



## Teaching Computational Physics in Undergraduate Physics Education: A Narrative Review and Implications for Pre-Service Teachers

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**Abstract:** Computational methodologies are now a fundamental part of applied science and are considered part of the teaching of the discipline of science. Because computation adds another level of engagement to the theoretical and experimental approaches of a discipline, teaching education programs in the science disciplines, particularly pre-service physics teachers, are required to use computational techniques and engage in modeling practices. Yet, the teaching practices and pedagogical techniques that are being employed for the teaching of computational physics in teacher education are not consistent or widely utilized. This study uses narrative literature review techniques to study the teaching of computational physics in undergraduate physics education programs, especially regarding pre-service physics teachers. The literature under examination in this review comes from international peer-reviewed journals in the education fields of physics and science published within the years of 2020 to 2025. The review uses thematic analysis to show that there are three most common teaching models in use, those being: 1. teaching computational physics as a separate discipline, 2. the teaching of partial computational practices within standard physics courses, and 3. the teaching of computational practices in all courses of the undergraduate curriculum. The results of this review show that even the teaching of computational physics most likely uses pedagogical techniques that focus on project based learning, modeling, and the use of software such as Python and interactive simulations for learning. Such techniques likely enhance the understanding of the pre-service teachers' pedagogical content knowledge as they learn computational thinking. They recommend that teacher education programs integrate computational physics in a systematic and manageable way to promote digitally enhanced learning environments for future physics teachers.

**Keywords:** Contextual Teaching and Learning, Social Studies, Classroom Action Research, Learning Interest, Learning Outcomes

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### Introduction

The importance of integrating computational methods into physics and science teaching and learning is becoming increasingly evident as part of practice in modern science. Computation is also called the 'third pillar' of modern physics since it is integral alongside theory and experiment. Together they are essential for higher-order work in the field (Ozdemir & Nakiboglu,

2023). Using computational methods, a physicist can perform analyses of complex data, derive and solve impractically difficult problems, and simulate systems/phenomena. Clearly, literacy in physics and computation is valuable for pre-service teachers as they train students in scientific reasoning and digital skills.

Getting in alignment with the global trends, the higher education institutions in the world have recently

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begun embedding computational physics into their undergraduate programs as part of the efforts to integrate the use of technologies into the teaching of science (Bati, 2021). The Computational literacy has been considered as a fundamental literacy in the sciences which has led to the revision of curricula where computational techniques are integrated with the other discipline content (Önal & Özdemir, 2024). In some teacher education programs, Python and other programming applications have been added to physics courses with the aim of enhancing the pre-service teachers' computational thinking and working in modern science (Qiang et al., 2024).

However, there are still differences between the computational training of the research physicists and the pre-service physics teachers. While physics majors are trained in the use of computational practices to analyze various complex physical phenomena, the teacher education curriculum usually offers limited use of computational tools to learn and teach physics (Carvalho, 2025). Educational teacher preparation in the field of science has primarily focused on the theory, paying little attention to the use of computational modeling as a specific teaching skill that is highly necessary in today's digitally enhanced learning environments (Ayub et al., 2024). For pre-service secondary school physics teachers having adequate knowledge of computational tools and systems and effective use of them incurred discrepancies need to be addressed.

While much of the literature recognizes the importance of integrating computational modeling in the preparation of teachers across several different fields, computer modeling remains mostly absent from teachers' preparation programs (Martin et al., 2022). Most programs still use the traditional model of teaching, with little engagement of the prospective teachers in the use of computational tools, thereby retarding their ability to teach in a computationally enhanced classroom (Mitsikopoulou, 2020). As a result, students remain largely unprepared to join a workforce that requires computational skills.

Most literature lacks comprehensive reviews that center on computational modeling in physics education specifically. Many authors have pointed to the lack of literature reviews that take into consideration the specialized methods of instruction and the teaching of computational skills to teacher candidates (Levrints, 2021). The bulk of literature that addresses computational pedagogy revolves around students' education in physics. There is a significant lack of literature that focuses on the use of computational physics in the education of prospective teachers (Abdildauly et al., 2024). This literature deficiency needs

to be addressed especially in the design of systems that serve to mentor future teachers of physics.

Therefore, this literature review examines the incorporation of computational physics into undergraduate physics education programs. The purposes of this review are: describing what is available in the field of instructional educational computing that is relevant to pre-service physics instructors; discussing what obstacles exist in the field of educational pedagogy that create a blockage of the use of computational modeling; and presenting informed recommendations for the advancement of teacher education in relation to the digitally.

