling Practices," Ph.D. Diss. NC State University (2012)

l. Weatherford, S.A. "Student Use of Physics to Make Sense of Incomplete but Functional VPython Programs in a Lab Setting" Ph.D. Diss. NC State University (2011)

m. Kohlmyer, M.A. "Student Performance in Computer Modeling and Problem Solving in a Modern Introductory Physics Course," Ph.D. Diss. Carnegie Mellon (2005)

n. Sherin, B.L., "The Symbolic Basis of Physical Intuition: A Study of Two Symbol Systems in Physics Instruction," Ph.D. Diss. UC Berkeley (1996)

G. Resources on Computational Thinking and Computing Education (general)

a. Guzdial, M. and du Boulay, B. "History of computing education research." In Fincher S. and Robins, A., eds, *The Cambridge Handbook of Computing Education Research.* Cambridge University Press, (2019).

b. Shute, V.J., Sun, C., and Asbell-Clarkeb, J. "Demystifying computational thinking" *Ed. Rsch. Rev*. **22** 142-158 (2017)

c. Weintrop, D., et al. "Defining Computational Thinking for Mathematics and Science Classrooms" *Journal of Science Education and Technology* **25**, 127– 147 (2016)

d. Guzdial, M. "Learner-centered design of computing education: Research on computing for everyone." *Synthesis Lectures on Human-Centered Informatics.* Morgan and Claypool, eds. (2015)

e. Brennan, K. and Resnick, M. "New frameworks for studying and assessing the development of computational thinking" Proceedings of the AERA (2012) f. Barr, V. and Stephenson, C. "Bringing computational thinking to K-12: what is Involved and what is the role of the computer science education community?" *ACM Inroads* **2**, 1, (2011); doi.org/10.1145/1929887.1929905

f. Wing, J.M. "Computational thinking" *Communications of the ACM* **49**, 3 (2008); doi.org/10.1145/1118178.1118215

g. diSessa, A., *Changing Minds*, MIT Press, Cambridge M.A., (2000) H. Articles on the state of computation in the physics classroom

h. Young, N.T., et al. "Identifying features predictive of faculty integrating computation into physics courses," *Phys. Rev. Phys. Educ. Res.* **15**, 010114 (2019); doi.org/10.1103/15.010114

i. Caballero, M.D., and Merner, L. "Prevalence and nature of computational instruction in undergraduate physics programs across the United States" *Phys. Rev.: PER* **14**, 020129 (2018)

j. Caballero, M.D., Grecco, E.F., and Murray, E.R., "Comparing large lecture mechanics curricula using the Force Concept Inventory: A five thousand student study" *Am. J. Phys.* **80**, 638 (2012); doi.org/10.1119/1.3703517

k. Kohlmyer, M.A., et al. "Tale of two curricula: The performance of 2000 students in introductory electromagnetism," *Phys. Rev. ST Phys. Educ. Res.* **5**, 020105 (2009); doi.org/10.1103/PhysRevSTPER.5.020105

l. *Advancing Interdisciplinary Integration of Computational Thinking in Science: A Conference Report*, Fisler, K; Hilborn, R., Megowan Romanowicz, C. and Vieyra, R. (American Association of Physics Teachers, 2020).

H. Online curricular resources

a. *GlowScript.org* This resource hosts many sample VPython programs, including those used as part of the Matter & Interactions text. www.GlowScript.org

b. *Open Source Physics*. This resource hosts many computational materials for physics courses at various levels.
https://www.compadre.org/osp/

c. *Code.org* A website aimed at introducing K-12 students to computational practices. www.code.org

d. *Bootstrapworld.org* This BootStrap project focuses on helping elementary high school instructors introduce their students to computation. www.bootstrapworld.org and www.compadre.org/precollege/CMP/

I. Online Student-Facing Instructional Videos

a. *STEM Coding*. Youtube series run by Orban, C.M. et al. on C++ modeling aimed at high school and college-level students.
https://www.youtube.com/c/STEMcoding

b. Let's Code Physics. Youtube series run by Lane, B.W. on Python modeling. https://www.youtube.com/c/LetsCodePhysics

J. Commonly used Textbooks

a. *Introductory Textbooks*

   i. Chabay, R. and Sherwood, B. *Matter & Interactions* 4th ed. (2015) John Wiley publishers.

b. *Upper-level texts that include computational exercises*

   i. Nelson, P., *Physical Models of Living Systems,* 2nd edition (2021).

   ii. Schroeder, D. *Notes on Quantum Mechanics* (2020) Unpublished.

   iii. Griffiths & Schroeter, *Quantum Mechanics* 3rd ed. (2018) Cambridge University Press

   iv. Thornton, S. and Marrion, J., *Classical Dynamics of Particles and Systems* 5th ed. (2012) Cengage Learning Publishing.

   v. Schroeder, D. *Thermal Physics.* (2000) Addison Wesley Longman publishing.

c. *Scientific Computation Textbooks Suitable for a Numerical Methods course or as a supplement to a core course.*

   i. Kinder, J. & Nelson, P. *A Student's Guide to Python for Physical Modeling*: 2nd Edition (2021) Princeton University Press

   ii. Wang, J. *Computational Modeling and Visualization of Physical Systems with Python* (2016) John Wiley Publishing

   iii. Gould, H., Tobochnik, J., & Christian, W. *An Introduction to Computer Simulation Methods: Applications to Physical Systems,* revised 3rd ed. (2016) CreateSpace Independent Publishing Platform.

   iv. Shiflet A. & Shiflet G. *Introduction to Computational Science: Modeling and Simulation for the Sciences* 2nd ed. (2014) Princeton University Press.

   v. Newman, M. *Computational Physics* (2013) CreateSpace Independent Publishing Platform

   vi. Giordano, N.J. & Nakanishi *Computational Physics* (2006) Pearson Prentice Hall Publishing

K. Resources in interactive engagement Pedagogy

a. Mestre, J.P. and Docktor, J.L. *The Science of Learning Physics: Cognitive Strategies for Improving Instruction,* (World Scientific Pup. 2021)

b. "Resource Letter ALIP–1: Active-Learning Instruction in Physics," Meltzer, D.E. and Thornton, R.K., *Am. J. Phys.* **80**, 478 (2012)

c. Singer, S.R., Nielsen, N.R., and Schweingruber, H.A., eds. *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering* (The National Academies Press, Washington, DC. 2012).

d. Ambrose, S.A, Bridges, M.W., Lovett, M.C., DiPietro, M., and Norman, M.K., *How Learning Works: Seven research-based principles for smart teaching* (Jossey Bass, San Francisco, 2010)

e. Knight, R.D, *Five Easy Lessons* (Addison Wesley Longman, San Francisco, CA, 2003)

f. Carl Wieman Science Education Initiative website with many resources on reformed pedagogy in college science courses.
   http://www.cwsei.ubc.ca/index.html

g. PhysPort. This website provides a searchable and annotated database of tested physics pedagogies for a wide variety of physics courses. https://www.physport.org/.

