education sciences

Review

An Overview of Teaching Physics for Undergraduates in Engineering Environments

Janusz Zalewski [1,*], Gregor Novak [2] and Randall E. Carlson [3]

1 Florida Gulf Coast University, Ft. Myers, FL 33965, USA
2 Indiana University Purdue University Indianapolis, Indianapolis, IN 46202, USA; gnovak@iupui.edu
3 US Air Force Office of Scientific Research, Arlington, VA 22203, USA; randall.carlson@us.af.mil
* Correspondence: zalewski@fgcu.edu; Tel.: +1-239-590-7317

Received: 19 October 2019; Accepted: 18 November 2019; Published: 22 November 2019

Abstract: This paper is an overview of approaches to teaching physics courses delivered to students of engineering disciplines. It addresses, first, the history of teaching physics to engineering students starting in the early 20th century, then reviews the main issues presented and discussed over the last decade in a series of conferences on Physics Teaching in Engineering Education (PTEE). Finally, this paper discusses more contemporary views on the subject, including the latest technologies and new methodologies. It is not a critical review of teaching physics to engineering students, but rather a summary of various views and approaches over the span of the entire century. The common denominator of the study is the relevance to the competency-based approach: how the papers focus on teaching engineers the principles of physics in a manner that contributes to success in their professional careers.

Keywords: physics teaching; engineering education; project- and problem-based learning

1. Introduction and Historical Background

The objective of this paper is to provide an overview of the literature on teaching physics to engineering students, since it was first addressed in writing in 1903 to current times. Given the important role physics plays in engineering, the major reason for embarking on this task was to see how perspectives on this subject matter have evolved and identify the trends that may lead to potential improvements in teaching, helping physics instructors, students, and ultimately, engineering graduates. As the discipline of engineering evolved over the decades, so did engineering education and the current educational objectives focus more on issues, such as solving interdisciplinary problems, addressing the global perspective, and preparing graduates for the job markets. In this view, as physics is so essential to the engineering professions, it is becoming increasingly important to understand the most effective approaches to its teaching and follow modern pedagogy.

This paper is not meant to be a critical review of teaching physics to engineering students, but rather a summary of various views and approaches over the span of the entire century. It does not address the description of the curricula either, although the curricula are often mentioned in the discussion of teaching goals. Instead, the common denominator of the overview is the relevance of competency-based approaches: how the papers focus on teaching engineers the principles of physics in a manner that contributes to success in their professional careers.

The paper is structured as follows. The remainder of this section discusses the earliest papers and reports, those published in the first half of the previous century and shortly after World War II. Section 2 provides a structured review of papers presented at a series of European conferences on Physics Teaching in Engineering Education (PTEE) for the past decade and Section 3 discusses more contemporary contributions of teaching physics in engineering. The latter two sections present general and fundamental issues, first, which is followed by an overview of teaching methodologies, teaching tools, and assessment methods. The paper ends with concluding remarks and observations.

1.1. First Half of the 20th Century

Although there are claims that the teaching of physics within engineering education has been the subject of discussion since the earliest efforts to define engineering as a profession during the industrial revolution [1], one of the very first recorded attempts to formulate thoughts on teaching physics to engineering students was an enlightening six-page treatise by William S. Franklin, published in 1903 [2]. To place this date in context of engineering accomplishments, this was the year the Wright brothers performed the first powered aircraft flight. Franklin, a later Columbia (1915–1917), Harvard (1917–1925) and MIT (1917–1929) professor, asserted that "the primary object of physics teaching is, in my opinion, to develop in the young man's mind a logical structure consisting of the aggregate of physical conceptions and theories." And further, he outlined how to implement this assertion:

> "My idea of the teaching of physics is to use a sharply, clearly and concisely written text-book, to give explanatory lectures of such character as to appeal properly to the student's imagination (theoretical lectures, in fact, illustrated by the simplest kind of experiments), to require of the student a large amount of numerical calculation, and to give a laboratory course based upon highly generalized printed directions supplemented by a vanishing series of verbal suggestions from an instructor."

He extended this view to engineering, next, by saying: "I think that the chief object in a course in physics for technical students should be to give conceptual and analytical knowledge of the most important facts of physics." This is to be done through laboratory work, which encompasses two phases, one "to vivify algebraic formulae" followed by another, which "consists of elaborate and precise measurements carried out with every possible precaution for the elimination of error." With this, he is very close to German physicist Hermann von Helmholtz, whom he mentions earlier in this essay. For both, measurements, as a high point of every physics experiment, are of ultimate value to scientists and engineers [3].

The issue of teaching physics principles to engineering students was of so much concern during and after World War I that special studies were ordered by the Society for the Promotion of Engineering Education (a predecessor of the American Society for Engineering Education) and the American Physics Association, with reports issued in 1916 [4] and 1922 [5], respectively. A long list of questions was presented to teachers and engineers whose answers were collected and analyzed. Among the findings in [5], it was stated that the principles physics taught should be in a form immediately available for the solution of new practical problems. This meant that the problems set for exercise should be of a practical nature and not deteriorate into numerical substitution in a formula. Laboratory work was deemed to be of essence. The report concluded that the following five objectives should be conveyed when teaching physics to engineers:

(1) The scientific habit of thought;
(2) Knowledge of the laws of physics;
(3) Initiative and ingenuity;
(4) Knowledge of facts and methods;
(5) Accurate observation.

One of the 1922 Report's contributors published a separate article [6], with an interesting perspective on the relationship between physicists and engineers. Recognizing the challenge of teaching physics, which he derives from the fact that "the average grade in Physics is lower than that in any other subject", he expresses a conjecture that "It is probable that a part of the difficulty which the student experiences in the study of Physics comes from the lack of appreciation of the fundamental importance which the subject plays in subsequent work in engineering."

In 1938, the American Institute of Electrical Engineers' committee on education, at their summer convention, launched a review of the role of mathematics and physics in engineering education, especially in electrical engineering. As a result, several papers were published the following year, two of which [7,8] concerned the issues relevant to this survey. Malti [7] gave an overview of the role of an engineer in society and described such a person as being capable of

(1) Reducing the engineering problems to fundamental physical facts;
(2) Expressing the physical facts in mathematical form;
(3) Deriving from the mathematical statement the desired mathematical result;
(4) Interpreting the mathematical result physically.

To illustrate these skills, he applied them to an example of determining the transient current in a circuit with resistance and inductance, claiming that these four processes are involved in all engineering problems. He further admitted that the majority of engineers lack these essentials and concluded that "something is wrong either in our teaching of physics and mathematics or in the proper co-ordination of these subjects with engineering courses or in both." He later elaborated on potential causes of this situation, quoting mostly incompetence and lack of co-operation. In conclusion, he made suggestions on how to improve the situation, of which the only relevant one from the perspective of this survey is the following: "Have the faculty keep in touch with industry in order to follow the developments of the time."

In the same journal, Teare [8] addressed the problem from a slightly different perspective, pointing out that to cure the situation, in teaching physics in engineering, two issues have to be addressed simultaneously:

(1) first, mastery of the basic sciences, which involves focus on the most effective instruction and
(2) second, adequate training in their application, which involves the most effective use of the subject matter.

He advocated the use of problem assignments in a class and summarized in the following six steps of how students should proceed:

(1) Stating the problem and specifying the desired result;
(2) Formulating a plan for solution;
(3) Stating in precise English the implication of the chosen principle in the problem;
(4) Translating the statement of (iii) into mathematical form, writing it as an equation;
(5) Solving (iv), giving it a fresh start if a solution is not possible;
(6) Testing the solution.

In contemporary terms, steps (2)–(4) form a design stage and step (5) corresponds to an implementation. The author stated in conclusion that "the courses to develop facility in the use of mathematics and physics in engineering problems" should have three essential features:

(1) Training in an orderly thought process;
(2) Integration of the student's knowledge of the basic science;
(3) Extensive practice in the solution of actual engineering problems.

Compared to the objectives stated in [5], the only new feature listed above is (3).

For the record, there were three additional papers included in the same block of the AIEE Transactions, which discussed co-ordination of physics and math, specifically with teaching of electrical engineering, but they were more specific in their focus on electrical engineering.

Around the same time, Lapp [9] outlined and discussed four major objectives, in his opinion, that engineering physics and its teachers should try to reach:

(1) A thorough mastery of the basis of general physics;
(2) The student should learn a great deal about the measuring instruments of physics that are useful to the engineer, and should develop some skill in handling them;
(3) The student should develop a scientific attitude;
(4) The course should kindle the imagination and fire the creative abilities of the students.

On its face, all four objectives correspond well to those listed in the 1922 APS report [5], which advocated for the teaching of principles, experimentation with emphasis on measurements, the scientific method, and—what can be called a meta-objective—creativity.

To summarize these early critiques, the following essential characteristics were required in teaching physics in engineering environments:

(1) Mastery of the basic laws of physics, its facts and methods [5,8,9];
(2) Knowledge of the scientific method [5,8,9];
(3) Familiarity with the observation process and measuring instruments [5,9];
(4) Creativity and ingenuity [5,9];
(5) Practice in solving actual engineering problems [8].

It is also worth mentioning the efforts towards defining laboratory work, described by Martin in [10]. Referring explicitly to the four objectives of a course on engineering physics formulated by Lapp [9], Martin asked the question: "In what specific ways does the laboratory part of the course contributes to these objectives?" To answer this question, he suggested five contributions of laboratory work:

(1) Increase a student's grasp of the subject matter by bringing them into an intimate contact with the factual material and the applications of the basic principles;
(2) The development of manipulation skills;
(3) The development of self-reliance and ingenuity;
(4) Essential training in the interpretation of experimental data;
(5) Cultivation of scientific attitude and an appreciation of scientific methods through experimental investigation.

These are in sync with the characteristics of teaching physics for engineers, as listed in the previous paragraph, perhaps except the last one: "Practice in solving actual engineering problems", since, to accomplish it, lab work is not sufficient.

1.2. Developments after WW II

The literature on teaching physics to engineering students in the first 40 years after WW II is relatively sparse. Even an article on the history of teaching physics in the U.S. [11] did not mention any connection with engineering. Likewise, a paper on the history of engineering education [12] did not use the word "physics" even once. Notably, a committee report on the evaluation of engineering education, nicknamed the Grinter Report [13], mentions physics only as an educational component in a single paragraph (see Appendix A).

In the 1950s, teaching physics in engineering was addressed in two reports, [14] and [15]. Based on his work on committees of the American Society for Engineering Education (ASEE) and knowledge of a related work done by the American Association of Physics Teachers (AAPT), Seeger [14] discussed general complaints about the subject and quoted some proposed solutions, coming essentially to the following conclusion: "It is evident that engineers and physicists must both answer the questions: What contributions can physicists make to engineering education? What contributions should physicists make to engineering education? In short, what is the role of physics in engineering education?"

A couple of years later, the Committee of the American Institute of Physics published a comprehensive report [15] outlining seven recommendation related to the role of physics in engineering education:

(1) Improved communication between engineers and physicists at the institutional level to discuss objectives and determine mutual needs;
(2) Early contact of engineering undergraduates with physics;
(3) Increased participation of research-minded professors in undergraduate teaching;
(4) Introduction of more challenging experiments in laboratory instruction;
(5) Greater emphasis, particularly in textbooks of general physics, on ideas, principles, and methods;
(6) More appropriate use of mathematics in general physics teaching;
(7) Greater encouragement of experimentation in teaching.

Looking at these recommendations from the perspective of the summary list (1)–(5) presented in the previous section, it becomes apparent that, with the exception of points (5) and (7) above, which relate to laboratory work, all of them can be viewed as meta-objectives. They concern the ways and means to achieve the objectives of improving the teaching of physics to engineering students rather than being such objectives themselves.

In a quest to improve the teaching of physics in engineering, further discussion involved the responsibility of a physics teacher in engineering education [16]. Smith argued that the basic reason for a mismatch in education is "a lack of understanding of what the true objectives of engineering education and training really are in various schools". The emphasis was on "various schools", as distinguishing training of a usual engineer from the one whose career is to be "in industrial research or advanced engineering department". For the latter, one of the essential emphases is on a specific technical area he names "engineering practice". In this view, the responsibility of a physics teacher is to "give the student in this program the opportunity to acquire an extensive knowledge of basic physics and help him to develop analytical ability to a high degree."

In the following year, W.V. Houston published an article [17] on the mutual relationships of physics and engineering, dealing with some educational issues. First, he discussed extensively the role of William Thomson in building the transatlantic telegraph cable line, praising him for his physicist/engineer's approach to solving problems, which led him to a viable question:

> "What kind of an education, what kind of a training, what kind of a tradition is it that will enable the proper judgment to be made, and the proper balance to struck, between engineering experience and scientific theory?"

Then, Houston discussed the sequence of three prominent names, Maxwell, Hertz and Marconi, outlining how each one subsequently built on another's work. In particular, he praised Hertz as

> "he rapidly went on to demonstration of the electromagnetic waves and a measurement of their wavelength, exhibiting all along that practical sense for making things work which characterizes the engineer."

Finally, he moved to the invention of a transistor, concluding with a remark that may be seen as crucial in connecting the two disciplines,

> "These are the instances in which physics has made significant and immediate contributions to engineering. There will be more. And each of us, as a teacher of physics, has the responsibility of making sure that no merely the facts, but the spirit of physics, is made a living reality to students of engineering."

In another paper [18], a year later, the author discussed the impact of modern physics on engineering education. First, he recognized that due to modern discoveries in physics, "a gap developed between the new frontiers of physics and everyday work of engineering production or instruction." Consequently, he discussed a challenge of "whether engineering education will recognize the existence of modern physics research, will survey its extent, and will take swift action to meet the requirements for comprehension and absorption of these new engineering tools." Giving examples of the role of physics in recent developments of a transistor and magnetic memories, he argued that understanding of this educational gap is being comprehended and respective efforts are being conducted. One interesting observation, not present in any previous publications, is on the social position of the engineer. In modern terms, this relates to introducing innovations and creating start-ups, which he phrases as a suggestion that "engineers and scientists must have a growing part in the top management of successful corporations", which adds a new dimension to the education of engineers. Overall, he concluded that meeting the challenges of modern engineering "requires that we acquaint the students with the accumulated knowledge of modern research in physics and other fields, and that we keep our faculty members and student bodies abreast of the new sciences."

Additionally, two articles were published on teaching physics in engineering curricula at some academic institutions in this era. Weaver presented a description of physics courses in the engineering curriculum at University of Arizona [19]. He argued that elimination of the general physics course in favor of delegating respective topics to specific courses offered by individual departments increases the flexibility and relevance of the material covered. He was aware of some weaknesses of this approach and pointed out, in particular, that "it will be more difficult to make it clear to the students that the science at the base of engineering is unified and that the compartments into which it is normally divided are arbitrary." The motivation, however, is clear and derived from the fact that "at some point in his career the engineer be thoroughly exposed to science courses as taught by the physicist. It is equally important that the future scientist be exposed to some engineering courses." Two other observations are important from a contemporary perspective. First, the recognition of the need for life-long learning is expressed: "The student who is broadly trained in science and engineering will be better fitted to educate himself through the years as he needs further education." And secondly, the need for teamwork is emphasized as follows: "There is a well-recognized and growing tendency of industry and government to rely on teams to solve the complex problems of modern technology."

A year later, W.W. Watson published an article on teaching physics to engineers at Yale [20]. Drawing extensively from the conclusions of the 1955 Report on the Role of Physics in Engineering Education [15], the author focused primarily on the contents of the curriculum, rather than the objectives of preparing the students of engineering in physics. He emphasized one important point, though, that "especially in the preprofessional physics course, [the] producing scholars should be the most stimulating teachers," by whom he meant the physicists doing research.