## Method

The aim of this study was to review international studies on the instruction of computational physics at the undergraduate level. The aim of the approach taken was to ensure that the varying studies or instruments captured differences in teaching situations, settings, in pedagogy, and in curriculum design in the field of physics education, especially in physics teacher education programs.

A narrative review of the literature was undertaken on education and science education. Other peer reviewed literature that touched on undergraduate education was also reviewed. To ensure that it was current within the field of education, literature published from 2010 to 2024 was used. The studies reviewed stemmed from literature that had a connection to teaching, education, or instruction and the implications of such on teaching physics in the education of pre-service teachers.

The studies selected were reviewed and analyzed in a narrative format, focusing on themes. The reader/researcher identified the literature and through constant comparing and contrasting of the literature, the reader identified the literature that spoke to the instructional models of teaching computational physics. The educator themes that came to the forefront were around the use of pedagogy, and the implications for the preparation of teachers in the field of education. The results were constructed narratively to center on the themes and findings in education and to analyze the literature, rather than to review the literature and construct an overview of the literature.

## Result and Discussion

### Instructional Models of Teaching Computational Physics in Undergraduate Physics Education

The ability to perform computations is becoming a more important skill to learn in undergraduate physics courses. In addition to being able to understand the fundamentals of a given topic, students should be capable of implementing computational techniques to

address modeling, data analysis, and the study of phenomena that may be too complex to tackle through analytical methods. Studies and articles helped to shape the three main teaching approaches to computational physics: stand-alone computational physics courses, moderate fusion of computational tasks in core physics courses, and total fusion of computational methods in all core undergraduate courses.

The standalone computational physics courses help create more opportunities for teaching students computational techniques in the field of physics. These classes typically have a primary focus on the goals of numerical modeling, simulation, and data analysis, including the target objectives of computational problem-solving and the use of a range of computational tools in different physics disciplines (Tufino et al., 2025; Kouh, 2022). Teaching in these courses is often in the form of projects that promote experiential learning through the use of visualization, and iterative model refinement to promote deep understanding of the concepts (Pavlenko et al., 2025; Ross & Thomas, 2022). Kouh (2022) emphasizes the strength of this model to be the computational work within the model and the time provided to design, implement and test in order to achieve mastery of the computational techniques. Partial integration into core physics courses is the second method described in the literature. In this method, students engage in computational activities within existing courses, such as mechanics or electromagnetism. The target is to enhance comprehension of concepts through illustrating the connection among theory and computation (Margulieux et al., 2022; Faux & Godolphin, 2021). Educational exercises aim to enable learners to engage with the physical systems of specific systems through the use of simulations or models.

This method is particularly useful since students use computational tools with the physics problems they are studying, which increases engagement and perceived value of the exercises (Apple et al., 2021; Fuller et al., 2022). Fully inclusive integration covering the curriculum exemplifies the most inclusive/expansive model. In this model, developmental stages of computational thinking and modeling are taught in all levels of the undergraduate studies. The aim of the learning outcomes is to equip students to select and utilize different computational skills in different areas of physics (Sousa et al., 2024; Margulieux et al., 2022; Love et al., 2022).

Stick and adapt (scaffolded) instructions are often used, and students are further taught in interdisciplinary projects which enable them to gradually acquire and adapt their computational skills toward complicated problems (Tufino et al., 2025; Juškevičienė et al., 2021). It aids in the awareness of the

practice of computational modeling in science as something that is valuable rather than as a marginal skill. To summarize the instructional models identified in the reviewed literature, Table 1 presents the dominant approaches to teaching computational physics at the undergraduate level.

**Table 1.** Instructional models of computational physics in undergraduate physics education

No	Instructional Model	Main Characteristics	Representative Studies
1	Stand-alone courses	Dedicated computational physics courses focusing on simulation and numerical modeling	Kouh (2022); Tufino et al. (2025)
2	Partial integration	Computational activities embedded in core physics courses	Apple et al. (2021); Margulieux et al. (2022)
3	Comprehensive integration	Computational modeling integrated across the undergraduate curriculum	Love et al. (2022); Sousa et al. (2024)

### Pedagogical Approaches in Computational Physics Education

How well students learn computational physics is influenced by curriculum design and by how a given instructor approaches teaching a particular course. In unit of study in undergraduate education courses in the discipline of physics, Project Based Learning (PjBL) and Problem Based Learning (PBL) are designed to foster active learning and the teaching of computational problem solving and are most widely used. PjBL focuses on long-term inquiry, where students create a final product, like a simulation or a computational model This fosters various interdisciplinary skills that are essential in education of modern physics (Salam, 2022). On the other hand, PBL focuses on problems that are open-ended for students to collaborate on and use computer based solutions and is designed to foster computational 2.2 thinking through iterative approaches (Tongal et al., 2022). In the education of teachers, these are taught alongside pedagogies that pre-service teachers can use themselves in their future technology classrooms (Bati, 2021; Couso et al., 2022) 2022.