L. Resources on curricular and course reform

a. Grant Wiggins and Jay McTighe, *Understanding by Design,* 2nd ed. (Association for Supervision and Curriculum Development, 2005). A practical guide to designing a course by starting with learning goals and objectives

b. Dancy, M. and Henderson, C. "Physics faculty and educational researchers: divergent expectations as barriers to the diffusion of innovations" *Am.J.Phys.* **76**, 79 (2008) doi.org/10.1119/1.2800352

c. Chasteen, S.V., Perkins, K.K, Beale, P.D., Pollock, S.J., and Wieman, C.A., "A Thoughtful Approach to Instruction: Course Transformation for the Rest of Us," *Journ. Coll. Sci. Teach.* **40**, 76 (2011).

d. http://www.cwsei.ubc.ca/resources/files/CourseTransformationGuide_CWSEI_C U-SEI.pdf. A guide to course transformation at the college and university level.

e. Catherine Fry, ed. *Achieving Systemic Change: A Sourcebook for Advancing and Funding Undergraduate STEM Education* (AACU, 2014). http://www.aacu.org/sites/default/files/files/publications/E-PKAL-Sourcebook.pdf

M. Examples of the importance of computation in recent basic research

a. Doeleman, S. for the Event Horizon Collaboration, "Focus on the First Event Horizon Telescope Results", *Astrophysical Journal Letters*, (2019). Available at: https://iopscience.iop.org/journal/2041-8205/page/Focus_on_EHT Retrieved: 9 Feb 2022.

b. Aad, Georges, et al. "Combined Measurement of the Higgs Boson Mass in p p Collisions at s= 7 and 8 TeV with the ATLAS and CMS Experiments." *Phys. Rev. Lett.* **114.19** (2015): 191803.

c. Abbott, Benjamin P., et al. "Observation of gravitational waves from a binary black hole merger." *Phys. Rev. Lett.***116.6** (2016): 061102.

Appendix B: Faculty Development Workshop Schedule

Monday, July 8

Afternoon: Arrival and Check-In for those attending the "Computational Basics" tutorials.

5:00-5:30 **DINNER**

5:30-7:00 For those participating in "Computational Basics" tutorials on Tuesday, we will provide assistance with downloading software and preparing your laptop computers for the Tuesday sessions.

Evening/Night: Feel free to hike to the river and/or local taverns.

Tuesday, July 9

7:30-8:00 **BREAKFAST**

9:00-9:30 **Welcome and brief introduction to PICUP** (Kelly Roos)

9:30-10:30 **Computational Basics Session I**

10:30-10:45 **BREAK**

10:45-11:30 **Computational Basics Session II**

11:30-12:00 **LUNCH**

Afternoon: Arrival and Check-In (for those arriving on Tuesday)

12:30-2:30 **Computational Basics Session III**

- Finite Differences
- Solutions to First Order Differential Equations
    - Simple Euler Method
    - Spreadsheet Implementations
- Nuclear Decay Example
- Falling Sphere

2:30-2:45 **BREAK**

2:45-5:00 **Computational Basics Session IV**

- Spreadsheet Implementation
    - Simple Harmonic Oscillator and Euler-Cromer Method
- Programming Implementation
    - Simple Pendulum

5:00 - 6:00 **BREAK** (and coordinators meeting)

6:00-6:30 **Welcome Dinner**

6:30-7:00 **Introductions, Workshop Overview**

7:00-7:30 **Explore PICUP website and using Slack**

This session will serve as an introduction to the PICUP website and materials repository at www.gopicup.org (aka https://www.compadre.org/picup/), and also provide the opportunity for us to get feedback on the site's friendliness and usability as we have recently rolled out some new content and functionality.

gopicup.slack.com is the main communications/collaboration software used by PICUP.

7:30 - 8:30 **Computational Basics Extended Help**

Wednesday, July 10

7:30-8:00 **BREAKFAST**

8:30-9:00 **Morning Briefing**

DAILY PARTICIPANT GOAL: Outline of Computational Integration Plans

9:00-10:15 **Spreadsheet Physics**

This session is intended to provide a brief demonstration of the usefulness of the ubiquitous spreadsheet tool, and a refresher on the modified Euler algorithm applied to the ODEs for velocity and position, while setting the working mood for the workshop. Even seasoned spreadsheet users will benefit from this session.

10:15-10:30 **BREAK**

10:30-11:30 **PANEL #1: Models for Integrating Computation** (Marié, Ernie, Jay, Josh, Gillian, Michele M)

Where do your courses fall in the Computation Implementation Space?

11:30-12:00 **LUNCH**

12:15-1:30 **Pair Programming Workshop** (Michelle Kuchera)

1:30-1:45 **BREAK**

1:45-3:45 **Learning Goals Workshop** (Danny Caballero)

What do you want your students to be able to do? This simple, yet poignant, question should be answered before you outline your plan for integrating computational activities into your course(s). This session will provide a practical approach to setting learning goals and objectives for your students.

3:45-4:00 **BREAK**

4:00-4:45 **At your table:** Discuss plans for the week, draft computational implementation plan, and post "themes" on Slack (for breaking into groups on Thursday morning). Possible themes: class, programming language, setting. Request tutorial topics.

4:45-4:55 **Daily Wrap-Up**

5:00-5:30 **DINNER**

6:00-7:00 **Optional tutorial: vPython / Glowscript** (Todd, Brandon, Michele M)

7:00-8:00 **Optional tutorial: More advanced Python with Jupyter/Spyder** (Larry, Jay) Symbolic Math, Animating, Array Slicing, Compiling

Evening/Night: Optional Tutorials / Continue Work on Plan Outlines / Hike to the river and/or local taverns

Thursday, July 11

7:30-8:00 **BREAKFAST**

8:30-8:45 **Morning Briefing**

DAILY PARTICIPANT GOAL: Draft of Exercises and Learning Goals

8:45-9:00 **ALPhA**

9:00-10:30 **PANEL #2: Challenges of Integrating Computation** (Danny Caballero)

What are the specific barriers to including computational activities in physics courses, and how are they overcome?

10:30-10:45 **BREAK**

10:45-11:30 **Computational Activity Design & Components of an "Exercise Set"** (Larry Engelhardt)

Practical guidelines on how to prepare materials that will be easily transitioned into an Exercise Set.