While prominent physicists of that era may not have been particularly interested in making physics students aware of engineering issues, one great physicist, Richard Feynman, made an exception when he published an article on teaching physics to students in Latin America [21], probably his only paper on physics education. Explaining, first, the role that physics plays in engineering and technology:

> " ... physics is a basic science, and as such is used in engineering, chemistry, and biology, and has all kinds of applications in technology. Physics is the science, or knowledge of nature, that tells us how things work. In particular, I am stressing here how devices of various kinds—invented by men in present and forthcoming technology—work. Therefore, those who know physics will be much more useful in coping with the technical problems arising in local industry."

He then outlined his view on making the engineering students equipped with the knowledge, which will make them more useful to the industry:

> " ... how to bring engineers and other applied scientists closer to their real world of application. It is not enough for them to remember exactly how to use the formula, providing that the situation is exactly the same as the situation was in the engineering school when the professor dictated the lecture. We must do something to make the applied engineer more flexible, so that he is effective in a wide range of applications."

In the following two decades, between the mid-sixties and mid-eighties, teaching physics to engineering students was not discussed beyond what has already been said in the reports mentioned above, except of a few more general considerations, one of which is worth mentioning [22]. L.A.A. Thomas tackled the issue of connecting physics to engineering in his annual chairman's address to the Science, Education and Management Division of the Institution of Electrical Engineers (IEE). While not much of his paper is related to physics education, he began with a reminiscence of his own education, which, viewed from today's perspective, sets a solid ground for the educational connection of the two disciplines: "Soon after graduating, and with a little industrial experience behind me, I paid my first visit to a large works which made electricity-supply equipment. The sheer scale of the engineering—the large alternators being assembled, the giant transformers being wound—caught my imagination; these people really were making something! So I returned to the sophisticated minutiae of my own world of crystals and solid-state structure chastened with the realization that physics and physicists, albeit important, depended on the successful implementation of their findings by engineers." This is, of course, one of many similar statements about mutual inderdependency of both disciplines, but expressed slightly differently than usual, because it reverses the direction: it is not only engineering that depends on physics and its discoveries, but it is also physics that has a vested interest in engineering and its accomplishments.

1.3. Historical Developments Summary

In summary, the most important points from the survey of publications addressing the teaching of physics to engineers up to the mid-twentieth century come from the findings in [5], where the following five objectives are considered to be of paramount importance:

(1) Mastery of the basic laws of physics, its facts and methods [5,8,9];
(2) Knowledge of the scientific method [5,8,9];
(3) Familiarity with the observation process and measuring instruments [5,9];
(4) Creativity and ingenuity [5,9];
(5) Practice in solving actual engineering problems [8,10,16].

This list can be enhanced by other findings and recommendations, especially expressed in reports and articles produced after WW II, as follows:

(1) Keeping in touch with industry [7];
(2) Putting more emphasis on laboratory work [15];
(3) Introducing a business factor as a new dimension in engineering [17];
(4) Additional focus on teamwork and life-long learning [18];
(5) Exposing future scientists (physicists) to some engineering concepts/courses [18];
(6) Advising future physicists that the engineering profession is a natural extension of physics [20].

These six points are meant as learning objectives. Another issue is how to accomplish them (through meta-objectives), which was extensively discussed in many of the papers reviewed, but is not an explicit purpose of this survey. In addition, many of the papers reviewed above discussed the contents of the curriculum, but summarizing these efforts was not a goal of this survey either, because curricula change over the years and can include new branches of physics, cover newly emerging engineering disciplines, and should serve the purpose of achieving the learning objectives rather than the other way around.

2. Physics Teaching in Engineering Education (PTEE) Series of Conferences

The series of conferences on Physics Teaching in Engineering Education (PTEE) is sponsored by a European society named SEFI, Sociéte Européenne pour la Formation des Ingénieurs (http://www.sefi.be/), and its Working Group on Physics in Engineering Education (http://sefiphysics.be/). The SEFI, in its mission and objectives, corresponds to the American Society for Engineering Education (ASEE), with which it is associated. The PTEE conferences have been held every 2–3 years, since 1997, and are nearly unknown in the western hemisphere.

The objective of this section is to review selected papers from the last five PTEE conferences [23–27], capture the trends in teaching physics at the cross-section with engineering and make observations about prospective improvement of teaching methods and practices in both disciplines. In this view, the process of reviewing was organized as follows. First, all papers in their respective volumes were browsed for potential relevance to the subject matter. Then, selected papers were reviewed and categorized into one of the following four groups: (1) Fundamental Concepts; (2) Teaching Methodologies; (3) Teaching Tools; and (4) Assessment. Finally, each category was summarized and compared against the background of similar practices. The structure of this section reflects this process.

The following review assumes a certain view of the mutual relationships of science and engineering, in a narrower sense, and of all four STEM disciplines, in a broader sense. Speaking very briefly, the view is based on the fact that science deals foremost with discovery, while engineering is principally based on using the results of sciences and their discoveries in the construction of artifacts. This is the fundamental distinction between these two areas of human activity and correspondingly, the teaching methods for each reflect these differences.

Furthermore, when dealing with science, one should take into account the ways in which scientific facts are discovered. As Glimm and Sharp, for example, point out [28], "It is an old saw that science has three pillars: theory, experiment, and simulation." This principle is broadly applied in physics, but it has also been adopted in various ways in other disciplines [29]. This is how the teaching categories applied below have been conceived. In addition to teaching methodologies (Section 2.2), one has to address teaching theory combined with simulations (Section 2.3.1) and experiments (Section 2.3.2).

2.1. General Concepts

In general, the PTEE papers fell into one of the categories mentioned above, with the exception of a handful of papers, which are general enough to be treated separately [30–32]. When looked at from the contents perspective, one paper [30] addressed the essential issue of education: key competencies of future engineers, trying to find a balance between physics, math and social sciences. Its author set the stage for educating engineers more than anyone else, by saying, "There can be no doubt that engineering constitutes the basis of our civilization, and that we need innovative engineering to deal with the challenges of our times. Engineers create and operate the tools that are necessary to make our kind of technological society possible." After reminding that "the origin of engineering is in the military", he discussed an array of competencies, calling them "the profile of the engineer of the 21st century". Among them, he included:

(1) analytical skills;
(2) communication skills;
(3) teamwork;
(4) awareness of multicultural aspects.

Then, he added that the contemporary engineering processes can be characterized by two important but somehow orthogonal trends: increasing specialization and an increasing the need for training in non-technical subjects. To address these two challenges, the author reported the following list of competencies that a handful of Dutch technological universities developed, stating that an engineer has to

(1) be competent in one or more scientific disciplines;
(2) be skilled in scientific research;
(3) be skilled in design;
(4) have a scientific approach;
(5) possess intellectual skills;
(6) be competent in cooperation and communication;
(7) take the societal context into account.

To address the shift in educational paradigm, as he called it, de Graaff advocated that "applying an educational method like Problem-Based Learning instead of a series of teacher directed courses results in a curriculum emphasizing practice-oriented competencies rather than theoretical knowledge"—the concept he developed over the years and extended to active learning [33–35].

Another paper [31] attempted to "identify the essential segments which are necessary in physics education so that it can play its expected role in the upbringing of future engineers." Coming from the assumptions that "Physics is the most successful brand of science in terms of its achievements" and that "As far as the technical disciplines are concerned, they all stem from and rely heavily on the methods which physics has discovered for its own sake," the author's thinking is guided, among other things, by the principal questions:

(1) What should be the principal goal of teaching physics to the students of engineering?
(2) What are the essentials that need to be focused on in the process of physics teaching?

which are transformed during the discourse into taking from physics its primary values and advantages to address students' concerns in the acquisition and expansion of knowledge:

(1) How it promotes her/his thinking to a higher level of abstraction, and;
(2) How it trains him/her in discerning the facts from fictions.

With this background, the author distinguished six essential areas, which, as he said, "need to be focused on in order to maximize the benefits of the physics education"—rephrased here as learning objectives:

(1) Apply the rigorous thinking and articulation;
(2) Avoid the Aristotelian misconceptions;
(3) Emphasize the role of the experiment;
(4) Understand the meaning of the physics units;
(5) Embrace of the basic notions and laws;
(6) Realize how your physics problem relates to the basic question of physics.

Each area (learning objective) was discussed next, with thoughts on the role of experiment being particularly to the point. What we mean by this is the following: "the physics lab should focus on the development of the essential skills and on understanding of the measurement process."

The skill development, however, as the author stated, "should avoid the temptation to turn the physical labs into the driving school for various complex devices." On the contrary, "For the students to grasp the essentials of the experimental work they need to experience the uncertainty and dubiousness of the task. They should have a freedom to experiment with the experiment." What appeals to us, in particular, is the "freedom to experiment", which translates into formulating the hypothesis for an experiment, and when supported by understanding of the measurement process and its limitations, leads to meeting the learning objectives.

In a more recent PTEE paper Tiili and Suhonen [32] addressed the development of engineering skills in an introductory physics lab as a learning environment. Based on the set of minimum requirements for engineering programs published by the European Network for Engineering Accreditation EUR-ACE [36], and grouped into eight categories:

(1) Knowledge and understanding;
(2) Engineering practice;
(3) Engineering analysis;
(4) Making judgements;
(5) Engineering design;
(6) Investigations;
(7) Communication and team-working;

(8) Lifelong learning

the authors focused on including not only the essential technological knowledge but also the ability to adapt in the changing professional environments. They implemented respective concepts in a sequence of two lab courses. The first one, “Basics of measurements and scientific reporting”, conveyed basic engineering skills, having the students make controlled measurements, process the data and write a lab report. In the second course, “Laboratory works of physics”, the students conducted four traditional laboratory tasks; however, the last task had them design, implement and report a new laboratory problem on their own. In the last task, the students made all major decisions themselves, from choosing the subject and planning the measurements to designing the equipment and reporting. The authors concluded that this approach “has led to the situation that introductory physics laboratory can be seen as a learning environment for several *soft* skills that are seen important in engineering profession.”

Van der Veen [37] based his approach on addressing the most recent trends in engineering education, which include, among others, combining science and engineering views, interdisciplinary learning, societal relevance, with some technical focus, such as modeling and visualization, teamwork and capstone projects. He reported on several physics project of practical importance, for example, building a hovercraft, x-y pen plotter, a maglev train, and a gas-expansion cooling device with two bicycle pumps. In contrast to the traditional approach to such projects, called an experimental approach, the author advocated a model-based design, which is a typical engineering design method that encompasses development activities in a V-shape model, including requirements and architecture, detailed design, implementation, followed by integration and a test, system verification and validation, and operation. This approach, implemented as “maker” projects, had the following positive aspects:

(1) Maximized retention due to hands-on experience;
(2) Learning to solve problems and open-ended questions in an iterative process;
(3) Educating students in executing designs and multidisciplinary tasks;
(4) Natural embedding of various professional skills, such as project planning, presenting results, conducting professional meetings, teamwork, and producing documentation.

2.2. *Teaching Methodologies*

There are, of course, a multitude of educational theories and teaching methods based on these theories. It has been clear, however, for the last two decades at least, that all new methods are challenging the traditional centuries old teaching model consisting of a cycle of lecture, followed by assignment, ending with an exam. This trend is clearly visible in the presentations at all PTEE conferences, where around a dozen papers report on new teaching methods and practices.

2.2.1. Active Learning

Most recently, Bašista and Ješková [38] discussed an approach that has become a new teaching standard, interactive methods in teaching physics at the introductory level. They tried to address the issue that “students have a lot of learning difficulties related to the conceptual understanding of physics concepts”. They cited the early work of Mazur on peer instruction [39] and Novak on Just-in-Time Teaching [40], among others, and pointed out that via interactive methods “the teacher guides the process of teaching and his students are active participants”, so the “teacher acts as a facilitator of students’ learning.” They described the technique as follows:

> “The interactive engagement methods are defined as those designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors.”

The authors also stressed that the teaching and learning materials were available to students on a Moodle e-learning platform, which is used for mutual communication between teacher and students, for collecting the required assignments and for regular feedback from teacher to students.

Manninen and Tiili [41] also reported on pre-lecture assignments, in the spirit of active learning methods, such as peer instruction [39], at Tampere University of Applied Sciences. They stated that one of their main objectives was to recognize and increase students' prior knowledge and considered that "Active learning methods are the key to better learning outcomes. Using pre-lecture assignments students can be activated before and between lectures and teacher can focus on more demanding aspects of the topic during lectures." In particular, the main objectives of the technique of using pre-lecture assignments are to

(1) increase students' prior knowledge;
(2) perceive students' preconceptions;
(3) concentrate on more demanding aspects of a topic;
(4) concentrate more on examples concerning students' own field of study during lectures;
(5) use lecturing time more efficiently and;
(6) motivate a student to spend more time on studying.

Although not claiming explicitly the use of active learning, in an article by Zwiers and Dederichs-Koch [42], the authors applied it in the classroom. They described what they call a student-centered learning unit on kinematics, with the use of robots, which are treated as strictly educational tools, with no programming or control. What is important is not the subject matter, which can be different from kinematics, but the teaching approach, which follows the principle of active learning by structuring the learning unit into three parts:

(1) Two-hours introductory laboratory workshop, in which the student teams are built, learning objectives are specified, and the participants are encouraged to experiment with the robots; in other words, it is all preparatory;
(2) Written homework assignment to be completed by each student team before entering the second laboratory workshop, based on the first workshop, prior knowledge, as well as literature and Internet search. The students are required, in this particular lab unit, to elaborate on the kinematic model of the two-wheeled differential-drive robot and its trajectories;
(3) Four-hour laboratory workshop scheduled a couple of days after the first one, in which the kinematic model is briefly reviewed by instructor and potential questions raised by students are discussed. However, no solution is handed out to the students, as they should use their own notes, ideas and creativity to work on the workshop's challenges.

A written test concludes the unit to evaluate student progress. A list of learning objectives summarizes what the students should know after completion of the learning unit. Among more general competencies, this type of active learning addresses logical reasoning and self-learning ability.

In [43], Beichner discussed the principles of SCALE-UP projects (one of the meanings of the acronym is: SCALE-UP = Student-Centered Active Learning Environment for Undergraduate Programs), which have been successfully adopted in multiple college level courses at institutions across the United States. In the author's own words, "It describes a place where student teams are given interesting things to investigate while their instructor roams—listening in on student conversations, sending one team to help another, or asking why someone else got a different answer." The method is not restricted to teaching science, but when it is: "In science classes there are usually some longer, hypothesis-driven lab activities where students have to write detailed reports. Occasionally there will be lecturing, but that is mostly to provide motivation and a view of the big picture." Example of learning objectives provided by the author for a Calculus-based Introductory Physics course, include the following:

(1) develop a good functional understanding of physics;

(2) begin developing expert-like problem solving skills;
(3) develop laboratory skills;
(4) develop technology skills;
(5) improve communication, interpersonal, and questioning skills;
(6) develop attitudes that are favorable for learning physics

and can be mapped onto the Accreditation Board for Engineering and Technology (ABET) outcome requirements [44], with one additional objective "have a positive learning experience", which is not in the ABET list. These objectives, however, or their assessment techniques (listed in the paper) are not method-specific and could be accomplished with other teaching methodologies. In addition, by its very nature, as described by the author of this paper and in other relevant publications (for example [45]), the SCALE-UP method is clearly designed for an environment involving in-class teaching and is hard to adapt to teaching online.

Kautz [46] reported on the use of three educational approaches in an integrated manner, to address student difficulties in introductory engineering courses:

(1) Active Learning, understood as having students discuss conceptual questions during class time;
(2) Just-in-Time-Teaching (JiTT), that is, requiring students to read material before class and submit specific questions, and;
(3) Tutorials, by using a set of collaborative worksheets that help students master relevant concepts.