Constructing and refining computational models help learners to understand a particular physical system and the scientific assumed representations of that system. This also assists in scientific procedures like

visualization and exploration of a parameter space in a set of scientific procedures, and reasoning iteratively (Liang, 2023; Omojemite, 2023). For pre-service teachers, computational modeling also helps in structuring of their mind how is that it helps in structuring. Their students explanation, how it helps in structuring inquiry based learning, in how it helps in structuring, demonstrations and learning how to design explanations.

The implementation of studio and laboratory-based teaching methodologies advances the discipline of computational learning even further. It has been discovered that studio-based teaching allows collaboration and interactive engagement. It enables students to use peer feedback in real time during the testing of theories and the comparison of different representations (Liu & Sun, 2022; Saltalı et al., 2023). Instruction that is laboratory oriented is focused on the modeling of different experiences and learning opportunities, which expands the computation range to include the collection and analysis of data (Bati, 2021; Connolly et al., 2021). Such methodologies enhance students' confidence in their ability to troubleshoot, as well as use iterative problem-solving techniques which are vital for computational work.

**Table 2.** Pedagogical approaches and implications for pre-service physics teachers

No	Pedagogical Approach	Key Features	Implications for Pre-Service Teachers
1	Project-based learning	Extended projects using computational modeling	Develops problem-solving and instructional design skills
2	Problem-based learning	Learning driven by real-world computational problems	Enhances inquiry skills and computational thinking
3	Computational modeling	Numerical representation of physical systems	Strengthens conceptual understanding and PCK
4	Scaffolded instruction	Gradual increase in computational task complexity	Supports diverse programming backgrounds

Since students come from various programming backgrounds, the development of scaffolding techniques becomes even more essential. Efficient scaffolding restructures the tasks so that they range from

the simplest to the most sophisticated modeling and simulation activities. This gives students the opportunity to build their confidence while keeping the focus on the concepts (Omojemite, 2023; Tsakeni, 2021). Such approaches are especially relevant in teacher training programs in order to assist the learners in building their content knowledge and pedagogical skills in computational learning (Bati, 2021; Rivadeneira & Toledo, 2024). Table 2 summarizes the pedagogical approaches commonly employed in computational physics education and their contributions to pre-service physics teacher preparation.

### 3.3 Tools and Learning Environments

Curriculum structure impacts how well students learn computational physics and how specific instructors teach specific courses. Specifically within undergraduate education courses in the discipline of physics, Project Based Learning (PjBL) and Problem Based Learning (PBL) are designed to teach computational problem solving and foster active learning. PjBL is focused on students constructing a long-term inquiry culminating in the creation of a final product, for example, a simulation or a computational model. This develops interdisciplinary skills, which are important for modern physics education (Salam, 2022). PBL, in contrast, is more focused on integrating computational 2.2 thinking through an iterative approach to problem solving and is designed for students to collaborate in solving open-ended computational problems (Tongal et al., 2022). In teaching education, these are paired with pedagogies that we expect pre-service teachers to adapt in their future technology classrooms (Bati, 2021; Couso et al., 2022). Building and modifying scientific models have the power to give learners a more in-depth understanding of the nature of that physical system and the scientific model representations of that system.

This helps with science activities like visualizing and navigating through a parameter space in a number of scientific activities and reasoning in an iterative way (Liang, 2023; Omojemite, 2023). For preservice teachers, computational modeling assists in organizing their never mind how it helps in organizing. Their students explanation, how it helps in organizing inquiry grounded pedagogy, in how it helps in organizing, demonstrations and learning how to structure explanations.

This further evolves computational learning as knowledge is augmented with studio and laboratory-based instructional methods. As stated in the research of Liu and Sun (2022) and Saltalı et al. (2023), the studio-based teaching promotes collaboration and engages the students actively where they can give peer feedback in real time while they hypothesize, test, and compare different models. Bati (2021) and Connolly et al. (2021)

explain that the Laboratory Instruction transitions to modeling and analyzing different learning opportunities which expands the computing range to data collected and its interpreted information.

These approaches assist students in becoming more self-assured when it comes to troubleshooting and adopting techniques that involve iterative problem-solving, skills that are essential in computational work.