11:30-12:00 **LUNCH**

12:00-12:15 **Split into Groups**

12:15-2:00 **Small Group Collaborative Work Time**

- Discussion on computational activity design process
- Produce learning goals for the courses, learning objectives for a computational activity
- Produce first draft of exercise set / first few exercises

2:00-2:15 **BREAK**

2:15-4:30 **Small Group Collaborative Work Time (continued)**

4:00-4:30 **Coordinators Meeting**

4:30-4:50 **Daily Wrap-Up**

5:00-5:30 **DINNER**

Optional Tutorials:

6:00-7:00 **Git** (Daniel Borrero, Michelle Kuchera) @ Trimbelle River Room

7:00-8:00 **Jupyter in the Cloud** (Daniel Sinkovits, Todd Zimmerman) @ Trimbelle River Room

Round Table Discussions:

6:00-7:00 **Diversity and Inclusion** (Gillian Ryan)

7:00-8:00 **Departmental Level Integration** (Ernie Behringer, Kelly Roos)

Evening/Night: Optional Tutorials / Continue Work on Plan Outlines / Hike to the river and/or local taverns

Friday, July 12

7:30-8:00 **BREAKFAST**

8:30-8:45 **Morning Briefing**

DAILY PARTICIPANT GOAL: Refined Computational Exercises/Activities

8:45-10:00 **Small Group Collaborative Work Time**

- Intra-group presentations of models for integration and planned exercises
- Share ideas
- Collaborative discussion and feedback

10:00-10:30 **BREAK and GROUP PHOTO!!!**

10:30-11:30 **Coordinators Meeting**

10:30-11:30 **Small Group Collaborative Work Time**

Computational Activity Design

Refine:

- computational activity
- integration plan
- assessment plan

11:30-12:00 **LUNCH**

12:15-1:15 **PANEL #3: Institutional implementation: Challenges and Strategies** (Kelly Roos) Departmental- and curriculum-wide integration of computational activities

1:00-2:00 **Small Group Collaborative Work Time (continued)**

(Optional) **Authoring and Submitting an Exercise Set to gopicup.org** (Larry Engelhardt)

1:30 (Optional) **Cheese Curd Run I**

2:00-2:15 **BREAK**

2:15-4:30 **Small Group Collaborative Work Time (continued)**

3:00 (Optional) **Cheese Curd Run II**

4:30-4:45 **Daily Wrap-Up**

4:45 **3-minute slide** (for those who can't stay for the evening showcase)

5:00-5:30 **DINNER**

6:00-8:00 **Computational Plan Showcase!**

One slide, 3-minute presentations

8:30 **RIVER FALLS DAYS: live music @ Heritage Park Main Stage!**

Saturday, July 13

7:30 **RIVER FALLS DAYS: 10K/2mi race!**

7:30-8:00 **BREAKFAST**

8:30-8:45 **Morning Briefing**

DAILY PARTICIPANT GOAL: Develop Student-Facing Documents for Computational Exercises/ Activities; Complete Package

8:45-10:15 **Small Group Collaborative Work Time**

Work on student-facing documents.

10:15-10:30 **BREAK**

10:30-11:30 **PANEL #4: Assessing Computational Modeling in the Classroom** (Marié Lopez del Puerto)

- Assessment of student learning
- Grading
- Exams
- Educational effectiveness of computational activities

11:30-12:15 **LUNCH**

12:00-1:00 **Optional Tour: ALPhA Immersions at UW-River Falls**

12:15-2:00 **Small Group Collaborative Work Time**

- Add assessment plan to computational integration plan
- Refine exercise set

2:00-2:15 **BREAK**

2:15-4:30 **Small Group Collaborative Work Time**

4:45-4:50 **Daily Wrap-Up**

5:00-5:30 **DINNER**

6:00-8:00 **Computational Plan Showcase! Part 2**

One slide, 3-minute presentations

9:00 **RIVER FALLS DAYS: live music @ Heritage Park Main Stage!**

Sunday, July 14

7:30-8:00 **BREAKFAST**

8:30-8:45 **Morning Briefing**

DAILY PARTICIPANT GOAL: Finalize Integration Plan; Practical Consideration of Continued PICUP Involvement

8:45-9:15 **What Next? – Continued Involvement in PICUP Community** (Kelly Roos)

- Stay in touch via Slack, virtual meetings, workshops/sessions/events at AAPT and APS, etc.
- 2020 PICUP Capstone Conference, July 15-18 @ Calvin University, Grand Rapids, MI
- Contribute Materials
- Exercise Sets
- Faculty Commons Materials
- Topical Collections Curator
- Reviewer/Referee
- Associate Editor
- Resources Curator
- Host a Workshop
- Synchronous Meeting Committee
- Other—we're very much open to (and in need of) YOUR ideas for positions and moving this community forward!

9:15-10:00 **Small Group Collaborative Work Time**

- Finalize materials
- Set SLACK reminders for to-dos before Fall semester

10:00-10:15 **BREAK**

10:15-11:00 **Small Group Collaborative Work Time**

- Finalize materials
- Set SLACK reminders for to-dos before Fall semester

11:00-11:30 **Workshop Wrap-Up**

11:30-12:30 **LUNCH**

Afternoon: Check-Out and Departures

Appendix C: Capstone Conference Schedule

Wednesday August 11

10-10:15 **Welcome** (Marie Lopez del Puerto)

10:15-11:15 **Plenary I:** Brian O'Shea, "The future of computational and data science"

11:15-11:30 **Coffee Break**

Breakout rooms will be open for conversations:

1. Continued discussion with Brian O'Shea
2. Faculty Development Workshop at UW-River Falls, 2016 and 2019
3. Faculty Development Workshop at UW-River Falls, 2017 and 2018
4. Workshops at APS and AAPT national meetings
5. Regional / local / institutional / virtual workshops

11:30-1:10 **Invited Session: The state of integrating computation** Moderated by Gillian Rya

11:3-11:55 **Ruth Chabay, "Computation in the Introductory Physics Course"**

11:55-12:20 **Elizabeth George, "Connecting computational and laboratory instruction in physics"**

12:20-12:45 **Nicholas Young, "Why physics instructors choose to include computation in their courses"**

12:45-1:10 **Paul Irving, "Integrating Computation in Science Across Michigan"**

1:10-2 **Lunch Break**

Breakout rooms will remain open for conversations.

1. Continued discussion with Ruth Chabay from 1:10 to 1:30
2. Continued discussion with Elizabeth George from 1:10 to 1:30
3. Continued discussion with Nicholas Young from 1:10 to 1:30
4. Continued discussion with Paul Irving from 1:10 to 1:30
5. Two-year Colleges
6. Four-year colleges and universities
7. R1s

2-3 **Networking Birds-of-a-Feather**

Join your selected group's breakout room:

1. Intro Mechanics
2. Intro E&M
3. Labs
4. Upper-level
5. Astronomy
6. Research
7. Programming language wars?

3-4:40 **Invited Session: Assessment:** Moderated by Jay Wang.

3-3:25 **Danny Caballero, "Assessing Computational Knowledge and Skills: The Role of Community"**

3:25-3:50 **Tor Odden, "Using Computational Essays to Support Student Creativity and Agency in Physics"**

3:50-4:15 **Chandralekha Singh, "Including computation in physics courses at all levels using evidence-based approaches"**

4:15-4:40 **Dan Weller, "Learning Goal Framework for Computational Thinking in Computationally Integrated Physics Classrooms"**

4:40-5 **Coffee Break**

Breakout rooms will be open for conversations.

1. Continued discussion with Danny Caballero
2. Continued discussion with Chandralekha Singh
3. East coast
4. Midwest
5. South and international
6. West coast

5-6:10 **Contributed Talks,** Moderated by Danny Caballero.

Thursday August 12

Connection information for workshops (either Zoom or gather.town) will be sent out by the individual workshop facilitators.