The comprehensive approach, applied by Kautz and his team, is designed to deal with broader issues in the teaching and learning processes. It is based on several assumptions concerning the student population. First, one can tell that most people learn primarily not by listening to others but by acting themselves. Next, in academic learning, the acting to a large extent consists of thinking, i.e., constructing one's own understanding of the subject matter. Specifically, in STEM, the thinking processes have to involve key ideas in the respective discipline, including treatment of common incorrect beliefs (misconceptions). Finally, in the Information Society, students need to learn how to learn, in addition to learning the knowledge of their discipline.

Teaching Engineering Mechanics in such a student-centered environment, where there were no regular lectures (i.e., no complete coverage of content by a lecturer), students had to familiarize themselves with content through reading (inverted classroom or JiTT), and worked with conceptual problems in small groups aided by the instructor. The data collected showed that active-learning methods are potentially much more effective than traditional lectures or problem-solving demonstrations. Interestingly, it was found out that for the approach to be effective, students need to be constantly reminded that the course is run in this particular manner (non-traditional lectures).

2.2.2. Project- and Problem-Based Learning

Project-Based Learning (PBL) has been a popular method to enhance teaching and learning. Lock and Lambers [47] reported briefly on applying the method in an advanced course on photonics, where the students perform the research projects in the following steps:

(1) selecting an experiment form a list given by Instructor;
(2) searching the literature and designing an experiment by formulating a research question (which probably means a hypothesis);
(3) putting the equipment together, including making order for parts not available in the lab;
(4) performing the experiment on their own equipment, as well as two different experiments prepared by two other groups of students;
(5) writing a report on the results obtained during the experiment.

According to the authors, by conducting the projects this way, students acquire or improve a number of soft skills, such as communication skills, ability to handle deadlines, and teamwork understood as cooperation with other student groups.

In a study by Kralova and Kukurova [48], project-oriented teaching and learning was discussed for a program teaching physics to medical students. Thus, it is not exactly technical but in line with common understanding of PBL, viewed by the authors as follows:

> “projects are complex tasks, based on challenging questions or problems, that involve students in design, problem solving, decision making or investigative activities; give students the opportunity to work relatively autonomously over given periods of time; culminate in realistic products or presentations”.

In [49], Stankowski discussed project-oriented teaching, with so called “thematic blocks”, which are not full-fledged projects but share many characteristics with them and initiate students to do later project work. A 3-day thematic block was spent on a specific topic in the lab, with two lecture sessions, run by physicists but involving colleagues from the engineering department. As the author phrased it for a specific thematic block on magnetism:

> “Most activities are hands-on lab, done in small groups and coached by teachers or assistants. The change in working style and rhythm, the mixture of general physics and technical application, interdisciplinary aspects and a general atmosphere living from individual work and common inputs, give these “magnetic days” some sort of project flair which is very motivating for the students.”

In the author’s opinion, this method of teaching improves competencies, such as global thinking, understanding different disciplines, and teamwork.

Although not identified as PBL, Suhonen and Tiili [50] effectively applied this method when they discussed implementing a change in their Physics Laboratory I course. The change addressed the four types of skills the students need to acquire (learning objectives, otherwise): mastering the laws of physics, learning the measurement process, evaluating uncertainty in measurements (analyze data), and conducting scientific reporting.

They rephrased the students’ activities in three steps, as follows: “First they go to physics laboratory to carry out measurements. Next week they bring their measurement results to mathematics workshop, which content is related to the analysis of their results. In reporting workshop they learn how to report them in a correct way.”

In a subsequent article, Suhonen and Tiili [51] gave a broader background and more extensive view of the change. Based on the premise that “data analysis skills and reporting skills can be considered as fundamental objectives of engineering laboratories”, the course was restructured to involve three essential parts: ensuring different physical phenomena, handling and analyzing the data, and presenting results in a meaningful way as a scientific report.

This innovation is not only in the new structure of the course, by which “physics, mathematics and communication studies are therefore integrated in the same course,” but also, and more importantly, in the way the course is conducted. Namely, in the words of the authors:

> “Students start the cycle in physics laboratory. With their measurement log book, they then continue to mathematics workshop during with they carry out the calculations and analysis. Once the results are ready, they have a reporting workshop. Usually, all these take place in three consecutive weeks and this three-week cycle is repeated throughout the course.”

Admittedly, an important side effect of this way of structuring the lab teaching was a heavy increase in teacher’s workload.

Radojewska and colleagues [52] presented a slightly different approach, although their concern was the same: “how to activate students to learn more than a minimum.” The authors discussed a couple of innovative methods to conduct experiments, keeping in mind that the experiment should explain a physical mechanism of a phenomenon, be related to phenomena applied in technology, show future prospects and possible developments, and even prompt the students to minimize the costs. The experiments described involved not only the measurements but also computer simulation of a physical phenomenon, with small code changes needed to observe different behaviors.

Langereis et al. [53] applied project-based learning in a higher vocational college for engineering physics and described several projects on various topics, including acoustics, optics and photonics, application in medicine, and others, coupled to a company or a societal context. Their paradigm is to keep projects structurally embedded in the entire curriculum to give them a central position in learning.

A very unique method among project-based approaches, which could be also included in the Active Learning section, is the Lab-Team-Coaching (LTC) presented by Sum and colleagues [54]. It relies on applying the flipped classroom approach to the laboratories, making a shift, as the authors say, from "teaching contents" to "learning methods". The process of Lab-Team-Coaching consists essentially in the following three steps:

(1) After an individual preparation, running an experiment alone or in a pair, without instructor;
(2) Evaluating the results in a small team and having discussions still without instructor;
(3) Attending a coaching session to discuss results and reporting, with participation of instructor.

As reported by the authors, this method has been successfully used for over a dozen years, with participation of more than 6000 students, and has been extremely successful in shifting the learning process to be embraced by the learners themselves, relieving the requirements on the teaching staff, floor space and the financial means.

2.2.3. More General Approaches

While most of the previous methods discussed in this section provide clear teaching guidance, oftentimes, even practical recommendations for teachers, indicating a number of steps to follow to effectively transmit knowledge and meet learning objectives, there are a number of more general approaches, which address teaching and learning from a higher-level perspective and provide only general guidance, if any.

An interesting view on teaching physics to engineers was presented by Stankowski [55]. He addressed the question of what is "physical thinking." If this concept is defined, one can try and naturally address it in teaching. The author attempted to list a number of characteristics of this concept, including

(1) knowledge of and ability to apply fundamental concepts (e.g., conservation laws);
(2) ability to apply formal methods and logical thinking to real world problems;
(3) ability to transfer between different disciplines, exploiting analogies;
(4) order of magnitude estimations;
(5) interpretation of data (including error analysis);
(6) interpretation of diagrams, and;
(7) knowledge and skill in using measuring instruments.

The author explained that "physical thinking is not so much a special method, but rather a general attitude, the ability to interpret the real world—be it our environment or technical systems or measurement outcomes." To pursue respective teaching methods to get the students to acquire "physical thinking", the author suggested using two principal and interrelated concepts, which he called variations and analogies, where variations are the way of presenting a problem from different points of view, and analogies mean discovering and exploiting common aspects in seemingly different problems as they may arise in different disciplines.

Bernhard, Karstensen and Holmberg [56] promoted their idea of teaching improvement by having the students learn a "complex concept", which is understood "as a whole that is made up of single interrelated concepts". Their rationale is that "In engineering and in physics education a common objective is that students should learn to understand theories and models and their relation to objects and events and learn to apply these models and theories." Thus, making connections (links) between models and engineering practice is essential in this approach. Unfortunately, even though the idea itself may be very appealing, the authors offered little practical guidance on how to apply this approach in practice.

2.3. Teaching Tools

2.3.1. Computational Aspects

Computational aspects of teaching physics actually have two flavors: one—to use computational methods to teach physics by illustrating its laws, and another—to use computational methods to make scientific discoveries. For this survey, we are concerned only with the former.

One approach is to teach the students to write a simple code, or modify an existing code, to illustrate certain phenomena that are not easy to show in lab. This method was shown by Kúdelčík [57] to demonstrate the propagation of electromagnetic wave. He used the method named FDTD (Finite Difference Time Domain) and developed a program in Matlab, which can be successfully used in physics courses, allowing students to choose different parameters for illustrating the desired situations.

The same tool, Matlab, was used by Tarnowski and Salejda [58] for applying the Transfer Matrix Method (TMM) to calculate transmittance, reflectance and absorption, in courses in various subdisciplines of physics, material engineering, electronics and telecommunications. Although it requires basic familiarity with TMM, the authors designed the software with adequate graphical user interface to facilitate the use by physics students and teachers.

A similar approach has been taken by Mala and Scholtz [59], who used Mathematica to illustrate phenomena in chaos theory and fluid dynamics, in their graduate level physics course in the transportation department. As reported by the authors, the value of the tool relied on the fact that "While some of the problems investigated during exercises can be solved analytically, the most of equations describing realistic situations do not possess solution which could be expressed in a closed form."

Computational tools, such as Matlab, Mathematica or Maple, are convenient and relatively easy to use in physics and engineering courses, but normally have very expensive licenses. Orlik and Pawlik [60] proposed using open source software. They used Maxima, with essentially the same capabilities as the above-mentioned commercial computer algebra systems (CAS) and developed a user interface based on the Qt library, another open source system. They described an approach to use it "in teaching mathematically difficult issues for a first year students of physics."

A characteristic for using computational tools in physics and engineering courses is to treat them as teaching tools, with an easy to grasp structure and a user-friendly interface. Therefore, software packages, such as Matlab, Mathematica, etc., are, in most cases, the first choice of instructors, with well-developed open source tools being the next choice. There is, however, a more in-depth and orthodox approach which relies on using numerical methods to illustrate phenomena in physics and engineering. This approach was advocated by Scharoch [61]. The author argued that "various aspects of numerical modeling should become an important element of academic education." Consequently, he developed related lessons, called subject units, in which students are guided to solve numerical problems as follows:

> "Subject Unit (Project) begins with presenting the physics problem, discussing it and identifying the mathematical tools needed. Then, appropriate numerical methods are introduced, the algorithms developed and a respective computer code shown and discussed. On the level of programming, the simple FORTRAN77 language is used, to avoid complication on that level. During computer laboratory sessions students have an opportunity to test and modify the codes, and finally perform some experiments which resemble the real ones, but offer much more freedom of setting the conditions and therefore open large space for creativeness and learning physics."

From the perspective of pedagogy, the students have the opportunity to learn multiple skills by discussing the problem on the conceptual level, together with mathematical formulation, finding numerical methods, appropriate algorithms and writing the computer codes, and testing the programs and using them to perform virtual experiments and to analyze the problem. It must be noted that the code for the solution is actually available in advance for most projects and can be modified by students. Additionally, two more steps are included: representing the computational results graphically and preparing brief reports.

Although it is unlikely that this approach can be successful in low-level service courses with large number of students, it definitely has merit, since physicists and engineers commonly use computational methods in making discoveries.

Two additional methods that can be viewed as computational, because of their processing power, are Virtual Reality [62] and smartphones [63]. Viewing Virtual Reality as an evolution of computer-assisted instruction, Engeln and Gomez Puente [62] described a setup for experiments in optical techniques, such as emission and absorption spectroscopy, laser-induced fluorescence, and others, seeing clear advantage in applying this technology from the point of view of financial benefits (it is much cheaper than purchasing actual instruments) and safety (by avoiding real manipulation of lasers in a lab).

Dorsel et al. [63] presented a software application for a smartphone, developed at RWTH Aachen, which uses numerous sensors embedded in a smartphone (acceleration sensor, light and pressure sensor, gyroscope, microphone, etc.), as well as external sensors that can be connected via Bluetooth, to create measurement experiments and labs. The enormous computational power of smartphones transforms them into a useful measurement device capable of simple averaging to complicated Fourier analysis.

2.3.2. Laboratories

An experiment in the laboratory is a fundamental teaching tool, both in physics and engineering, and knowledge acquisition as well as skills development highly depend on proper lab organization. The discussion of articles on laboratories, due to specific interests of these authors, is divided into two categories as reflected in the corresponding subsections below: (1) articles on self-contained labs, which form sufficiently well-isolated units that could be reused in various courses, and (2) articles, which discuss or refer to various forms of remote access to laboratories.

Labs as Learning Objects

It is surprising that among the multitude of topics discussed at PTEE conferences, the concept of a lab as a self-contained entity, so essential in physics and engineering, has been covered in only a handful of papers. Nearly all papers mentioned the laboratories in one way or another; nevertheless, only very few presented or discussed a specific lab as a whole unit.

The labs identified as self-contained entities form candidates for learning objects. A Learning Object is understood as a closed well-defined unit that can be offered for use in education to any interested party who is sufficiently prepared to apply it in teaching or learning. The concept itself has been around for at least, two decades [64]. The property of the labs, which makes them suitable for use as Learning Objects, as a resource for use by multiple instructors and different institutions, is their clearly defined interfaces. Knowing the interfaces, that is, allowed actions (and their sequences) to be performed on the physical devices (instruments), formulated in a prescribed language (traditionally presented in a form of instruction manuals) is all the learner needs to pursue the acquisition of knowledge.

Two papers by Radojewska et al. [65,66] are particularly closely matching the concept of lab as a Learning Object. Two lab topics were selected thoughtfully and were sufficiently narrow to create self-contained lab units: (1) application of the Peltier effect and (2) application of the Seeback effect. Although lab objectives were not stated explicitly, they correspond to

(1) Lab #1 Objective: study the Peltier effect in heat pumps and thermoelectric coolers;

(2) Lab #2 Objective: study the Seebeck effect in electric thermogenerators.

The theoretical background for both effects is outlined in the papers, plus equipment configuration (instruments and devices) and tools illustrating the application of both effects are described. Pedagogically, the lab description is also valuable to instructors by stating the learning objectives of each lab, which, for the first lab are listed in terms of what the student will learn, as follows:

(1) understand the thermoelectric phenomena and their description, particularly the Peltier effect;
(2) investigate the basic parameters of the Peltier module in the cooling mode as well as in heat pumping, particularly the figure of merit;
(3) investigate the temperature difference between the cool and hot sides of the module as a function of the DC intensity;
(4) investigate the cooling efficiency for the Peltier module, and;
(5) investigate the temperature difference between the cool and hot sides of the module as a function of the AC intensity in order to determine a role of the Joule heating.

Procedures explaining how these learning objectives are to be met would constitute the definition of a Learning Object, but this is stated rather vaguely in the papers (as a bulleted paragraph on lab procedures named "Course of the measurement").

These two labs are interesting in that the authors advocate that merely to understand a certain physical phenomenon, its principles are not sufficient to serve as a learning objective; the lab should offer more. Relating the phenomenon to actual circumstances in practice (real life) and even more importantly, investigating various options (combinations of parameters) and their consequences, for example, to study some boundary conditions, is much more critical for the learning process than just understanding the phenomenon.

An earlier paper from the same team of researchers [67] discussed a lab on studying piezoelectric effects as an example of reversible phenomena. It begins with an assumption that the role of lab experiments is "not only illustrate physical laws," which is in line with learning objectives of later projects, discussed above. In this regard, the paper mentioned multiple actual applications of both direct and converse piezoelectricity in technology and real life, as well as offering the students studying the relationships of some relevant variables, for example, "investigate a dependence of the deformation upon the electric field intensity for samples made of different ferroelectric materials." Similarly to the labs mentioned above, the theoretical background of both processes was explained and lab devices (instruments) were described to some extent. Only a brief explanation of lab procedures was given, however.

This group [68] also described a laboratory designed for studying photo-electric effects for students of electronics. Multiple single experiments were mentioned without describing them in sufficient detail. However, a number of steps in conducting a lab unit were mentioned, or rather, spread across the paper, which can be extracted and summarized as follows: students learn theoretical background prior to a start of the laboratory, and they also set up all connections, adjust all devices and meters by themselves. According to the authors [68], these activities serve the purpose of learning by improving self-control, self-reliance, comprehensive thinking, and technical creativity. There was no mention of the lab procedures either and whether the students had to write a report discussing their findings.