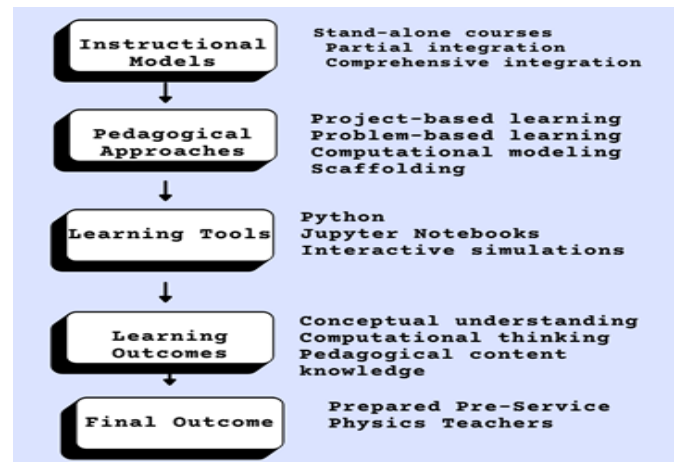
The importance of developing scaffolding techniques becomes even more critical, given that students have diverse backgrounds in programming. Effective scaffolding breaks down modeling and simulation tasks from the most complex to the most straightforward to optimize restructuring of the tasks.

### Implications for Pre-Service Physics Teachers

Having teacher educators learn and apply computer modeling enhances both their understanding of physics and their PCK. Pre-service teachers learn to think about and visualize multi-system and dynamic relationships, which deepens their understanding of physical systems and variables through computer modeling (Vieyra et al, 2024; Cabrera et al, 2023). As teachers work with their computer models, they are able to transition from knowing procedures i.e. algorithmic thinking, to explanatory (theoretical) reasoning; an important aspect of teaching physics (Kouh, 2022). By designing instructional activities with pre-service teachers, both participants will experience the benefits of PCK in teaching with computers. Teaching becomes an easier task when the teacher can integrate pedagogic and content knowledge seamlessly, which is facilitated with the computer modeling as it lays the reasoning of the learners (Schiering et al, 2022). With computer modeling, teachers can work with pre-service teachers to identify possible ideas and content misconceptions through the use of targeted representations, construct appropriate PCK, and scaffold inquiry in learning. (Darragh et al, 2021).

In addition, the use of computers in teaching can enhance both formative and summative assessments as computing is embedded in the processes of each. PCK is enhanced in real-time when the teacher can analyze the students' models, identify their ideas and misconceptions, and adapt to their learning. For both teachers and students, the computer modeling process reflects scientific inquiry, and it promotes iterative teaching (Vieyra et al, 2024; Deogratias et al, 2025). Although the advantages are apparent, obstacles are present, especially concerning technology access and instructor knowledge. Starkey et al. (2023) mention how numerous teacher education programs are hindered by inadequate infrastructures, making it difficult to offer sustained computational experiences.

To overcome such obstacles, it is suggested that programs utilize open-source applications, as well as seek collaborations that broaden availability of computational tools and knowledge (Arnold & Mundy, 2020; Kouh, 2022). These approaches are likely to provide the means by which the teaching of computational physics can be accommodated and taught effectively in a wide range of settings (Margulieux et al., 2022).



**Figure 1** provides a model that shows how various instructional designs, pedagogy, educational resources, and educational outcomes interact within underlying the education of computational physics for future physics teachers.

### Conclusion

The value of this review illustrates the capturing impact of the computational approaches in undergraduate level physics across the education sector, and more specifically the education of pre-service physics educators. As reported in the literature, the combination of computational modeling together with inquiry-based pedagogical designs improves the degree of engagement, conceptual understanding, and the level of critical thinking in the learning of physics (Khaeruddin & Bancong, 2022; Başaran & İltter, 2023).

As the future educators of physics, the ability of computational thinking will provide them with the capacity to plan and implement lessons that use technologies in meaningful ways (Çıldır & Şen, 2023; Albayrak & Özden, 2021). Teacher education programs that promote project-based learning along with modeling, and the active use of computational technologies, is promising in building the confidence and pedagogical preparedness of pre-service teachers (Anggaryani et al., 2024).

From the perspective of the curriculum developers, the undergraduate physics teacher education programs must provide due attention to the

acquisition of computational modeling together with other core physics concepts of the curriculum (Couso et al., 2022). There is a need for further research to understand the impact of specific teaching models and pedagogical strategies on the competencies and classroom practices of pre-service teachers (Dong et al., 2023). To ensure that no is lost on the creativity that is required to ensure that the education and practice of teaching physics is relevant to modern practices and demands, a lot more research on the different ways to integrate computational modeling to teaching physics is required.

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