10-11:50 **Parallel Workshops**

- Th-1 Introductory Physics: Planning a Coherent Course and Choosing the Right Tools
- Th-2 Integrating Computation and Experiment
- Th-3 Department-wide Computational Integration
- Th-4 Lessons from Computer Science Pedagogy
- Th-5 Computational Integration into Astronomy and Astrophysics Classes
- Th-6 The Computational Physics Course: Objectives, Design, and Assessment

11:50-12:10 **Coffee Break** (in your workshop)

12:10-2 **Parallel Workshops (continued)**

2-3 **Lunch Break (back to MSU's Zoom)**

Breakout rooms will be open for conversations.

1. Intro Mechanics
2. Intro E&M
3. Labs
4. Upper-level
5. Astronomy
6. Research

3-4 **Plenary II: Courtney Lannert, "Integrating computational physics into your curriculum using the EP3 guide"**

4-4:10 **Zoom Picture** - wear your PICUP shirt!

4:10-4:20 **Coffee Break**

Breakout rooms will be open for conversations.

1. Continued discussion with Courtney Lannert.
2. Two-year Colleges
3. Four-year colleges and universities (<5,000 students)
4. Four-year colleges and universities (>5,000 students)
5. R1s

4:20-5 **Contributed Talks** Timeslots 1-4: Moderated by Larry Engelhardt

5-5:10 **Break**

5:10-6 **Contributed Talks** Timeslots 5-9: Moderated by Kelly Roos

Friday August 13

Connection information for workshops (either Zoom or gather.town) will be sent out by the individual workshop facilitators.

10-11:50 **Parallel Workshops**

- Fr-1 Introductory Physics: Planning a Coherent Course and Choosing the Right Tools Fr-2 Integrating Computation and Experiment
- Fr-3 Department-wide Computational Integration
- Fr-4 The Computational Physics Course: Objectives, Design, and Assessment
- Fr-5 Preparing and Submitting an Exercise Set, and Becoming a Reviewer
- Fr-6 Upper-Division Physics: Planning a Coherent Course and Choosing the Right Tools

11:50-12:10 **Coffee Break** (in your workshop)

12:10-2 **Parallel Workshops** (continued)

2-3 **Lunch Break** (back to MSU's Zoom)

Breakout rooms will be open for conversations.

3-4 **Invited Panel: Case Studies of Integrating Computation**
Moderated by Brandon Lunk.
Panelists: Aaron Titus, Tony Musumba, and Michele McColgan.

4-4:20 **Coffee Break**

Breakout rooms will be open for conversations.

1. Continued discussion with Brandon Lunk.
2. Continued discussion with Michele McColgan.
3. Continued discussion with Tony Musumba.
4. Continued discussion with Aaron Titus.

4:20-5 **Contributed Talks:** Moderated by Danny Caballero

5-5:30 **Concluding Remarks (Kelly Roos)**

Appendix D: Capstone Conference Abstracts

Session	Title	Presenters	Abstract
Wednesday Plenary	The future of computational and data science	Brian O'Shea, Michigan State	Physics as a discipline has been on the leading edge of computational and data science since these fields were conceived. The evolution of computational science as a means of scientific exploration, as well as the emergence of data science as a field in its own right, has occurred very rapidly over the past decade. This trend is virtually guaranteed to continue through the 2020s. I will focus on the recent past and on the future of these fields, using case studies taken from recent scientific advances. In addition, I will make some suggestions on what these trends mean in terms of the training that STEM students will need to be successful in the future.
Wednesday Invited Session: The State of Integrating Computation	Computation in the Introductory Physics Course	Ruth Chabay, Santa Fe	Integrating computation into the introductory physics course involves many challenges, both pedagogical and political. Most students have no background in computation; there are already too many required topics in the course; many faculty who teach this course are uncomfortable with computation. The possible payoff – empowering students to model complex real-world situations by applying fundamental physical principles – makes it worth persevering in this effort. After more than two decades of effort, however, many questions remain. This talk will focus on setting realistic and appropriate goals, providing a supportive computational environment, appropriate assessment, and identifying important research questions.
Wednesday Invited Session: The State of Integrating Computation	Connecting computational and laboratory instruction in physics	Elizabeth George, Wittenbergy University	Because "there is a close connection between the skills and practices used in computation and in the laboratory" (AAPT Recommendations for Computational Physics in the Undergraduate Physics Curriculum), there are natural opportunities in the undergraduate physics curriculum for computational and laboratory instruction to complement and reinforce each other. The PICUP and ALPhA (Advanced Laboratory Physics Association) communities provide many examples of integrating computational work and advanced laboratory experiences. These illustrate how connecting computation and experiment can help students develop their physics skills, attitudes, and thinking.
Wednesday Invited Session: The State of Integrating Computation	Why physics instructors choose to include computation in their courses	Nicholas Young, Grant Allen, Michigan State; John M. Aiken, U. Oslo	Computation is a central aspect of 21st century physics practice and physics departments are increasingly recognizing the importance of teaching computation to their students. We completed a national survey of 1257 faculty in physics departments to understand the state of computational instruction and the factors that underlie that instruction. We then used supervised machine learning to explore the factors that are most predictive of whether a faculty member decides to include computation in their physics courses. We find that faculty's experience with computation and the benefits they believe computation provides are most predictive of including it in their courses.

Wednesday Invited Session: The State of Integrating Computation	Integrating Computation in Science Across Michigan	Paul Irving, Marcos Caballero, David Stroupe, Niral Shah, Michigan State	Integrating Computation into Science Across Michigan (ICSAM) is an NSF-funded project that focuses on supporting teachers who wish to incorporate computational activities into their physics classrooms in an equitable way. The emphasis of the workshop is to build up teachers' efficacy and ability with computation while also considering the impact on equity that computation can have in the physics classroom. Parallel to running the workshop and building a community of integrating teachers we have developed focused on both the teachers and students in these integrated environments. In this talk, we discuss the current state of the ICSAM project and how it has informed our understanding of integrating computation in the high school setting.
Wednesday Invited Session: Assessment	Assessing Computational Knowledge and Skills: The Role of the Community	Danny Caballero, Michiga State and the University of Oslo	Computation is increasingly becoming a major part of the undergraduate physics experience with developing students' computational capabilities now a central goal of many physics programs. But how do we gain confidence that students have developed the knowledge and skills we intend? How can we scaffold that development process? I will highlight the role that assessment plays in helping students develop computational knowledge and skills. I will present the need for theoretically-grounded and community-developed assessments that can be used widely to evaluate learning outcomes, pedagogical approaches, and course designs. Finally, I will discuss the approaches that the PICUP community can take to start developing these new assessments.
Wednesday Invited Session: Assessment	Using Computational Essays to Support Student Creativity and Agency in Physics	Tor Ole Odden Anders Malthe-Sørenssen, Devin Silvia University of Oslo	Computation holds great potential for enabling students to engage in creative, exploratory, and investigative scientific coursework. At the University of Oslo, we have been exploring this potential through the development and testing of a new teaching tool known as a computational essay. In this talk, I will describe how we are conceptualizing student creativity and agency in physics, how we use computational essays to support these qualities in our teaching, and the various possibilities for using computational essays as an alternative mode of physics assessment.
Wednesday Invited Session: Assessment	Including computation in physics courses at all levels using evidence-based approaches	Chandralekha Singh, David Nero, University of Pittsburgh	Integrating computation with the physics curriculum is important with a principal goal of developing students' computational skills, and leveraging those skills to gain physical insight. First, I will discuss how, using Open Source Physics simulations and other tools, we have incorporated computer simulations within Quantum Interactive Learning Tutorials (QuILTs). QuILTs are research-validated learning tools to help students in upper-level undergraduate quantum mechanics course develop a solid grasp of relevant concepts without compromising the technical content. Then, I will discuss the effectiveness of a flipped computational physics course which uses evidence-based approaches to improving students computational thinking skills.