Summarizing these descriptions, it is rather clear that according to the authors of these papers, the lab should offer more than just learning about a certain physical phenomenon, or understanding it. Stating it even more strongly, in terms of real experiments (a scientific method), ideally, the students in the lab should experience the following: formulating a hypothesis, designing an experiment to confirm or deny the hypothesis, conducting an experiment to collect data, and analyzing the results (to derive a conclusion) and presenting them in a report. Student activities, such as changing parameters, proposing a new set-up, or producing a structured write-up, increase the labs' impact on acquiring knowledge and will have a dramatically higher positive effect on learning.

In the most recent paper from this group, Radojewska et al. [69] presented a sophisticated lab experiment, designed for students of electronic engineering, on studying the properties of ferroic materials. The description involved theoretical fundamentals and computational methods with suggestions on how to conduct the experiment.

Several other papers from the recent PTEE conference [23] discussed the labs at different levels. Tarjanyiova et al. presented a concept for the demonstration lab named Land of Waves [70] to illustrate the basic properties and principles of generating and observing various sorts of waves. The open lab allows not only to demonstrate the propagation of waves but also to conduct some simple exercises to capture the impact of parameter change, for example, in generating acoustic waves with a guitar or mechanical waves on a water surface.

While demos and exercises in the Land of Wave are designed to be essentially passive and may be good for introducing students to understanding the subject matter, real experiments in physics require active attitude on the part of a student and the application of knowledge to make discoveries of certain phenomena for which the lab is designed.

Jödicke et al. presented their take on the issue of conducting labs, calling it "optimization" [71]. They stated their paradigm as follows: "How can we design the physics laboratory in such as way that students can derive maximum benefit for their education as engineers?". This approach shifts focus of the labs on physics methods and allows transferring knowledge actively, rather than by passively performing the lab instructions. As reported by the authors, the resulting procedure gives students a chance to make mistakes, teaches the students how to use the tools for analyzing their activities, and allows the students to make corrections and choose the most suitable solutions (optimize).

The last two papers bring attention to the concept of hierarchy in organizing the laboratory activities, summarized in [72] as DEEP learning. The entire concept relies on teaching labs in progression, beginning from simple Demos followed by Exercises, which leads to building Experiments and conducting full-scale Projects, thus the acronym DEEP learning—a concept that allows students to learn the subject in-depth by conducting hands-on activities, depending on their current level of knowledge.

Remote Labs

Due to technological progress, nowadays, the question of remote labs in physics and engineering is essential for the development of both professions. On a general level, the most prominent example of remote operations is NASA's Pathfinder mission to Mars in 1997 when the rover control software had a glitch and had to be analyzed back on Earth at the mission control in Jet Propulsion Laboratory. Once the bug was fixed, the software was uploaded back to the rover on Mars. A more contemporary, but also spectacular, example is remote access to the experiments at Large Hadron Collider (LHC), in Geneva, where physicists and engineers around the world can not only collect data but also program their data acquisition and control systems over the Internet. In today's terms, with the widespread proliferation of the Internet of Things, this issue is no longer so spectacular, but gradually becomes a matter of everyday life. It is the responsibility of educators to adequately prepare the future scientists and engineers for this task. There are hundreds of publications and a number of books, for example [73], discussing the topic of remote laboratories.

In PTEE conferences, Svoboda and Stockel [74] described a project developed in response to the fact that "education in the field of high temperature plasma physics suffers from a lack of appropriate experiments in which students have access to hands-on experience with tokamaks, complex laser systems etc." As a result, a remotely accessible system was created, which "is connected via a web server to the Internet and offers remote control either in the online mode via WWW or SSH [Secure Shell] interface, or in the offline mode with the batch processing code." Multiple educational uses of this system were reported by the authors, with experiments controlling all technological aspects of the tokamak operation, conducted by users (students) from several foreign countries.

Haluskova [75] approached remote labs very enthusiastically and reported their value in the fact that "all teachers can use real remote experiments without buying expensive experimental devices." She reported on remote laboratory exercises in electromagnetic induction, when the actual lab was located at a university in a different country, stating in conclusion: "Interesting result is that the students don't consider the real remote experiment less interesting than experiment performed in the laboratory. In our opinion in the 21th century the real remote experiments can aptly supplement the classical form of education."

While the above-mentioned arrangements are for online experiments, Hockicko [76] advocated a slightly broader strategy combining virtual and online labs. With the use of a video analysis and a modeling tool called Tracker, "The prepared set of video experiments was placed at the World Wide Web as an aid serving for visual demonstration, explanation and physical analysis of real processes." That way, as the author claims, "Online literature, simulation with an online tutoring system and association of the remote experiments can result in an online practical course, which can be very useful in engineering education and can be helpful for the engineering students throughout their academic studies and also the career as an engineer." This is because "The physical analysis using Tracker is for students more demonstrative, learning physical equations is quicker, application of the physical laws is more illustrative," thus, leading to better mastering of key competencies.

A blend of hands-on, virtual and online labs, named laboratory immersion, was described in two papers by Langie, Verelst and coworkers [77,78]. A laboratory immersion is an intensive on-campus lab preceded by and finished with distance learning activities. The experimental work was divided into three phases: a pre-lab phase at home focused on preparation (literature, simulation, tests, etc.), an on-site laboratory session for hands-on activities, and a remote post-lab phase for reflection and reporting.

More details on each of these three phases can be found in the papers, but what is important are some of the key aspects of the phases reported by the authors. They emphasized that students should be able to work in teams, that the hands-on phase is an important element which should not be skipped, that coaching is an important element, since students fear less support and more responsibility, and that total study time needs to be comparable to the regular labs. All this, however, if seen as disadvantages, can be reduced when the lab immersion into courses is viewed as a flexible tool with respect to time and location.

For the complete view of online labs, one has to look at their incorporation into Learning Management Systems (LMS). Although papers, such as the one by Suhonen [79], looked into comparison of specific LMS's, in this case MOODLE and Claned, it is not clear what tools are available for using online labs from within these systems.

In summary, having said this, one may want to ask the question: what is the intellectual value of using remote (online) labs in teaching? While this question is legitimate, this overview paper is not the right forum to give an answer, although it should be mentioned that online labs in science and engineering are blooming around the world, including the standardization efforts [80], in which one of the authors is involved.

2.4. Assessment

In applying all teaching methods, it is essential to study their effectiveness, that is, how well or how fast students learn the subject matter and—importantly in engineering—can apply the concepts they learned. At the most recent PTEE conference [23], a number of papers were presented related to various aspects of assessing a student's progress in physics [81–83]. Schäfle and Kautz [81] studied how students in the first year of engineering struggled with several essential concepts in physics, with the objective of helping instructors in fluid dynamics gain insight into student thinking. They developed a questionnaire that allowed for quantitative and qualitative analysis of student reasoning. The findings confirmed that the active learning methods (peer instructions and JiTT) were more effective than traditional teaching by a ratio of almost 3:2.

Hockicko and coworkers [82] addressed a pressing question on how to expand or replace traditional lectures with active learning exercises. They applied a video technology in teaching and an automated program for video analysis called Tracker. The essential idea was to use a video set to explain physical laws in lectures and follow up with video analysis in seminars. Based on experiments conducted at two universities, one in Slovakia and one in Russia, applying the Force Concept Inventory (FCI) test to verify students' knowledge of kinematics and dynamics, they concluded that "interactive methods make learning physics easier for the students, [as] they can set individual pace for their work, and they have fun when analyzing videos."

Stanzel et al. [83] also used the FCI as a tool to study the impact of interactive teaching methods on the heterogeneity of knowledge in the student population entering the university. Applying the FCI test as pre-test at the beginning of a course on Newtonian mechanics and then as a post-test at the end of semester, the authors concluded that the heterogeneity was slightly reduced when active learning methods (JiTT and peer instruction) were used, but the differences between different groups of students remained due to the fact that students with better knowledge of the subject also benefited from the active learning technique.

2.5. Summary of PTEE Findings

Whether we realize it or not, in teaching, the concept of reuse is critical. Everyone is familiar with the reuse of teaching methods and we all do it. All methodologies referred to in the body of this section, whether active learning, JiTT, or PBL, etc., have been well developed by their authors and followers and offered for use (actually, reuse) by others in their own teaching. This is a well-recognized process, which we all follow, although not necessarily calling it "reuse". However, in the same spirit, instructors should realize that they can create and let others reuse Learning Objects, although this is not that common. For this to happen and be widespread, we need to define more precisely the term Learning Object and convince instructors that the learning objects can be reused just like we reuse computer programs for teaching. There is only one sign of this trend in all four PTEE conferences, where instructors have developed a lab so concise and self-contained that it was sold to other universities (one of the labs described in [66]).

One other extremely important issue in teaching physics—and not only to science and engineering students— is the measurement process. For example, students should realize from the very first class period that the result of a measurement is, in fact, two numbers, that is, the value of the measurement and an error (accuracy), to reflect the uncertainty. There are several more fundamental issues like that in teaching the measurement process, which go back historically to the 19th century, as formulated first by Hermann von Helmholtz in his groundbreaking work "Zählen und Messen" [3], briefly reviewed and summarized in [84]. In the PTEE proceedings, there are only a few authors who emphasized the importance of understanding measurements, although not going into detail [31,50–54,64,65].

Another critical point in teaching physics to engineering students is to make them realize that these two disciplines, or even more broadly, science and engineering, are substantially different. Science is essentially problem-based because of the element of discovery, which results in some findings about the real world, while engineering is project-based because of the construction (development) focus, which results in developing a product or, at least, designing it. Certainly, the distinction is not black and white, since there may be many problems in engineering and projects in physics. However, keeping this in mind leads us to two substantially different processes, which we need to apply in teaching. The process of teaching sciences should include the scientific method, which translates in the labs into the following steps that were already mentioned in Section Labs as Learning Objects and are repeated here for convenience:

(1) formulating a hypothesis;
(2) designing an experiment aimed at confirming or denying the hypothesis;
(3) conducting an experiment to collect data;
(4) analyzing the results (to derive a conclusion) and presenting them in a report.

A similar process for the labs, in teaching engineering subjects, and roughly parallel in steps, although with different contents and focus, should look like this:

(1) agree on product specification;
(2) develop the product design;
(3) execute the implementation;
(4) perform testing/verification.

Surprisingly, only a few papers in PTEE conferences mention the focus on hypothesis, sometimes using the term "research question" [31,43,47] in the scientific method and not a single paper mentions the engineering process.

One very positive fact, clearly noticeable when reading these articles, is the general concern about pedagogy. When designing a curriculum, a course or a lab, one should look primarily at the guidelines formulated by professional institutions and societies. This could be ABET or the National Academy of Engineering, for engineering disciplines, perhaps comparing the guidelines with practice [85], or for physics—the AAPT, which has formulated a set of competencies and a corresponding set of guidelines—stating that the learning outcomes should be based on the following areas (taken verbatim from [86], with implementations described in several papers, e.g., in [87]):

(1) Constructing knowledge—collect, analyze, and interpret real data from personal observations of the physical world to develop a physical worldview;
(2) Modeling—develop abstract representations of real systems studied in the laboratory, understand their limitations and uncertainties and make predictions using models;
(3) Designing experiments—develop, engineer, and troubleshoot experiments to test models and hypotheses within specific constraints, such as cost, time, safety, and available equipment;
(4) Developing technical and practical laboratory skills—become proficient using common test equipment in a range of standard laboratory measurements while being cognizant of device limitations;
(5) Analyzing and visualizing data—analyze and display data using statistical methods and critically interpret the validity and limitations of these data and their uncertainties;
(6) Communicating physics—present results and ideas with reasoned arguments supported by experimental evidence and utilizing appropriate and authentic written and verbal forms.

As a final comment, even though the content of this sub-section is heavily skewed towards the authors' professional and educational practices, they believe that these practices are sufficiently general to contribute to any teaching methodology.

3. Contemporary Issues in Teaching Physics in Engineering

3.1. General Issues

Recent papers on teaching physics in engineering environments discussed a variety of issues, from focusing on psychological aspects of teaching physics [88] to presenting the broader context of the relationship between science education and technology education, in general [89], to discussing consequences of the evolution of physics for engineering education [90], the most important trend on competency-based teaching [91].

Stankowski [91] addressed the issue of competency-based teaching before it was fully tackled in the ABET and AAPT guidelines. He made a point about the shifting role which physics plays in engineering education, stating that "Conveying knowledge is getting less important and at the same time conveying methodological skills is getting more important." Clarifying it further, he claimed that rather than conveying knowledge "methodological aspects are gaining importance instead: experimental techniques, evaluation ad model building." In this view, he suggested two general approaches to teaching physics: the principle-based approach, and the analogy-based approach.

The principle-based approach responds to claims from engineers, whom he quoted as saying that "graduates, at the beginning of their industrial careers, tend to make too complicated assumptions trying to understand systems in their full complexity." This leads to a waste of time and energy, since "it is extremely important to fix the basic simple structures first."

The analogy-based approach, despite appearing to be very important, does not receive as much attention in his paper, except a general statement that "A physics course based on principles shows up analogies between different application fields." He also gave an interesting tip on looking for analogies between formulae appearing in different contexts, for example, from his own teaching experience, comparing inertia caused by mass m, in a formula for the driving force $F = m*a$, and resistance R, in a formula for potential $U = R*I$. To illustrate the application of these concepts, he gave an example of an open laboratory where

> "Normally, students do not have theoretical knowledge about the systems they work with, because the aim of this laboratory is not to demonstrate the validity of known physical laws, but to challenge the explorative spirit of the students and to show them how to proceed in front of a completely unknown situation."

Rendevski and Abdelhadi [92] offered a very thorough analysis of a subset of competencies initially based on the ABET guidelines, which they called soft skills, applied to teaching physics courses. Among the essential soft skills, as determined by ABET, they listed the following (although there are others):

(1) an ability to function on multidisciplinary teams;
(2) an ability to communicate effectively and;
(3) the necessity of understanding the impact of engineering solutions in a broader societal context.

Translating these skills into more specific competencies, they listed an array of soft skills that need to be gained by an engineer to be used throughout their entire career:

(1) learning skills;
(2) communication skills;
(3) domain-general and domain-specific skills;
(4) management skills;
(5) business skills and;
(6) leadership skills.

Although strictly speaking, these skills per se do not constitute any meaningful relation to physics, the authors saw the relationship and stated the following:

> "Physics courses are among the early courses taught to students. They provide the perfect opportunity to introduce basic skills related to professional development at an early stage. Students can pick up on what they learn in Physics and improve their soft skills throughout their engineering courses at higher levels."

Consequently, they listed a number of soft skills to be acquired by students in physics courses, compatible with those included in the report by the Institute of Physics [93], which they called transferrable skills:

(1) problem-solving skills;
(2) investigative skills;
(3) communications skills;
(4) analytical skills;
(5) information technology skills;
(6) personal skills, and;

(7) ethical behavior.

Rendevski and Abdelhadi also proposed an assessment strategy, how to evaluate that these skills have been taught and actually acquired.

McNeil and Heron [94] addressed the problem of skills most desirable for the engineering students to acquire in physics courses. They quoted a survey of graduates from 2013–2014 that indicated some 65% of graduates with Bachelor's degrees in physics who entered the workforce got employment in the private industry. The article then claimed that in industry, "Working in teams, technical writing, programming, applying physics to interdisciplinary problems, designing and developing products, and managing complex projects are all acquired skills." And further, the authors stated: "But for most physicists, developing them [the skills] was only a small part of their educational experience." This is very important, since it clearly indicates additional skills that should be addressed in physics courses. Yet, these skills are not necessarily emphasized in the existing teaching practice.

A number of additional papers include a discussion of skills needed by engineers that can be acquired in physics courses. Zhao et al. [95] addressed the problem in Chinese universities that "now aim to produce engineering undergraduates with practical skills to reinforce their competence in application and innovation." They described their approach to introducing a reform in college physics courses. More recently, Fadhilah [96] reviewed almost a dozen publications dealing with teaching physics in engineering environments and identified their relevance to building models of teaching physics, teaching methods, and conducting assessments. Although it has not been expressed explicitly in this paper, the categorization as outlined by Fadhilah [96] is extremely important because it addresses three crucial aspects of teaching physics for engineers: stating the learning objectives, selecting teaching methods to achieve these objectives, and assessment of reaching the objectives. Adding one more point, the use of technologies to support the teaching methods in achieving these objectives creates a complete structure of an approach to teaching physics in engineering environments. This section is further organized based on these four stated aspects.

3.2. Teaching Methods

There are a number of papers focused on addressing learning objectives or competencies with select teaching methods. One particular methodology applied in teaching engineering courses is, again, Project-Based Learning (PBL).

Coming from the objectives understood as soft skills, Evans et al. reported as early as in 1996 [97] on team-based projects in first year courses for engineering students. The purpose was to have the students acquire the ability to work in teams, communicate, and apply science and engineering to problem solving.

The authors reported mixed success: "Our experience indicates that project-based learning is indeed a viable and very useful means of instruction, but that its use is decidedly hindered by a lack of classroom-proven projects, learning plans, and assessment tools." However, a positive effect was achieved, since—as reported—the projects enforced design initiative, critical thinking, creative experimentation, computer data acquisition, and formal written articulation of the results.

PBL was also used by Bowe et al. [98] for the development of key skills: group work, problem solving, critical thinking, self-directed learning, and communication. The authors realized, though, that "There has been reluctance to introduce problem-based learning into first-year physics courses, due to the pedagogical view that the students require a sound body of knowledge and mathematical skills before they are equipped to engage with this process." Therefore, they very carefully designed the course by including a number of component processes that involved the following steps:

(1) orientation program;
(2) problem development process;
(3) group process;
(4) assessment/feedback process;

(5) reflection process;
(6) tutorial support, and
(7) evaluation.

No statistical data were reported on the course successes/failures; only 'the following conclusion was stated: "The major advantages of problem-based learning courses are that the students develop the ability to learn independently and in groups, and develop key skills and the ability to contest and debate. It helps the students acquire ownership of their learning experiences by giving them control of the learning process."

Williams et al. [99] explained their motivation to apply problem solving processes in teaching physics to engineers, as follows: "It is clear that for many students, motivation would be increased if the presented scientific concepts could be applied to real-life situations." They used a learning module based on Mathematica software package to address the following learning objectives:

(1) Increase student transferability of knowledge and skills in physics;
(2) Increase student motivation for learning physics;
(3) Increase the number of contexts which will be addressed in the subject;
(4) Improve student perceptions of the relevance to their future career plans;
(5) Enhance student problem solving skills, especially with regard to complex applications;
(6) Enhance student understanding of physical concepts and idea.

Without giving specifics, the authors claimed that with this approach, they were able to improve the student abilities to work collaboratively and focus on problem analysis. There was no discussion on how these objectives and corresponding outcomes were related to teaching engineering problem solving.

Viegas et al. [100] also aimed in their research at increasing the competencies of engineering students in physics courses. To accomplish this task, they relied on collaborative work among students and attempted to answer the question of whether this competence development approach affected final grades. Their results showed that "the efforts contribute to a more effective teaching, producing academic results that are progressively better." In particular, their results support the thesis that "where the learning environment was based on autonomous real work, solving complex real problems and teacher mediation was diversified and centered on student work:

(1) The academic results were equal or even better than those whose classes presented a more traditional teaching approach;
(2) High level competencies were better developed in a larger number of students than those whose classes presented a more traditional approach.

Gnitetskaya and Ivanova [101] proposed their own method for teaching physics to engineering students. They justly mentioned that "the labor market has suddenly increased the requirements to professional level of graduates of engineering specialties", and in this view "The main task for teachers is not just to transfer already built knowledge, but to help develop practical skills to apply that knowledge." Their essential pedagogical instrument to build these skills was a technological module, which was applied in the following six stages:

(1) Building the approximate action's foundation; the students are to learn the module's academic contents and complete individual work;
(2) Students make individual notes according to the plan, formulating a list of questions on the studied phenomena to be answered in the following stages;
(3) Discussion of the knowledge on the topic accumulated previously and review of typical and individual problems;
(4) Students are suggested to write a lab and accomplish an individual task or model the studied phenomena with the computer;

(5) Students review internally their individual problems and labs;
(6) Problems and accomplishments are discussed during the seminar.

In the summary, the authors stated that this approach assists in "the formation of sustainable skills that can be invariant with respect to different objects of knowledge required in everyday engineers' activity."

Several others [102–105] published short notes on their research on methods of teaching physics in engineering environments. Hamlin and Hein [102] reported success in integrating maths, physics and engineering, with a focus on teamwork. Srinivasa and Bassichis [103] advised on differences in teaching for engineers and suggested integrating the freshman physics course with freshman engineering courses, additionally focusing on teamwork and integrated the use of laboratories. The example they gave involved both disciplines: "while a truss bridge is being designed and tested in engineering classes, physics labs are devoted to exploitation of forces, torques and bonding strength of the bridge components." Benito et al. [104] studied teaching physics in engineering via the use of interactive learning objects in the form of simulations. They advocated linking "concepts and content through interaction with active engagement of the student." Gnitetskaya [105] advocated the use of a "physical worldview". According to her, "The worldview is a network with fundamental laws and concepts serving as its nodes. The connections between these fundamental elements [...] can consist of cycles and occupy different hierarchical levels." The author explained that a student can conceptualize respective physical notions within such a "worldview" and maintain it over his/her college and professional career.

A number of authors presented work on the use of more specific methods of teaching physics to engineers, such as design modules, dimensional analysis or concept maps. Oliver and Kane [106] reported the use of engineering design modules in physics courses at the pre-college level. They reversed the way of thinking and introduced engineering thinking to physics courses in addition to insisting on passing physics concepts to engineering students. Chuev [107] advocated using dimensional analysis to describe physical quantities and their dependencies to integrate an understanding of physics concepts into physics and engineering courses, but without putting emphasis on their practical use in engineering.

Research on the use of concept maps in teaching physics to engineering students was presented in two papers [108,109]. Martinez et al. [108] found a statistically measurable difference in learning for students who used concept maps compared to those who did not and assessed the technique as an effective teaching strategy. More recently, Senthilkumar [109] confirmed, in a similar study, the effectiveness of using concept maps in physics teaching. None of these two papers, however, related their findings to how physics should be taught specifically to engineers, mentioning only that students in this research were in engineering programs.

Within the last 5 years, a new wave of papers appeared that discuss methodological approaches to teaching physics to engineering students. Zavala et al. [110] presented research on applying techniques similar to SCALE-UP [45] in teaching physics and math in the engineering program. Emphasis was placed on the proper use of technology to address the learning process, with focus on problems-solving skills and communication skills. No detailed data on learning effectiveness were presented in this study. Following his motivational statement that "Exploring new techniques for teaching engineering physics is a never-ending quest" [111], Maheswaran reported on a study to apply an online tool, Mastering Physics (masteringphyscs.com), in teaching physics to engineering students. It was used in a flipped classroom approach, where "students are assigned to do the conceptual problems before the chapters in lectures are introduced and do more advanced problems after the chapters are covered in class." The students learned the chapters in advance. With this structure, the online tool helped with coaching problems, tutorials and chapter problems. Groups of four to five students were assigned to work on the chapter problems in interactive learning sessions.

Long [112,113] presented a view of teaching an engineering-physics course based on a flipped classroom principle, extending the preparation for a class, from plain textbook readings to what he called a "cloud-based model", which relies on student access to multimedia teaching materials placed in a continuously available cloud. The learning objectives for this course assume that upon its completion, the student will be able to

(1) explain basic principles in specific physical subdomains, depending on the specialization;
(2) apply these principles to natural phenomena;
(3) solve technical problems in basic mechanics;
(4) perform and report on basic physical measurements, and;
(5) employ experimental technology.

Based on first experiences, the author found this methodology very promising and planned on incorporating publicly available physics resources produced elsewhere, as well as publishing videos produced at his university, producing their own video clips by the teaching team to keep the course material in a local context and redoing and improving the quality of their online lecture recordings. Certainly, evaluation of student learning has also been conducted and student academic performance was found to be same as in the older structure.

Özsoy-Güneş et al. [114] conducted a thorough study on critical thinking dispositions to problem solving for engineering students in chemistry and physics. They analyzed the following factors:

(1) analicity;
(2) open-mindedness;
(3) inquisitiveness;
(4) self-confidence;
(5) truth-seeking, and;
(6) systemacity.

and obtained interesting statistical results but did not correlate them with teaching methods.

Cutri et al. [115] reported on teaching physics for engineering students with Project-Based Learning (PBL). The authors claimed that PBL helps develop skills such as critical thinking, information processing, analysis, reflection and questioning. They observed positive results linked to a better understanding of the relationships between the physics concepts and practical applications. The students revealed better motivation and greater commitment to learning.

Most recently, Sabag et al. [116] conducted a study on the effectiveness of active learning in a physics course for electrical and electronic engineering students. Their concern and motivation for change stemmed from consistent observations that "students' grades in physics courses are dramatically lower than in other courses, even compared to very complicated courses like random signals and noise or electrical fields." At the time of the reporting, it was not definitely clear from the statistical data whether the student groups who applied active learning acquired a significantly better knowledge of physics than those who did not.

3.3. Technologies and Tools

To support the implementation of teaching methods or, sometimes, without referring to a teaching method at all, a number of technologies and tools have been proposed and developed, which are relatively well known in the educational community. Those, however, which focus specifically on teaching physics for engineering students are not necessarily widespread or even described in publications. A sample of those presented at the PTEE conferences are described in Section 2.3. A handful of independent technologies and tools, some of them more recently developed, are discussed below.

Kurz et al. [117] outlined the entire system named SLICE (Self-directed Learning and Interactive Computer Environment) created specifically for teaching physics courses to engineering students. It is a multimedia system composed of learning units that integrate textual material, animations, simulation and standard software, such as Excel and Maple. In the authors' own words: "The structure and the results of physics are revealed in multiple representations and hypertext/hypermedia systems are suited to foster interactive learning and to strengthen the acquisition and comprehension of complex cognitive structures." The article described the details of the SLICE system and its usage without relating it to any specific teaching methodology.

Bruce-Lockhart et al. [118] discussed a visualization system named Teaching Machine (TM) for engineering and physics students, which focuses on explaining computing concepts, not physics concepts. Nevertheless, it is suitable for teaching computational aspects to physics students, since—as the authors suggested—" ... most physics students consider programming 'simple' when compared to laws, theories and models of the world. Consequently, as they are not easily convinced that a more complex programming world exists, they keep their misconceptions on how programs work."

Neri et al. [119] described a computer-supported tool designed to "coach engineering students in solving quizzes and exams during an undergraduate physics course." After presenting the tool's architecture and several examples, they came to an interesting conclusion about dealing with different levels of students' knowledge and preparation in the same course. According to them, "A classification of the problems according to their difficulty level is needed: complex, intermediate and basic ones. We can start with a complex problem and, if necessary, go back to intermediate or even basic ones. We can also do this in the opposite direction. In this way, the system can go forward and backward providing problems of different difficulty levels according to student's actual mastering level of physics concepts and their ability for problem-solving."

Amani [120] discussed the basic difficulties of teaching modern physics to engineering students with limited resources. With poorly equipped labs, his teaching of practical concepts focused on simulations, where an important part was implemented by developing didactic classroom (not computer) games. For example, to understand a photoelectric effect, a simple game is described, which used small paper balls representing incident photons.

The actual use of gamification processes in physics topics in education of engineering professionals has been described most recently by Panthalookaran [121]. His motivation was that due to the fast pace of technological developments' "paradigm shift in manufacturing in particular and engineering in general anticipates that the future engineers will need to equip themselves both in professional and life skills, so that their career as engineers and technologists are not critically challenged by the modern technology invasion." Rather than presenting fully developed computer games, the author outlined the principles for developing them. In the author's view, each physical concept can be related to a set of action verbs, which would provide an idea about the actions incorporated into the game. For example, for oscillations, which is one of the six games described, the following action verbs were proposed as defining related physical phenomena:

(1) Expand and restore energy to produce oscillations;
(2) Oscillate in response to supplied mechanical energy;
(3) Preserve the natural (maximum) frequency of oscillations;
(4) Dampen oscillator in order to dissipate mechanical energy;
(5) Force/drive oscillator to sustain oscillations;
(6) Resonate with a wave/oscillator;
(7) Match frequencies of an oscillator with that of a wave.

The remaining five game subjects for which action verbs have been defined include waves, interference, diffraction and polarization of light, and acoustics/sound. This is a "work in progress" project and, as the author admitted, "a suitable measure for the skill development is not attempted in this paper and is left to the future work." It must be stated, however, that the proposition of the approach to gaming in physics and engineering is very inspiring.

Fakhertdinova [122] advocated the use of online physics labs to build technical competencies in engineering students. Focusing on the education of engineers in Russia, she explained her motivation to produce graduates for high-tech industries, as follows: "So, specialist today must be professionally competent, and it means not simply to be good educated or just have a lot of knows, here we speak about the needs improvement in specialization and about personal professional development." Having described some details of online labs and their usage, she claimed that "Undoubtedly, the combination of innovation teaching ideas with the traditional system of teach[ing] physics with the introduction of online laboratory has a positive effect on the learning process."

More recently, there has been a great push observed towards using online labs. In [123] de la Torre et al., by giving examples of such labs and quoting work by several universities that implemented such labs worldwide, made several points about the usefulness of online labs. Unlike in traditional labs, students can complete or repeat experiments on their own time, with a flexibility to conduct the labs from any location. Online labs can provide access to equipment that may be too expensive or logistically difficult to handle for a particular institution. Certain experiments, such as those on radioactivity, laser, and other types of radiation, might be more appropriate to be performed remotely, for safety reasons.

Several very recent publications dealt with online labs for physics or engineering. Orduña [124] gave a broad perspective on a combination of multiple online laboratories from different providers, into a coherent federation for unlimited student access. He also discussed issues with making online labs more popular, listing, among them, problems with robustness and trust, scalability, development processes, reaching a critical mass of a lab, integration into the university context, and sustainability. Along these lines, Zalewski et al. [125] expanded the concept of online labs both regarding the subject—to all STEM disciplines—and regarding the scope—to the Internet of Things.

Arguedas-Matarrita et al. [126] reported on deploying access to online labs from multiple institutions around the world for teaching physics courses in Costa Rica. As a major advantage of such labs, they considered reduced costs of providing access to lab experiments and expanding the physical boundaries of education. Building a case for online labs in engineering education, Alves [127] reviewed major trends in engineering education for the last decade and in conclusion, made two points on the viability of such labs. First, he stated that "Only by offering a reasonable blend of hands-on, simulations and remote experiments, will it be possible to create a sustainable scenario where students acquire the right level and diversity of experimental skills". Secondly, he emphasized that "Only by federating remote labs will it be possible to provide 'One experiment to all students and all experiments to one student'".

3.4. Assessment Methods

It is widely accepted that educational projects claiming positive results obtained from the application of a certain methodology or technology must present and discuss proper assessment. In the specific area of teaching physics in engineering environments, only a few papers have been published that focus on assessment, in addition to those referred to in the previous sections [43,81–83,92,97–99].