Wednesday Invited Session: Assessment	Learning Goal Framework for Computational Thinking in Computationally Integrated Physics Classrooms	Daniel Weller Theodore E. Bott, Marcos D. Caballero, Michigan State	Computational thinking has been a recent focus of education research within the sciences. In this talk, we lay the foundation for exploring computational thinking in introductory physics courses. The computational thinking framework that we have developed features 14 practices contained within 6 different categories. We use in-class video data as existence proofs of the computational thinking practices proposed. In doing this work, we hope to provide ways for teachers to assess their students' development of computational thinking, while also giving physics education researchers some guidance on how to study this topic in greater depth.
Wednesday Contributed Session	Computational Curriculum Culminating in a Final Project for Introductory Mechanics	Daniel Sinkovits. U. Wisconsin-Stout	I have designed and implemented a series of nine in-class computational activities which use VPython/Glowscript. Each activity is linked to the current physics being taught, and they progressively introduce more challenging computational skills. I reserve the last week or two of the semester giving the students a chance to create a final project based on all they have learned. I have been impressed with the creativity and understanding of physics shown in their final projects. I will outline the curriculum and demonstrate some of the final projects.
Wednesday Contributed Session	Integrating numerical modeling into an introductory physics laboratory	Diana Sachmpazidi, Manuel Bautista, Zbigniew Chajecki, Claudio Mendoza, and Charles Henderson, Western Michigan	This presentation will describe the approach towards redesigning a calculus-based introductory physics laboratory course to incorporate numerical modeling using MS Excel spreadsheets. We will also discuss the structure and pedagogical approach of this revised lab course. We used interview data to assess student and instructor attitudes towards this course. Interview results suggest that students identified numerical modeling as the most important and beneficial lab course feature. Moreover, we found that the numerical models allowed students to engage in more complex and realistic situations, which triggered their interest and kept them engaged in the task.

Wednesday Contributed Session	Machine Learning in Upper-Level Physics Lab	Peter Bryant,Nicolas Desch, Bethany College	We used machine learning techniques to analyze data in a three-hour, independent-study laboratory course, which was a trial run for an upper-level laboratory course currently in development. Specifically, we compared the effectiveness of a simple classical analysis to that of a machine learning approach to identify structural defects in aluminum sheets, based on the sounds they make when lightly struck. In this presentation I will report on the project and its fit in the physics curriculum. I will also discuss the application of machine learning to physical systems and some of the available resources for non-specialists.
Wednesday Contributed Session	Bridging PICUP and ALPhA - An Integrated Computational and Advanced Laboratory Activity	Michael Olson, Nicholas Mauro, St. Norbert College	Inspired by the 2019 ALPhA/PICUP Immersion at UW River Falls, an example of an integrated computational and advanced-laboratory activity is presented, combining elements of “Harnessing the Power of the Arduino for the Advanced Lab”, (ALPhA Laboratory Immersion, Herbert Jaeger, Miami University of Ohio, 2016), "Heat flow -- Dynamics of a 1D Rod" (PICUP Exercise Set, developed by Larry Engelhardt, published July 17, 2016), and "2D Heat Flow" (Kelly Roos & Eric Ayars, 2019 ALPhA/PICUP Immersion at UW River Falls). It is intended that this project will serve as a template for future computationally-based activities in an integrated electronics/advanced-laboratory sequence at St. Norbert College.
Wednesday Contributed Session	When You Are Not the Instructor: Introducing Computation to a Physics Lab Course Taught by Graduate Assistants	Axel Mellinger, Central Michigan	Physics lab courses are a good opportunity to introduce computing to students. However, when the course is taught by graduate assistants, with a faculty member serving as course coordinator, unique challenges arise, such as the need to train the graduate instructors and having a computing platform that is accessible to students with minimal support. At Central Michigan University, we started to add computational topics to our "University Physics I" lab course with a typical enrollment of 80-100 students, and set up a dedicated JupyterHub server with Nbgrader to facilitate online grading. The presentation discuss successes and challenges experienced in the years since initiating the project.
Wednesday Contributed Session	Design and Development of Open-source Capstone Project Management Portal	Divya Prakash Mittal,Ramit Koul, Utkarsh Chauhan, Aryamaan Pandey, Dr. Vinay Kumar, Thapar Institute of Engineering and Technology	The capstone project helps students to apply the engineering fundamentals, prepares for future challenges and provides an opportunity to work in teams and find solutions to real-world, open-ended technology-related problems. With a variety of stakeholders (students, mentors, coordinators) managing such a large project is a difficult task. In this paper, we present an open-source Capstone Project Management Portal, which provides the facility to manage all the processes involved in a year-long project. Until now many universities manage these processes manually or in a semi-automated manner. Research into the workflow of this whole system revealed major data inconsistency and redundancy issues which lead to the development of this portal.

Wednesday Contributed Session	Revision of a general education astronomy course through adding computational activities	Raymond Zich, Illinois State, Rebecca Rosenblatt, AAAS Science and Technology Policy Fellow James DiCaro, Illinois State	In this study fifteen spreadsheet-based computational exercises were designed and tested to complement an existing active learning astronomy curriculum. The development of these computational activities is presented along with examples of the exercises and the results of incorporating the computational activities. The reasons for introducing computational activities will be discussed, along with benefits supporting the inclusion, and difficulties faced implementing the change. Assessment of the success of incorporating these computational activities was measured with pre to post TOAST and LPCI testing. Additionally, student survey data was collected to investigate student attitudes toward computational exercises and perceptions of the course. Assessment revealed TOAST correctness gains of 20%, LPCI correctness gains of 29%, and overall positive attitudes towards the computational activities.
Thursday Workshop Session,Frid ay Workshop Session	Department-wide Computational Integration	Todd Zimmerman, U. Wisconsin-Stout	This workshop will explore the challenges and opportunities in integrating computation in a coherent way throughout a larger program of study -- either an introductory physics sequence or an entire physics degree. Participants will examine how to plan a coherent, program-wide set of computational learning goals so that students build on their previous skills in each new class, assessment strategies for both student work and for the computational aspect of the program itself, and the challenges inherent in creating program-wide curricular reform that aligns with other department objectives.
Thursday Workshop Session,Frid ay Workshop Session	Department-Wide Computational Integration	Todd Zimmerman, U. Wisconsin-Stout,Andrew Gavrin, Indiana University–Purdue University Indianapolis	This workshop will explore the challenges and opportunities in integrating computation in a coherent way throughout a larger program of study -- either an introductory physics sequence or an entire physics degree. Participants will examine how to plan a coherent, program-wide set of computational learning goals so that students build on their previous skills in each new class, assessment strategies for both student work and for the computational aspect of the program itself, and the challenges inherent in creating program-wide curricular reform that aligns with other department objectives.
Thursday Workshop Session,Frid ay Workshop Session	Integrating Computation and Experiment	Ernest Behringer, Daniel Borrero, Eastern Michigan	During this workshop, an initial overview of the AAPT guidelines for computational physics and for the undergraduate physics laboratory curriculum will focus attention on valuable skills physics students should develop in computation and experiment, and on the range of tools available to facilitate student acquisition of these skills. Participants will be introduced to different experiments, spanning a range of cost and complexity, that have a significant computational component. Participants will have time to work through some of the computational tasks required for the experiments, including modeling, visualization, and comparison of model predictions to measurements.

Thursday Workshop Session,Friday Workshop Session	Introductory Physics: Planning a Coherent Course and Choosing the Right Tools	W. Brian Lane, U. North Florida; Larry Engelhardt, Marie Lopez del Puerto, Jason Ybarra	Computational integration is most effective when it is sustained and coherent across an entire course. In this workshop, participants will design an entire introductory curriculum incorporating computation, examining how computational activities fit together to serve course-wide learning goals. We will focus on curating exercises from published collections, assessment techniques, and choosing computational tools to best suit a variety of student populations and course formats. Workshop materials will appear in https://drive.google.com/drive/folders/1JE4UPBHoOl8dkUmtBd4ZyBIniPD0yjfI
Thursday Workshop Session	Computation in Introductory Astronomy	Walter Freeman, Syracuse, Michele Montgomery, U. Central Florida	Introductory astronomy may seem like an unlikely setting for computation; it is less mathematical than most physics courses, and the students who enroll often come from nontechnical majors. However, computation can still play an important role in introductory astronomy courses. Computers can allow students to visualize complex data sets that are common in astronomy, and can -- as always -- allow students to focus on the essential physics at hand by using a machine to calculate and visualize the consequences of mathematical laws. In this workshop, we will present several activities for introductory astronomy and explore how computation can fit into these courses.
Thursday Workshop Session	Lessons from computer science pedagogy	Michelle Kuchera, Davidson College	Teaching computational physics almost always involves teaching students to code, but physics faculty rarely have extensive training in best practices for programming pedagogy. Computer science departments, however, have thought carefully about this, and physics faculty can benefit from their experience. This workshop, led by a computer scientist, will examine best practices in teaching students the nuts and bolts of programming, including an exploration of "pair programming" exercises.

Thursday Plenary	Integrating computational physics into your curriculum using the EP3 guide	Courtney Lannert, Smith College	The EP3 Project (EP3guide.org) seeks to help strengthen and improve physics departments and programs nationwide by building on research and community knowledge and practice. The guide offers advice on a wide variety of topics, from Departmental Culture and Climate to Introductory Courses for STEM Majors, designed to be flexible, not prescriptive, and useful in the wide variety of local contexts experienced by physics programs in the US (and perhaps beyond). After a brief overview of the guide and its use, I will describe the development process for the section on Computational Skills as well as its recommendations and a sample of the ways in which it might be used to integrate these important skills into the physics curriculum.
Thursday Contributed Session	Integration of Computation into mechanics at WFU	Freddie Salsbury, Wake Forest University	Over several years, the sophomore-level majors' mechanics class (Physics 262) has been revised to include an introduction to computation using Matlab. This work will be presented along with lessons learned about the importance of group work for students and pacing. This integration of computation has also been extended to half of the corresponding Intermediate Lab to allow for more in-depth problems for those who take and also in graduate statistical mechanics.
Thursday Contributed Session	Implementing "Computational Mondays" in upper-level classical mechanics	Jed Rembold, Willamette University	An upper-level classical mechanics course can benefit from a strong computational element, allowing analysis of otherwise intractable problems and equipping students with visualization tools to check cryptic analytic results. However, ensuring that students have the necessary support and class time to develop those computational skills can be difficult. Over the past five years of teaching classical mechanics, I have iterated on a policy of setting aside one third of my lecture days for computational development. I will explain why such a time investment in computation is worthwhile, and discuss the details and content of my implementation of these "Computational Mondays". Additionally, I will cover lessons that I have learned along the way and discuss ideas for future implementations.
Thursday Contributed Session	Advanced Electricity and Magnetism Exercises: Scaffolding in the Lower Levels	Nicholas Mauro, Michael Olson, St. Norbert College	In this talk, we present the recent development of two long-form advanced electricity exercises focused on developing key physical ideas about (1) the electric potential through Poisson's equation and (2) Faraday's law while simultaneously introducing students to principles of computation. Small college physics programs often introduce mathematical and computation techniques in the context of the traditional content curriculum so care must be taken to balance all course elements. These two problem are designed to be computational laboratory exercises or long-form class / homework problems. We'll discuss the E&M exercises, key learning objectives, and how one can introduce the foundational computational elements at the lower levels.

Thursday Contributed Session	Interdisciplinary computational modeling of biophysical processes	Sorinel Oprisan, College of Charleston	Cross-disciplinary courses are rewarding and lead to a more robust and effective integration of knowledge. We developed and implemented an interdisciplinary computational biophysics/neuroscience class targeting biology and psychology-oriented students and physics, mathematics, and computer science-oriented minds. The cross-listed BIOL 396/ PHYS 396 Biophysical Modeling of Excitable Cells class aims to design and calibrate biologically realistic computational models for (neural) cells and biological neural networks. The emphasis is on mathematical and computational modeling of biological and psychological experiments. As such, the class prerequisites are both biology and physics.
Thursday Contributed Session	Counting microstates of the p-state paramagnet	Steuard Jensen, Alma College	One effective approach to introducing entropy and the second law is to study models with easily countable states at fixed energy. With the help of a spreadsheet program, students can compute a system's temperature, heat capacity, and interaction behavior. But such systems are hard to find: the only familiar examples are the Einstein solid and the two-state paramagnet, which limits the available questions for assignment or discussion. Here, we consider the more general case of the p-state paramagnet and describe the modestly more complicated counting of its microstates. By computing multiplicities in advance, an instructor can draw on these systems to assign a variety of new problems or open-ended projects.
Thursday Contributed Session	Singing the Praises of Octave for Fourier Analysis	Martin Connors, Athabasca University	Octave is a MATLAB workalike with ability to synthesize, record and play sound. Along with analytical abilities which include Fourier transforms, an understanding of frequency domain operations can be had without use of packages. By using the student's own voice, ownership of the data helps learning. Some aspects of FFTs are nonintuitive, but practice working with them, especially using graphical displays, helps to overcome barriers to understanding.
Thursday Contributed Session	Physicality, Modelling and Making in a Computational Physics Class	Tim Atherton, Tufts University	Computation is deeply interwoven with virtually every aspect of contemporary Physics, however computational activities in Physics classrooms have tended to limit themselves to a narrow range of skills. To bridge the gap between pedagogy and practice, we have developed a series of making activities whereby students create physical artifacts from low-cost materials, collect quantitative data describing their motion, build models to predict their behavior and reconcile experiment and theory. Results from our first two trials in a group and project-based Computational Physics class will be presented, showing how this approach enables students to engage in disciplinary practice. An epistemic model of how computation produces knowledges is used both to create the design and analyze student work. Design and implementation advice for instructors interested in adopting similar techniques will be provided.