In this view, the most interesting of those papers published over the previous decade, or so, appears to be the oldest one in the list, by McKagan et al. [128]. The authors reported on their reform of teaching the advanced physics course for engineering majors, whose content is mostly based on quantum mechanics. They applied interactive engagement techniques, involving peer instruction, collaborative homework sessions, interactive simulation, and focus on real-world applications. Their findings regarding assessment include "significant improvements in both content knowledge and beliefs compared with the same course before implementing these reforms and a corresponding course for physics majors." The assessment was based on two measures: Quantum Mechanics Conceptual Survey (QMCS) and Force Concept Inventory (FCI), and covered six offerings of physics and engineering courses.

Ablanque et al. [129] outlined briefly their approach to blended learning for teaching physics in engineering. In student experiments, which are actually only viewed by videos, they placed interesting emphasis on "quantifying the uncertainty of the results". They claimed they "have gathered feedback from the students and have taken note of how they rate it compared with more traditional subjects", but the actual numerical results were not given.

Simpson and Fernandez [130] analyzed student performance in first-year math and physics courses in the study of electrical and computer engineering (ECE). They focused on answering the question: "how does performance in these prerequisite courses affect student performance in engineering courses?" by studying "what effect, if any, the grades in these prerequisite courses have on students' grades in later [core engineering] courses." Several course sequences were analyzed and the analysis indicated that "Significant relationships were found between some math and science courses and ECE courses." This led to the important conclusion that "The relationships found are heartening as they lend support for having the prerequisite requirement and highlight the importance of the prerequisite courses. This has implication for the students, faculty and curriculum."

Jebaraj and Mohanasundaram [131] presented a thorough description of their findings regarding the effectiveness of e-contents in teaching physics to engineering students. Their motivation for introducing e-learning was that "Engineers of today and tomorrow are expected to be far more creative and innovative with greater need for self-learning than relying on syllabi and handbook [textbook]." They tested several hypotheses by comparing students' scores in teaching a course named Crystal Physics and found out that "There is a significant difference in the achievement in physics between the control group and experimental group [of] engineering students." Based on the results of the study, they discussed several recommendations and limitations related to e-learning, especially stating that "The e-contents for teaching Physics are found to be effective" and contribute to improving the quality of engineering education.

Hari et al. [132] discussed their approach to evaluating engineering students' performance in physics courses taken during foundation studies. In their university, before entering the engineering program, students take Physics I, which is focused on mechanical topics, and Physics II, focused on electrical topics. The study was aimed at discovering whether there is any difference in student performance between Physics I and II for students of different engineering fields, specifically, mechanical and electrical engineering. The data were analyzed from a four-year period and the results showed that for both Physics I and Physics II, there was no significant difference between the grades of students from two different specialties, mechanical and electrical engineering.

Kattayat and Josey [133] described an exploratory study focused on digital technologies in teaching physics concepts in engineering. Their results, based on test scores and student questionnaires, revealed that "students who studied physics, in engineering education with the incision of digital components in their instruction (experimental group) attained better learning and performed well compared to the students who did not use the digital components in instruction (control group)." Among digital components, the authors included all of the following, which can support instruction: Internet, digital video, webcasting, web browsers, email, simulations, wikis, learning management systems, productivity tools, such as word processors, and even typical computer tools, such as programming languages and operating systems.

Among thesis/dissertation works, those by Bagner [134] and Shaw [135] were identified. Bagner [134] focused on studying "how to make the Princeton's introductory physics course sequence for engineering students […] a more enjoyable and educational experience." This course sequence is very important in the preparation of engineers and is aimed "for the students to be able to understand the basic physics needed for further study in science and engineering by learning a logical, quantitative approach to problem solving and for students to be able to apply the fundamental concepts … "

In this view, she recognized that the "leading undergraduate physics educators throughout the country have been creating new approaches to teaching introductory physics to make the teaching of physics more effective", quoting the works of Mazur [39] and Tobias [136] that "traditional physics pedagogy has often been ineffective in conveying fundamental conceptual understanding." In her research, a questionnaire was used to ask alumni and current students over a span of 10 years to answer questions related to the topics covered: course pace, format, teaching and grading. From the point of view of this review paper, the most interesting were the questions related to the usefulness of the physics courses, which asked the students how useful was PHY 103/104 (the introductory physics course sequence), in providing you with the problem solving skills you needed and developing your intuition for the general physical concepts you needed.

While Bagner offered an extensive analysis of the survey, here, we only summarize her findings from answers to these questions. First, "The basic conclusion from these numbers seems to be that approximately three quarters of engineering students find PHY 103/104 useful for preparing them for upper-level engineering courses and a little less than half find the material learned in PHY 103/104 useful after graduation." And further, "The numbers also indicate that respondents found the courses just as useful in providing them with problem solving skills as they did in developing their intuition for general physics concepts."

Shaw's objective [135] was "to test the effectiveness of the use of advanced engineering tutorials," as he attempted to teach physics from the engineering perspective. His starting point was that "The perspective of a physics-only approach to understanding a physics phenomenon is different from an engineering approach, which must not only [help] understand a phenomenon, but also engage it to design an intended outcome and benefit." Based on this assumption, he attempted to incorporate an engineering design into physics courses through tutorials.

The courses included Physics I, covering classical mechanics and thermodynamics, and Physics II, covering electromagnetism and optics. The reported results show a very significant gain in average test scores for both courses, attributed to the use of engineering tutorials. In addition, the student feedback responses gave significantly higher ratings than in courses taught without the tutorials. In summary, in the author's opinion, the study "demonstrated that a high level of improvement of conceptual physics knowledge had been achieved."

To summarize the assessment strategies outlined in this and former sections, one could say that their most comprehensive set would include the following, as presented in one of the papers [114] discussed previously (Section 3.2), in relation to a PBL course evaluation, outlining several aspects such as

(1) measuring students' academic performance (scores, grades) in comparison with a traditional lecture-based course;
(2) comparison of the retention of knowledge by students (between PBL and non-PBL courses) into the following year;
(3) student response/feedback via surveys, and students' self-assessment;
(4) evaluation by an independent external evaluator, to which one could add;
(5) instructor's own evaluation and reflection.

4. Conclusions

As one can tell from this survey, the perception of how to teach physics to engineers or—more broadly—in the engineering environments, has evolved a great deal historically. While there have been many papers published keeping a single focus on physics education or just on engineering education, the objective of this study was to include only those which dealt consistently with both issues at the same time.

In reviewing the papers, we tried to capture the trends and perspectives and their evolution over the years, since the early 20th century until the most contemporary times. This time span, over a century long, gave us an unprecedented coverage regarding the breadth of approaches and topics, geographical spread worldwide, and inclusion of a wide range of engineering disciplines and physics specialties.

4.1. Observations

Looking at the material consistently with educational principles, one can see a trend in reporting on an unquestionable gap between physics education and the way engineering professions expect their students to be educated in physics. At one end, traditional teaching tries to convey a thorough mastery of the basis of general laws of physics, knowledge of the scientific method, and familiarity with the observation process and measuring instruments, occasionally adding emphasis on creativity and ingenuity and focus on life-long learning, making graduates educate themselves throughout the years of their professional careers.

Gradually, it became clear, however, that it is not only knowledge or understanding of the physical phenomena which make a successful physicist or engineer. According to some authors, e.g., [91], conveying knowledge is becoming less important and at the same time, conveying methodological skills appears to gain importance. It is the practice in solving actual engineering problems which contributes significantly to the success of an individual in the profession and makes physics play a huge role in upbringing future engineers.

The labor market has increased the requirements to professional level of graduates of engineering professions and in this view, a task for physics and engineering teachers is not just transferring already-built knowledge but helping develop practical skills to apply that knowledge. Extensive practice in approaching actual engineering problems is needed to assist in solving practical problems, keep in touch with industry, and make thoughtful application of the theories, in order to produce engineering undergraduates with practical skills that reinforce their competence in application and innovation.

This brings us to one of the key terms resulting from this survey: competencies. Expressed in many of the papers reviewed and in reports and recommendations of professional societies, in a variety of ways and under different names, competencies, among them soft skills, make a big difference in the successful education of engineers. Teamwork, communication skills and analytical skills were most commonly referred to, but there were many others.

One must state at this point that there have been several successful educational approaches applied to teaching college physics, including teaching physics to engineers, among them: Mazur's active learning [39], JiTT [40] and SCALE-UP [45]. These methods are being extended to match the requirements of the Internet era, where the preparation for a class changes from plain textbook readings to what is called "cloud-based model", which relies on student access to multimedia teaching materials placed in a cloud and continuously available. However, not ignoring or denying a value of these well tested, earlier educational approaches, there is more to it.

When one talks about a gap in teaching physics to engineering students and is trying to address newly emerged competencies these students have to acquire in college, we have to ask some fundamental questions:

(1) Why do we learn physics in engineering?
(2) What is the role physics plays in engineering and in engineering education?
(3) What is important in engineering courses or the engineering profession, so the physics courses would leverage or maximize respective impact and benefit?

The answer can be expressed in multiple ways, but what should be taken into account, in the first place, is how physics and engineering complement each other, which may amount to a key difference: discover vs. construct.

4.2. Perspectives

There have been scores of authors who studied and explained the key differences between science and engineering, but what appeals to us most is the distinction expressed succinctly by Henry Petroski [137]: "Science is about knowing, engineering is about doing". In this view, science is essentially problem-based, because of the element of discovery, which results in activities leading to some findings about the real world, while engineering is project-based, because of the construction focus, which results in designing or developing a product. This is, in our view, illustrated in Figure 1, which shows that sciences, physics among them, serve as the basis for engineering endeavors, supported on both sides by math and technology, to make the full STEM picture. With the addition of business as a discipline on the top, which is currently not a part of the official STEM hierarchy, one can build a more complete view of the educational world, in which engineering with its innovations paves a way for marketing and the adoption of new products to make them a commercial success.

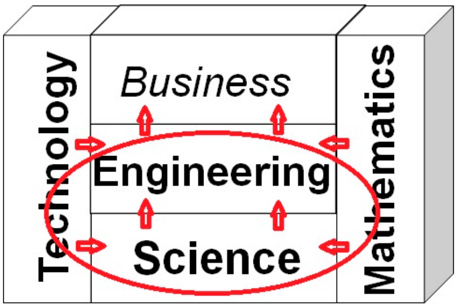

Figure 1. Hierarchy of STEM disciplines.

Both aspects, Problem- and Project-Based Learning (PBL), have been addressed quite extensively in the last couple of decades, as documented in Sections 2.2.2 and 3.2 of this overview. As the respective authors state, the major advantages of problem-based learning courses are that the students develop the ability to learn independently and in groups and develop key skills and the ability to contest and debate. This method helps the students acquire ownership of their learning experiences by giving them control of the learning process. It leads to the situation that many students' motivation is increased if the presented scientific concepts could be applied to real-life situations. This brings us from problem-based learning to project-based learning and, even a step further, to product-based learning. Since the PBL concept is so important in teaching both physics and engineering and the usage of the terms "problem", "project" and "product", sometimes interchangeably, looks confusing, let us offer a general view of the subject matter, as illustrated in Figure 2.

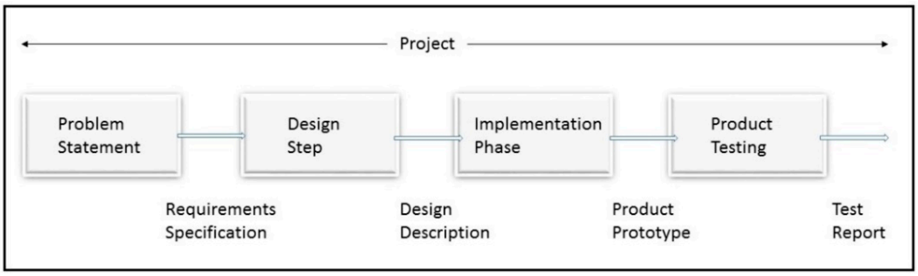

Figure 2. Simplified view of the engineering process.

The diagram is a rather a simplified picture to illustrate what happens in the engineering process. First, the problem is stated, usually in the form of a specification that defines the requirements for a product. Then, based on the requirements document, the product design is developed in the form of a design description. This design description document serves as an input to developing a product's implementation, which, after completion, proceeds to the next stage named product testing, concluding the entire project. As a practical matter, for simplicity, not reflected on the diagram are multiple cycles that lead back from each stage to previous stages to make improvements. As one can see, all the keywords used in the PBL methods have a very precise meaning. The "Problem" corresponds to just one initial phase of the entire process. The "Project" encompasses the entire engineering process and the "Product" reflects essentially what comes out of this process. All PBL methods have their origin in this engineering process, so when educators are talking about their PBL approach, they should clearly specify which kind of PBL they have in mind, according to the taxonomy in Figure 2.

It may be interesting to clarify further the more exact meaning of all four phases from Figure 2 by making a simple analogy with math. This is shown in the figure included in Appendix B, reflecting a simple mathematical task of solving a quadratic equation in a way mapped onto the project view.

4.3. Immersion of Engineering into Physics

In this context comes what we believe to be a very important consideration about teaching physics in engineering environments, which was expressed by some of the authors of the reviewed papers. Namely, physics has a vested interest in engineering and its accomplishments, so does the physics educational process. It is not simply that physics is in service to engineering or plays only a supportive role to engineering, as one would infer from the picture in Figure 1. It is that physics and physicists depend on the successful implementation of their findings by engineers. Thus, it is equally important that the future physicists (scientists) be exposed to the same engineering concepts. This calls to reverse the way of thinking and introduce engineering thinking to physics courses, in addition to insisting on passing physics concepts to engineering students. Effectively, this would be flipping the contents and starting to teach physics in a reverse order, from a practical application to the underlying concepts. This could happen by incorporating an engineering design into physics courses. One has to identify the essential segments which are necessary in engineering education and merge them with physics concepts so that it can play its expected role in the upbringing of future engineers.

With this major reflection, one should not neglect other important aspects of teaching physics in engineering environments raised in the reviewed papers. They include but are not limited to the following:

(1) Introducing basic skills related to professional development at an early stage; the sooner they are introduced to the learning cycle the better, since then, the students learn early how to work collaboratively and focus on problem analysis and developing solutions;
(2) When the measurement process is taught, it is critical to realize that uncertainty plays an important role in it; studying some boundary conditions is much more critical for the learning process than just understanding the phenomenon;
(3) Evolution of the labs, sometimes with revolutionary changes, including remote measuring instruments and experimentation, is imminent when technology is continuously progressing; however, data analysis skills and reporting skills should be still considered as fundamental objectives of engineering laboratories;
(4) What will increase the labs' impact on acquiring knowledge and will have a dramatically higher positive effect on learning is expanding student activities to let them not only change some experiment parameters to see desired effect, but also have them propose a new set-up, or produce a structured write-up;
(5) When more difficult material is concerned, teaching methods may involve adjustable steps; software tools can be used to choose different parameters for illustrating desired situations; the use of robots can be increased, as strictly educational tools, with no programming or control;
(6) With the pervasive use of the Internet and the web, course materials based on websites, videos, games, simulations and other multimedia tools are likely to evolve towards unified Learning Objects, facilitating their universal reuse via standardized interfaces.

In conclusion, we believe that a brief final note is in place. With all these reflections, findings and predictions, one must wonder: what has not yet been done? This is where many of us, both physicists and engineers, will have to fill in.

Author Contributions: Conceptualization and methodology, J.Z., G.N.; investigation, resources and data, J.Z., G.N., R.E.C.; writing—original draft preparation, J.Z.; writing—review and editing, G.N., R.E.C.; supervision and project administration, R.E.C.

Funding: This research received no external funding.