Thursday Contributed Session	Incorporating Open Data and Aspects of Modern Physics Research in a Course on Scientific Computing	James Dolen, Purdue University Northwest	Numerous scientific collaborations release datasets to the public. So-called "Open Data" represents an excellent learning tool for physics students seeking to learn aspects of modern scientific research. Increasingly, high-level data analysis techniques are used in physics research for the purposes of classification, clustering, and regression. Through the utilization of Python-based data analysis packages and Open Data, students are able to engage with these techniques and visualize their performance. The use of Open Data in an upper level physics course on the topic of Scientific Computing at Purdue University Northwest will be discussed. Open Data from NASA, CERN, and the Major Atmospheric Gamma Imaging Cherenkov Telescopes (MAGIC) will be included as examples. A summary of project-based learning strategies focussed on these concepts will be examined.
Thursday Contributed Session	Assessment of integration of computation in quantum mechanics	Jay Wang, U. Mass. Darthmouth	Integration of computation has demonstrated to be beneficial in many aspects to the teaching and learning of physics. In this presentation we discuss from a practitioner's perspective reflections and feedback on the integration of computation into an introductory quantum mechanics course. We describe the goals and outcomes of the course, sample computational activities (see https://jwang.sites.umassd.edu), and assessment of these goals and of students' experience and change of attitude on computation.
Friday Workshop Session	Preparing and Submitting an Exercise Set, and Becoming a Reviewer	Kelly Roos, Bradley University	The PICUP Exercise Set Collection needs you! These exercises are written by community members and peer-reviewed by other community members. If you'd like to learn how to publish your own exercises as part of the PICUP Collection, or act as a peer reviewer, this workshop is the right place. We will discuss best practices for authorship, formatting, and the review process.
Friday Workshop Session	The Computational Physics Course: Objectives, Design, and Assessment	Walter Freeman, Syracuse; Gillian Ryan	Many departments have a dedicated numerical methods or computational physics course, but its role in the curriculum is sometimes unclear. In this workshop, participants will explore the design of such a course. We will plan learning objectives, consider how a course fits into the broader curriculum, discuss format and assessment, and finally work through an exercise set on nonlinear vibrations in a guitar string that brings together many of the modeling, simulation, animation, and analysis techniques students in a computational physics course must learn.

Friday Workshop Session	Upper-Division Physics: Planning a Coherent Course and Choosing the Right Tools	Deva O'Neil, Bridgewater College, Jay Wang, U. Mass. Dartmouth	Computational integration is most effective when it is sustained and coherent across an entire course. In this workshop, participants will design a thread of computation throughout an upper division course, examining how computational activities fit together to serve course-wide learning goals. We will focus on choosing exercises, assessment techniques, and choosing computational tools to best suit a variety of student populations and course formats. The facilitators will demonstrate Mathematica and Python (Glowscript/Jupyter) and describe examples from Classical Mechanics, Quantum Mechanics, and Electromagnetism. We suggest arriving with an idea of which upper-level course you'd like to work with. The facilitators will guide you in developing a plan for computation and you will be encouraged to share your plan at the end of the workshop.
Friday Invited Panel	Case studies of integrating computation	Brandon Lunk, Texas State University, Brett DePaola, Michele McColgan, Tony Musumba, and Aaron Titus	PICUP community members have a unique opportunity to learn from each other about our collective successes, challenges, and approaches to integrating computation in the physics classroom, both to improve our own efforts and to better impact the broader community of physics educators. In this session, four panelists who together have experience integrating computation in two-year, private liberal-arts, and R1 institutions will share with us the successes and challenges they've faced (and continue to face) within their specific institutional and instructional contexts. Each will summarize their efforts after which we will shift into an open discussion and Q&A.
Friday Contributed Session	Well Begun is Half Done: Integrating Computation into the Physics Curriculum at Morehead State	J. Kevin Adkins, Jennifer Birriel and Ignacio Birriel, Morehead State University	Faculty at Morehead State began a unified integration of computation in physics courses in Fall of 2020. We targeted the first two years of study consisting of one physics course each term. Our sequence consists of "Introduction to Physics & Engineering Professions", "Introduction to Scientific Computing", and "Engineering Physics" I & II. We describe our implementation of computational exercises and tools in each course including MS Excel, C++, and/or Arduino programming. We conclude with future improvements and plans for a unified approach to computing in the junior and senior level curriculum using existing PICUP exercises in traditional theory courses, spreadsheets for data analysis in advanced labs, and LaTeX in our capstone course.

Friday Contributed Session	Revitalizing the Physics Program with a Computational Physics Minor at Marshall University	Maria Hamilton, Marshall University	In today's economy we are witnessing a dramatic increase in the use of computer modeling. This creates a demand in the job market for scientists and engineers with good computing simulation skills. Students hesitate to major in physics, because they are worried it won't ensure employment right after graduation. We broaden the range of carriers available to our students outside academia by designing a specialization/minor in Computational Physics at Marshall University. The curriculum starts with an introductory level class, suitable for freshmen and high-school seniors, followed by an intermediate, sophomore-level class, and culminating with a senior/graduate-level class. Physics students can add a specialization in Computational Physics to their major, while any other students in science and engineering can earn a minor in computational physics. We aim to make a difference in the way students relate to the physics major by showing that we care about their future career.
Friday Contributed Session	Radio astronomy observations and data reduction in Introductory Astronomy	Steve Cederbloom, University of Mount Union	Students in my Spring 2021 introductory astronomy course used Excel to analyze data they collected with the 20-meter robotic radio telescope at the National Radio Astronomy Observatory. A POGIL-like activity was used to introduce them to the online interface for programming the observations. After retrieving their data, they loaded it into a premade spreadsheet which broke down the reduction process into short, distinct steps. The students were able to successfully measure the rotation curve of the Milky Way, which measures the amount of dark matter in our galaxy.
Friday Contributed Session	Leveraging the pandemic moment: revamping a computational astrophysics class	David Chappell, University of LaVerne	The pandemic provided a unique opportunity to reevaluate our existing upper-division astrophysics class. Because this class is an elective for our physics majors, we have the ability to cover fewer topics in order to free up time for instruction on computational techniques and programming. The course was redesigned to center around a scaffolded, 6-week computational project that utilized prerecorded video lectures, synchronous class discussions, and collaborative, student-focused problem solving sessions. Lessons learned from this experience will be presented within the context of broader changes to our curriculum that are being proposed to provided more computational opportunities for math and physics majors.

Appendix E: Pre/Post conference Surveys

1. Which best describes your department's approach to integrating computation in physics courses? Check all that apply.

a. Some of the faculty would like to integrate computation but have been met with resistance from other faculty/the department.
b. We integrate computation in one course.
c. We are planning to integrate computation in at least one course
d. We have not integrated computation in any courses.
e. We have integrated computation in some but not all physics courses.
f. We focus on integrating computation in the courses for physics majors.
g. We focus on integrating computation in the courses for engineering and other science majors.
h. We focus on integrating computation in the courses for non-science majors
i. I am the only faculty member who is interested in integrating computation

2. What projects and reports support your department's work to integrate computation?

a. PICUP workshops at AAPT or APS meetings
b. PICUP FDW
c. AAPT report on Computation
d. AAPT report on computational thinking
e. PICUP Slack
f. PICUP webinars
g. PICUP Faculty Commons
h. PICUP peer-reviewed exercises
i. Other

3. To the best of your knowledge, how much computation integration has been done so far in the undergraduate physics curriculum?

a. Number of courses (major), percentage of the courses for majors, number of faculty involved
b. Number of courses (non-major), percentage of the courses offered for non majors, number of faculty involved
c. Percentage of total faculty involved with integration in non-major courses, percentage of total faculty involved with integration in major courses
d. Number of faculty involved (major)
e. What textbook(s) are you using for the courses where computation is integrated?

4. Why were you initially interested in joining PICUP?

5. What if any impact has PICUP had on your teaching especially regarding the integration of computation?

6. What if any challenges in integrating computation do you still have?

7. What do you think could help overcome these challenges?

8. What if anything do you think PICUP could do to help you overcome these challenges?

9. Why did you sign up for the PICUP Capstone?

10. In what ways are you participating in the Capstone? Please check all that apply.

a. Only attending
b. Presenting a contributed talk
c. Presenting an invited talk
d. Facilitating a workshop
e. Organizing a session

11. Which workshop(s) did you sign up for?

a. Introductory Physics: Planning a Coherent Course and Choosing the Right Tools
b. Lessons from Computer Science Pedagogy
c. Preparing and Submitting an Exercise Set, and Becoming a Reviewer
d. The Computational Physics Course: Objectives, Design, and Assessment
e. Upper-Division Physics: Planning a Coherent Course and Choosing the Right Tools
f. Computational Integration into Astronomy and Astrophysics Classes
g. Department-Wide Computational Integration
h. Integrating Computation and Experiment

12. The workshop facilitators are interested in knowing more about the workshop attendees to prepare themselves. Please answer the following question regarding your background and comfort level regarding the following. [Options for each included *No Experience, Somewhat Comfortable*, *Comfortable,* and *Very Comfortable*]

a. Glowscript
b. Python
c. NumPy
d. Trinket
e. Matlab
f. Mathematica
g. Spreadsheets (for scientific purposes)

13. I currently am (option to select multiple responses):

a. Student (undergraduate, graduate)
b. Postdoc
c. Research Scientist
d. Non-tenure track faculty member at a postsecondary education institution e. Non-tenure track teacher at a K-12 institution
f. Pre-tenure track faculty member at a postsecondary education institution
g. Pre-tenure track teacher at a K-12 institution
h. Tenured faculty member at a postsecondary education institution
i. Tenured teacher at a K-12 institution
j. Retired/emeritus
k. Other (please describe)

14. Institution name

15. The primary institution where you work/study is a:

a. Two-year college
b. K-12 school
c. Four-year institution (highest physics degree is a bachelor's)
d. Master's granting institution (highest physics degree is a master's) e. Doctorate (highest physics degree is a doctorate)
f. Other

Post Conference Survey

1. In what ways did you participate in the Capstone? Please check all that apply.

a. Only attending
b. Presenting a contributed talk
c. Presenting an invited talk
d. Facilitating a workshop
e. Organizing a session

2. Which workshop(s) did you sign up for?

a. Introductory Physics: Planning a Coherent Course and Choosing the Right Tools
b. Lessons from Computer Science Pedagogy
c. Preparing and Submitting an Exercise Set, and Becoming a Reviewer
d. The Computational Physics Course: Objectives, Design, and Assessment
e. Upper-Division Physics: Planning a Coherent Course and Choosing the Right Tools
f. Computational Integration into Astronomy and Astrophysics Classes
g. Department-Wide Computational Integration
h. Integrating Computation and Experiment

3. Which plenaries, invited sessions, contributed talk sessions, and networking/discussion sessions did you attend? The schedule is here. [Options were *attended* or *did not attend*]

Wednesday August 11

a. Plenary 1: Brian O'Shea, The Future of Computation and Data Science" b. Invited Session: The state of integrating computation
c. Lunch breakout room discussion session
d. Networking Birds-of-a-Feather
e. Invited Session: Assessment
f. Coffee break discussion
g. Contributed talks

Thursday August 12

a. Plenary II: Courtney Lannert, Integrating computational physics into your curriculum using the EP3 guide
b. Lunch breakout room discussion session
c. Coffee break discussion
d. Contributed talks

Friday August 13

a. Lunch breakout room discussion session
b. Invited Panel: Case Studies of Integrating Computation
c. Coffee break discussion
d. Contributed talks

4. What feedback do you have regarding your experience as a session organizer? [only appeared if the respondent indicated they were a session organizer]

5. What feedback do you have regarding your experience as a workshop facilitator? [only appeared if the respondent indicated they were a workshop facilitator]

6. What did you find most useful in the breakout discussions and networking sessions? [only appeared if the respondent attended at least one breakout discussion or networking session]

7. What improvements would you suggest for the breakout discussions and networking sessions?

8. What did you find most useful in the plenaries, invited sessions, and/or contributed sessions? [only appeared if the respondent indicated they attended at least one plenary, invited session, or contributed session]

9. What improvements would you suggest for the plenaries, invited sessions, and/or contributed sessions? [only appeared if the respondent indicated they attended at least one plenary, invited session, or contributed session]

10. What was useful or positive about your experience as a speaker? [only appeared if the respondent indicated they were a speaker]

11. What would have improved your experience as a speaker? [only appeared if the respondent indicated they were a speaker].

12. The following statements cover a variety of topics around the workshops. Please select the option that best describes your opinion. [Options were *yes, no, maybe*, and *N/A*; only appeared if respondent indicated they took at least one workshop]

a. Gather.town worked well for the workshop(s)
b. Zoom worked well for the workshop(s) I attended
c. The workshop(s) I attended were useful in helping me integrate computation in my physics course(s)
d. I would take another virtual workshop from PICUP

13. What are some positive aspects of the workshop(s) you attended? 14. What are some areas of improvement for the workshop(s) you attended? 15. I currently am (option to select multiple responses):

a. Student (undergraduate, graduate)
b. Postdoc
c. Research Scientist
d. Non-tenure track faculty member at a postsecondary education institution e. Non-tenure track

teacher at a K-12 institution

f. Pre-tenure track faculty member at a postsecondary education institution g. Pre-tenure track teacher at a K-12 institution
h. Tenured faculty member at a postsecondary education institution i. Tenured teacher at a K-12 institution
j. Retired/emeritus
k. Other (please describe)

16. Institution name

17. The primary institution where you work/study is

a. Two-year college
b. K-12 school
c. Four-year institution (highest physics degree is a bachelor's) d. Master's granting institution (highest physics degree is a master's) e. Doctorate (highest physics degree is a doctorate)
f. Other