Acknowledgments: Janusz Zalewski acknowledges consecutive Summer Fellowships from the Air Force Summer Faculty Fellowship Program (SFFP) at the U.S. Air Force Academy in 2018 and 2019. The authors would like to thank Kimberly de la Harpe and Jessica Dwyer from the Center of Physics Education Research at the United States Air Force Academy for their interest in this project and useful comments on the paper.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Excerpt from the Grinter's Report [13]. Section III. Curriculum Content as Related to the Objectives of Engineering Education. Subsection E. The Basic Sciences

Physics. Too often, physics as presently taught to engineers barely touches upon the many new physical concepts which have been developed during the past generation and which today strongly influence engineering practice. Modern physics, including an introduction to nuclear or solid-state physics, should be a part of undergraduate engineering curricula. As a contribution to making this presentation to engineers as effective as possible in a limited time, it is believed that the basic course in physics needs a new orientation. The duplication between classical physics and the engineering sciences of mechanics, thermodynamics, and electricity can be largely removed if the objective of the introductory physics course is redirected to place much greater emphasis upon sub-microscopic phenomena and the conservation principles, with virtual elimination of semi-engineering examples. An introductory course in physics that attempts to be a tool subject for engineering mechanics, thermodynamics, and electricity appears to serve less and less purpose. When engineering colleges request physics departments to present an introductory course in atomic physics for large numbers of engineers, it seems evident that the introductory physics course will then have to be remodeled to provide the strongest possible background for this new objective.

Appendix B. Analogy between Solving a Quadratic Equation and an Engineering Process

Figure A1 illustrates the analogy between solving a math problem and an engineering process, which may be useful in discussions on Project Based Learning.

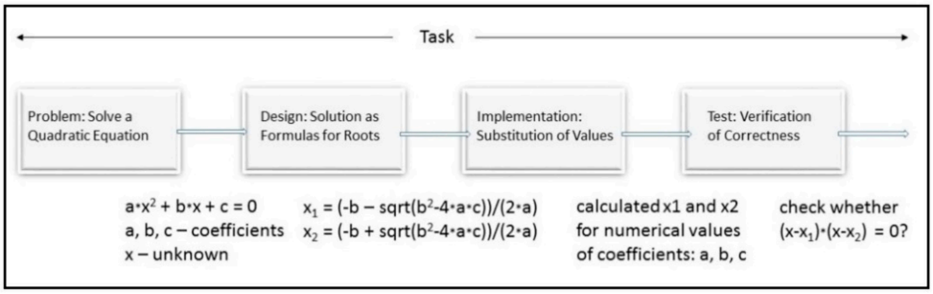

Figure A1. Solving a task in math compared to a simplified view of the engineering process.

A task in math, shown in Figure A1, corresponds to a project in engineering (see Figure 2). Then, each stage in the engineering project has its counterpart in a mathematical task, as follows:

(1) Problem Specification in engineering corresponds to a Problem Statement in math;
(2) Design Phase in engineering corresponds to Solution Formulas in math;
(3) Implementation in engineering corresponds to Calculations (Value Substitution) in math;
(4) Product Testing in engineering corresponds to Verification of Correctness in math.

References

1. UNESCO. *Engineering: Issues Challenges and Opportunities for Development*; UNESCO Report; UNESCO: Paris, France, 2010.
2. Franklin, W.S. The teaching of physics to engineering students. *Trans. AIEE* **1903**, *22*, 561–566. [CrossRef]
3. Von Helmholtz, H. Zählen und messen: Erkentnisstheoretisch betrachtet. In *Philosophische Aufsätze: Eduard Zeller zu Seinem Fünfzigjährigen Doctorjubiläum Gewidmet*; Fues Verlag: Leipzig, Germany, 1887; pp. 17–52.

4. Society for the Promotion of Engineering. Report of the committee on teaching physics to students of engineering. In Proceedings of the 24th Annual Meeting, Society for the Promotion of Engineering, Charlottesville, VA, USA, 19–22 June 1916; pp. 159–176.
5. Educational Committee, American Physical Society. *The Teaching of Physics, with Especial Reference to the Teaching of Physics to Students of Engineering*; Educational Committee, American Physical Society: College Park, MD, USA, 1922.
6. Richtmyer, F.K. The engineer and the physicist. *Sibley J. Eng.* **1917**, *31*, 230–233.
7. Malti, M.G. Mathematics and physics in engineering. *Trans. AIEE* **1939**, *58*, 38–40.
8. Teare, B.R., Jr. Courses to develop facility in the use of mathematics and physics in the solution of engineering problems. *Trans. AIEE* **1939**, *58*, 40–41.
9. Lapp, C.J. Teaching engineering physics. *Am. J. Phys.* **1940**, *8*, 346–354. [CrossRef]
10. Martin, J.M. The role of laboratory work in the early years of the engineering curriculum. *Am. J. Phys.* **1942**, *10*, 98–101. [CrossRef]
11. Meltzer, D.E.; Otero, V.K. A brief history of physics education in the United States. *Am. J. Phys.* **2015**, *83*, 447–458. [CrossRef]
12. Akera, A. Setting standards for engineering education. *Proc. IEEE* **2017**, *105*, 1834–1843. [CrossRef]
13. Grinter, L.E.; (Chairman). Report of the committee on evaluation of engineering education. *J. Eng. Educ.* **1955**, *45*, 25–60.
14. Seeger, R.J. The role of physics in engineering education. *Phys. Today* **1953**, *6*, 18–19. [CrossRef]
15. Committee of the American Institute of Physics. The role of physics in engineering education. The report of a committee of the American institute of physics. *Phys. Today* **1955**, *8*, 12–20. [CrossRef]
16. Smith, L.P.; Dodge, H.L. Responsibility of the physics teacher in engineering education. *Am. J. Phys.* **1954**, *22*, 468–473. [CrossRef]
17. Houston, W.V. Physics in engineering. *Am. J. Phys.* **1955**, *23*, 610–614. [CrossRef]
18. Everitt, W.L. The impact of modern physics on engineering education. *Phys. Today* **1957**, *10*, 22–26. [CrossRef]
19. Weaver, A.B. Physics courses in the new Arizona engineering curriculum. *IRE Trans. Educ.* **1959**, *2*, 117–120. [CrossRef]
20. Watson, W.W. Developments in teaching physics to engineers at Yale. *Sch. Sci. Math.* **1960**, *60*, 262–266. [CrossRef]
21. Feynman, R. The problem of teaching physics in Latin America. *Eng. Sci.* **1963**, *27*, 21–30.
22. Thomas, L.A.A. Physics in the service of the engineer. *Proc. IEE* **1972**, *119*, 99–107. [CrossRef]
23. Proc. 10th PTEE 2019, Physics Teaching in Engineering Education Conference, Delft, The Netherlands, 23–24 May 2019. Available online: http://sefiphysics.be/mirror_PTEE2019/proceedings/ (accessed on 21 November 2019).
24. Proc. 9th PTEE 2017, Physics Teaching in Engineering Education Conference, Žilina, Slovakia, 18–19 May 2017. Available online: https://fyzika.uniza.sk/~{}gintner/PUBLICATIONS/Proceedings_PTEE2017.pdf (accessed on 21 November 2019).
25. Proc. 8th PTEE 2014, Physics Teaching in Engineering Education Conference, Aveiro, Portugal, 22–24 May 2014. Available online: http://ptee2014.web.ua.pt/proceedings/ptee2014_200515_final.pdf (accessed on 21 November 2019).
26. Proc. 7th PTEE 2011, Physics Teaching in Engineering Education Conference, Mannheim, Germany, 21–23 September 2011. Available online: http://sefiphysics.be/mirror_PTEE2011/program.html (accessed on 21 November 2019).
27. Proc. 6th PTEE 2009, Physics Teaching in Engineering Education Conference, Wrocław, Poland, 10–12 September 2009. Available online: http://www.sefiphysics.be/mirror_PTEE2009/index.html (accessed on 21 November 2019).
28. Glimm, J.; Sharp, D.H. Complex fluid mixing flows: Simulation vs. theory vs. experiment. *SIAM News* **2006**, *39*, 1–4.
29. Longman, R.W. On the interaction between theory, experiments, and simulation in developing practical learning control algorithms. *Int. J. Appl. Math. Comput. Sci.* **2003**, *13*, 101–111.
30. De Graaff, E. Key competencies for future engineers. In Proceedings of the 6th PTEE 2009, Physics Teaching in Engineering Education Conference, Wrocław, Poland, 10–12 September 2009.

31. Gintner, M. Physics in the engineering education: Focus on the essentials. In Proceedings of the 9th PTEE 2017, Physics Teaching in Engineering Education Conference, Žilina, Slovakia, 18–19 May 2017; pp. 113–118.
32. Tiili, J.; Suhonen, S. Physics lab as learning environment for important engineering skills. In Proceedings of the 10th PTEE 2019, Physics Teaching in Engineering Education Conference, Delft, The Netherlands, 23–24 May 2019.
33. Christie, M.; de Graaff, E. The philosophical and pedagogical underpinnings of active learning in engineering education. *Eur. J. Eng. Educ.* **2017**, *42*, 5–16. [CrossRef]
34. De Graaff, E.; Kolmos, A. Characteristics of problem-based learning. *Int. J. Eng. Educ.* **2003**, *19*, 657–662.
35. De Graaff, E.; Kolmos, A. History of problem-based and project-based learning. In *Management of Change. Implementation of Problem-Based and Project-Based Learning in Engineering*; Sense Publishers: Rotterdam, The Netherlands; Taipei, Taiwan, 2007; pp. 1–8.
36. European Network for Engineering Accreditation. *EUR-ACE Framework Standards and Guidelines*; European Network for Engineering Accreditation: Brussels, Belgium, 2015.
37. Van der Veen, J. Trends in physics teaching for engineering education. Invited talk. In Proceedings of the PTEE 2019, International Conference on Physics Teaching in Engineering Education, Delft, The Netherlands, 23–25 May 2019.
38. Bašista, J.; Ješková, Z. Interactive methods in introductory physics course. In Proceedings of the 9th PTEE 2017, Physics Teaching in Engineering Education Conference, Žilina, Slovakia, 18–19 May 2017; pp. 95–102.
39. Mazur, E. *Peer Instruction: A User's Manual*; Prentice-Hall: Upper Saddle River, NJ, USA, 1997.
40. Novak, G.; Gavrin, A.; Christian, W.; Patterson, E. *Just-in-Time Teaching: Blending Active Learning with Web Technology*; Prentice-Hall: Upper Saddle River, NJ, USA, 1999.
41. Manninen, R.; Tiili, J. Using pre-lecture assignments to enhance students learning in introductory physics. In Proceedings of the 8th PTEE 2014, Physics Teaching in Engineering Education Conference, Aveiro, Portugal, 22–24 May 2014; pp. 91–97.
42. Zwiers, U.; Dederichs-Koch, A. Robots in mechanics teaching: A student-centered learning unit of kinematics. In Proceedings of the 7th PTEE 2011, Physics Teaching in Engineering Education Conference, Mannheim, Germany, 21–23 September 2011.
43. Beichner, R.J. SCALE-UP: A classroom environment to facilitate active, collaborative learning. In Proceedings of the 6th PTEE 2009, Physics Teaching in Engineering Education Conference, Wrocław, Poland, 10–12 September 2009.
44. ABET Criteria for Accrediting Engineering Programs. *2016–2017 Accreditation Cycle*; Engineering Accreditation Commission: Baltimore, MD, USA, 2015.
45. Beichner, R.J.; Saul, J.J.; Abbott, D.S.; Morse, J.J.; Deardorff, D.L.; Allain, R.J.; Bonham, S.W.; Dancy, M.H.; Risley, J.S. The student-centered activities for large enrollment undergraduate programs (SCALE-UP) project. In *PER-Based Reform in University Physics*; American Association of Physics Teachers: College Park, MD, USA, 2006.
46. Kautz, C.H. Integrating multiple active-learning techniques into a single course. Invited talk. In Proceedings of the PTEE 2019, International Conference on Physics Teaching in Engineering Education, Delft, The Netherlands, 23–25 May 2019.
47. Lock, A.J.; Lambers, J.H.R. Project based learning in photonics research. In Proceedings of the 6th PTEE 2009, Physics Teaching in Engineering Education Conference, Wrocław, Poland, 10–12 September 2009.
48. Kralova, E.; Kukurova, E. Project Oriented Teaching and Learning in Non-physical University Programs. In Proceedings of the 6th PTEE 2009, Physics Teaching in Engineering Education Conference, Wrocław, Poland, 10–12 September 2009.
49. Stankowski, S. "Thematic labs": Organizing physical labs with a project flair. In Proceedings of the 7th PTEE 2011, Physics Teaching in Engineering Education Conference, Mannheim, Germany, 21–23 September 2011.
50. Suhonen, S.; Tiili, J. Enhancing scientific analysing and reporting skills—Integrated physics laboratory course. In Proceedings of the 8th PTEE 2014, Physics Teaching in Engineering Education Conference, Aveiro, Portugal, 22–24 May 2014; pp. 31–40.
51. Suhonen, S.; Tiili, J. Review of integrated physics laboratory course: Pros and cons. In Proceedings of the 9th PTEE 2017, Physics Teaching in Engineering Education Conference, Žilina, Slovakia, 18–19 May 2017; pp. 36–43.

52. Radojewska, E.B.; Salejda, W.; Poprawski, R.; Szatkowski, J.; Cizman, A. What defines a success in lectures and labs? Case studies in physics teaching. In Proceedings of the 8th PTEE 2014, Physics Teaching in Engineering Education Conference, Aveiro, Portugal, 22–24 May 2014; pp. 21–30.
53. Langereis, G.R.; Voorn, S.; Blom, S.M.P.; Moerman, E.; Brocaar, H.G.J.; Linskens, H.G.J.; Dommels, A.F.P.; van de Loo, J.A.V. Applied research in a higher vocational engineering physics education environment. In Proceedings of the 10th PTEE 2019, Physics Teaching in Engineering Education Conference, Delft, The Netherlands, 23–24 May 2019.
54. Sum, J.; Jödicke, B.; Hettich, C. Lab-team-coaching: A flipped classroom techniques for physics experiments. In Proceedings of the 10th PTEE 2019, Physics Teaching in Engineering Education Conference, Delft, The Netherlands, 23–24 May 2019.
55. Stankowski, S. "Physical thinking": Can we teach such a thing? In Proceedings of the 7th PTEE 2011, Physics Teaching in Engineering Education Conference, Mannheim, Germany, 21–23 September 2011.
56. Bernhard, J.; Karstensen, A.-K.; Holmberg, M. Investigating the model 'learning of a complex concept'—The process of learning in a course in electric circuits. In Proceedings of the 6th PTEE 2009, Physics Teaching in Engineering Education Conference, Wrocław, Poland, 10–12 September 2009.
57. Kúdelčík, J. Numeric methods in photonics and application of one-dimensional FDTD. In Proceedings of the 9th PTEE 2017, Physics Teaching in Engineering Education Conference, Žilina, Slovakia, 18–19 May 2017; pp. 119–124.
58. Tarnowski, K.; Salejda, W. Didactic software for polarized light transmittance calculations. In Proceedings of the 6th PTEE 2009, Physics Teaching in Engineering Education Conference, Wrocław, Poland, 10–12 September 2009.
59. Mala, Z.; Scholtz, M. Introduction of subject theoretical physics in transportation to education of faculty of transportation sciences CTU. In Proceedings of the 7th PTEE 2011, Physics Teaching in Engineering Education Conference, Mannheim, Germany, 21–23 September 2011.
60. Orlik, R.; Pawlik, G. Open source programs as a platform for teaching selected issues in physics. In Proceedings of the 6th PTEE 2009, Physics Teaching in Engineering Education Conference, Wrocław, Poland, 10–12 September 2009.
61. Scharoch, P. An introduction to numerical modelling in physics. In Proceedings of the 6th PTEE 2009, Physics Teaching in Engineering Education Conference, Wrocław, Poland, 10–12 September 2009.
62. Engeln, R.; Gomez Puente, S.M. Does virtual reality help students learn to use optical measurement techniques? In Proceedings of the 10th PTEE 2019, Physics Teaching in Engineering Education Conference, Delft, The Netherlands, 23–24 May 2019.
63. Dorsel, D.; Hütz, S.; Staacks, S.; Heinke, H.; Stampfer, C. *Phyphox*—Teaching physics with smartphone experiments. In Proceedings of the 10th PTEE 2019, Physics Teaching in Engineering Education Conference, Delft, The Netherlands, 23–24 May 2019.
64. Boyle, T. Design principles for authoring dynamic, reusable learning objects. *Australas. J. Educ. Technol.* **2003**, *19*, 46–58. [CrossRef]
65. Radojewska, E.B.; Poprawski, R.; Poprawski, W.; Cizman, A. Physics experiments recommended for engineering education (1): The Peltier effect in heat pumps and thermoelectric coolers. In Proceedings of the 9th PTEE 2017, Physics Teaching in Engineering Education Conference, Žilina, Slovakia, 18–19 May 2017; pp. 54–63.
66. Radojewska, E.B.; Poprawski, R.; Poprawski, W.; Cizman, A. Physics experiments recommended for engineering education (2): The seebeck effect in electric thermogenerators. In Proceedings of the 9th PTEE 2017, Physics Teaching in Engineering Education Conference, Žilina, Slovakia, 18–19 May 2017; pp. 54–60.
67. Poprawski, R.; Radojewska, E.B.; Salejda, W.; Szatkowski, J.; Cizmasn, A.; Sieradzki, A. The direct and converse piezoelectric effects as a good example of reversible phenomena in physics. In Proceedings of the 7th PTEE 2011, Physics Teaching in Engineering Education Conference, Mannheim, Germany, 21–23 September 2011.
68. Popko, E. Photo-electric physics laboratory for electronics students. In Proceedings of the 6th PTEE 2009, Physics Teaching in Engineering Education Conference, Wrocław, Poland, 10–12 September 2009.
69. Radojewska, E.B.; Cizman, A.; Radojewski, J. Physics experiments recommended for engineering education: An investigation of the dielectric function in ferroic materials. In Proceedings of the 10th PTEE 2019, Physics Teaching in Engineering Education Conference, Delft, The Netherlands, 23–24 May 2019.

70. Tarjanyiova, G.; Tarjanyi, N.; Hockicko, P. Land of waves: Let's make the physics of waves available to all. In Proceedings of the 10th PTEE 2019, Physics Teaching in Engineering Education Conference, Delft, The Netherlands, 23–24 May 2019.
71. Jödicke, B.; Sum, J.; Hettich, C. How can an experiment be optimized? A question given to students during physics labs. In Proceedings of the 10th PTEE 2019, Physics Teaching in Engineering Education Conference, Delft, The Netherlands, 23–24 May 2019.
72. Zalewski, J.; Gonzalez, F. Evolution in the education of software engineers: Online course on cyberphysical systems with remote access to robotic devices. *Int. J. Online Eng.* **2017**, *13*, 133–146. [CrossRef]
73. Zubía, J.G.; Alves, G.R. (Eds.) *Using Remote Labs in Education*; University of Deusto: Bilbao, Spain, 2011.
74. Svoboda, V.; Stockel, J. Tokamak golem remotely for worldwide fusion education. In Proceedings of the 7th PTEE 2011, Physics Teaching in Engineering Education Conference, Mannheim, Germany, 21–23 September 2011.
75. Haluskova, S. Remote real experiment. In Proceedings of the 6th PTEE 2009, Physics Teaching in Engineering Education Conference, Wrocław, Poland, 10–12 September 2009.
76. Hockicko, P. Forming of physical knowledge in engineering education with the aim to make physics more attractive. In Proceedings of the 7th PTEE 2011, Physics Teaching in Engineering Education Conference, Mannheim, Germany, 21–23 September 2011.
77. Langie, G.; Verelst, F.; van den Bossche, J.; de Cock, M. Students' perceptions of a physical laboratory immersion. In Proceedings of the 7th PTEE 2011, Physics Teaching in Engineering Education Conference, Mannheim, Germany, 21–23 September 2011.
78. Verelst, F.; Langie, G.; van den Bossche, J.; de Cock, M.; Lauriks, N.; Janssen, P. An attempt to incorporate flexibility in physics laboratories: Laboratory immersion. In Proceedings of the 6th PTEE 2009, Physics Teaching in Engineering Education Conference, Wrocław, Poland, 10–12 September 2009.
79. Suhonen, S. Comparison of MOODLE and claned in physics online learning and teaching. In Proceedings of the 10th PTEE 2019, Physics Teaching in Engineering Education Conference, Delft, The Netherlands, 23–24 May 2019.
80. IEEE Std. *1876—Networked Smart Learning Objects for Online Laboratories*; IEEE Standards Association: Washington, DC, USA, 2019; Available online: https://standards.ieee.org/standard/1876-2019.html (accessed on 21 November 2019).
81. Schäfle, C.; Kautz, C. Students' reasoning in fluid dynamics: Bernoulli's principle vs. the continuity equation. In Proceedings of the 10th PTEE 2019, Physics Teaching in Engineering Education Conference, Delft, The Netherlands, 23–24 May 2019.
82. Hockicko, P.; Tarjanyiova, G., Kopylowa; Kopylowa, N.; Dyagilev, A. Video-analysis as an effective method for improving physics teaching and learning understandment. In Proceedings of the 10th PTEE 2019, Physics Teaching in Engineering Education Conference, Delft, The Netherlands, 23–24 May 2019.
83. Stanzel, S.; Schäfle, C.; Junker, E. Impact of interactive teaching methods on heterogeneity. In Proceedings of the 10th PTEE 2019, Physics Teaching in Engineering Education Conference, Delft, The Netherlands, 23–24 May 2019.
84. Zalewski, J.; Buckley, I.A.; Czejdo, B.; Drager, S. A Framework for Measuring Security as a System Property in Cyberphysical Systems. *Information* **2016**, *7*, 33. Available online: http://www.mdpi.com/2078-2489/7/2/33 (accessed on 21 November 2019). [CrossRef]
85. Passow, H.J. Which ABET competencies do engineering graduates find most important in their work? *J. Eng. Educ.* **2012**, *101*, 95–118. [CrossRef]
86. Subcommittee of the AAPT Committee on Laboratories. *AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum*; American Association of Physics Teachers: College Park, MD, USA, 2014.
87. Lewandowski, H.J.; Finkelstein, N. Redesigning a junior-level electronics course to support engagement in scientific practices. In Proceedings of the PERC 2015, Physics Education Research Conference, Greenbelt, MD, USA, 29–30 July 2015; pp. 191–194.
88. Pickthorne, B.; Wheldall, K. Behavioral approach to teaching subsidiary physics to engineering students. *Educ. Psychol.* **1982**, *2*, 79–85. [CrossRef]
89. Gunstone, R.F. Technology education and science education: engineering as a case study of relationships. *Res. Sci. Educ.* **1994**, *24*, 129–136. [CrossRef]

90. Sokol, J. The end of physics? (As we know it). In Proceedings of the ASEE 1997, Annual Conference and Exposition, Milwaukee, WI, USA, 15–18 June 1997; pp. 2.410.1–2.410.5.
91. Stankowski, S. Competency-based teaching physics for engineers. In Proceedings of the PTEE 2007, Physics Teaching in Engineering Education, Delft, The Netherlands, 25–26 October 2007.
92. Rendevski, S.J.; Abdelhadi, A. Teaching and learning soft skills in university physics courses: Perspectives of the UAE higher colleges of technology. *Int. J. Phys. Chem. Educ.* **2017**, *9*, 1–8. [CrossRef]
93. The Physics Degree. *Graduate Skills Base and the Core of Physics*; Institute of Physics: London, UK, 2011.
94. McNeil, L.; Heron, P. Preparing physics students for 21st-century careers. *Phys. Today* **2017**, *70*, 39–43. [CrossRef]
95. Zhao, L.; Dai, C.; Wang, Y. Reform on college physics experiments teaching for engineering students in agriculture and forestry universities. In Proceedings of the ICCSE 2012, 7th International Conference on Computer Science and Education, Melbourne, Australia, 14–17 July 2012; pp. 2007–2011.
96. Fadhilah. Teaching physics in engineering faculty (Review). In Proceedings of the 8th International Convention of Indonesian Association of Technological and Vocational Education, Medan, Indonesia, 3–6 August 2016.
97. Evans, D.; Doak, R.B.; Duerden, S.; Green, M.; McCarter, J.; Roedel, R.; Williams, P. Team-based projects for assessment in first-year physics courses supporting engineering. In Proceedings of the FIE'96, 26th IEEE Frontiers in Education Conference, Salt Lake City, UT, USA, 6–9 November 1996; pp. 934–937.
98. Bowe, B.; Flynn, C.; Howard, R.; Daly, S. Teaching physics to engineering students using problem-based learning. *Int. J. Eng. Educ.* **2003**, *19*, 742–746.
99. Williams, A.; Furst, J.; Clearly, K.; Dastoor, P. An integrated learning module: Teaching physics to engineers. In Proceedings of the 2003 IEE Engineering Education Conference, London, UK, 6–7 January 2003.
100. Viegas, C.; Lopes, C.B.; Cravino, J. Real work in physics classroom: Improving engineering students competences. In Proceedings of the ICEE 2007, International Conference on Engineering Education, Coimbra, Portugal, 3–7 September 2007.
101. Gnitetskaya, T.N.; Ivanova, E.B. Modular technology education in physics for engineering managers. *Appl. Mech. Mater.* **2013**, *411–414*, 2846–2849. [CrossRef]
102. Hamlin, B.H.; Hein, G.L. Work in progress—A four year follow-up: Integration of math, physics and engineering, a pilot study for success. In Proceedings of the FIE 2004, 34th IEEE Frontiers in Education Conference, Savannah, GA, USA, 20–23 October 2004; pp. F4F-4–F4F-5.
103. Srinivasa, A.; Bassichis, W.H. Work in progress—The role of physics in engineering education. In Proceedings of the FIE 2006, 36th IEEE Frontiers in Education Conference, San Diego, CA, USA, 28–31 October 2006; pp. M1E-27–M1E-28.
104. Benito, R.M.; Camara, M.E.; Arranz, F.J. Interactive physics: The role of interactive learning objects in teaching physics in engineering (Abstract). *Geophys. Res. Abstr.* **2009**, *11*, 7638.
105. Gnitetskaya, T.N. Physical worldview as essential outcome of teaching students of engineering. In Proceedings of the CMEE 2017, 2nd International Conference on Computer, Mechatronic and Electronic Engineering, Xiamen, China, 24–25 December 2017; pp. 760–765.
106. Oliver, D.L.; Kane, J. Engineering design modules as physics teaching tools. *Phys. Teach.* **2011**, *49*, 242–245. [CrossRef]
107. Chuev, A.S. System approach to teaching physics to engineers. *Sci. Educ.* **2012**. Available online: http://engineering-science.ru/doc/299700.html (accessed on 21 November 2019).
108. Martinez, G.; Perez, A.L.; Suero, M.I.; Pardo, P.J. The effectiveness of concept maps in teaching physics concepts applied to engineering education: Experimental comparison of the amount of learning achieved with and without concept maps. *J. Sci. Educ. Technol.* **2013**, *22*, 204–214. [CrossRef]
109. Senthilkumar, R.D. Concept maps in teaching physics concepts applied to engineering education: An explorative study at the middle east college, sultanate of Oman. In Proceedings of the EDUCON 2017, IEEE Global Engineering Education Conference, Athens, Greece, 25–28 April 2017.
110. Zavala, G.; Dominguez, A.; Rodriguez Gallegos, R. ACE: Innovative educational model to teach physics and mathematics for engineering students. In Proceedings of the ASEE 2013, 120th Annual Conference and Exposition, Atlanta, GA, USA, 23–26 June 2013. Paper ID #7988.

111. Maheswaran, B. A new teaching for ancient engineering physics: Master physics via mastering physics! A study and survey. In Proceedings of the ASEE 2014, 121th ASEE Annual Conference and Exposition, Indianapolis, Indiana, 15–18 June 2014. Paper ID #8735.
112. Long, J. How online learning in an engineering-physics course helped us flip the classroom. In Proceedings of the 21st Annual Online Learning Consortium Int'l Conference, Orlando, FL, USA, 14–16 October 2015.
113. Long, J.M. Cloud-based teaching in an engineering-physics course. In Proceedings of the FIE 2015, 45th IEEE Frontiers in Education Conference, El Paso, TX, USA, 21–24 October 2015.
114. Özsoy-Güneş, Z.; Güneş, I.; Derelioğluc, J.; Kırbaşlara, F.G. The reflection of critical thinking dispositions on operational chemistry and physics problems solving of engineering faculty students. *Procedia Soc. Behav. Sci.* **2015**, *174*, 448–456. [CrossRef]
115. Cutri, R.; Marim, L.R.; Cardoso, J.R. Teaching physics for engineers using and active learning approach. In Proceedings of the CEEA17, 2017 Canadian Engineering Association Conference, Toronto, ON, Canada, 4–7 June 2017.
116. Sabag, N.; Pundak, D.; Trotskovsky, E. Initiating pilot research on enhanced physics 1 for electrical and electronic engineering students. In Proceedings of the EDUCON 2018, IEEE Global Engineering Education Conference, Canary Islands, Spain, 17–20 April 2018; pp. 394–398.
117. Kurz, G.; Harms, U.; Krahn, H. Multimedia in the introductory physics course for engineering students. In Proceedings of the MMEE 1996, IEEE International Conf. on Multi Media Engineering Education, Melbourne, Australia, 5 July 1996.
118. Bruce-Lockhart, M.; Norvell, T.S. Program and algorithm visualization in engineering and physics. *Electron. Notes Theor. Comput. Sci.* **2007**, *178*, 111–119. [CrossRef]
119. Neri, L.; Enrique, D.E.; Noguez, J.; Robledo-Rella, V. Design of questions and distracters for a dynamic, algorithm-based suite of physics problems for engineering students. In Proceedings of the FIE-2008, 38th ASEE/IEEE Frontiers in Education Conference, Saratoga Springs, NY, USA, 22–25 October 2008; pp. T3C-9–T3C-14.
120. Amani, M.R. Pedagogical tools for teaching modern physics to engineering students in a developing country. In Proceedings of the ICL 2014, International IEEE Conference on Interactive Collaborative Learning, Dubai, UAE, 3–6 December 2014; pp. 1000–1002.
121. Panthalookaran, V. Gamification of physics themes to nurture engineering professional and life skills. In Proceedings of the EDUCON 2018, IEEE Global Engineering Education Conference, Canary Islands, Spain, 17–20 April 2018.
122. Fakhertdinova, D.I. Online physic laboratory (online labs) in engineering educational environment. In Proceedings of the ICL 2013, International IEEE Conference on Interactive Collaborative Learning, Kazan, Russia, 25–27 September 2013; pp. 440–443.
123. De la Torre, L.; Sanchez, J.P.; Dormido, S. What remote labs can do for you? *Phys. Today* **2016**, *69*, 48–53. [CrossRef]
124. Orduña, P. Democratizing STEM Experimentation with the Labsland Global Network. Invited Talk. In Proceedings of the eTEE 2019, eTechnologies in Engingineering Education Conference, Gdansk, Poland, 19–20 September 2019; Available online: https://pg.edu.pl/documents/70523227/96262108/SESJA_1_PABLO_ORDUNA_eTEE2019.pdf (accessed on 21 November 2019).
125. Zalewski, J.; Wang, C.H.; Kenny, R.; Stork, M.G. Virtual and cyber-physical STEM LABS. In *Shaping Future Schools with Digital Technology. An International Handbook*; Yu, S., Niemi, H., Mason, J., Eds.; Springer: Singapore, 2019; pp. 75–94.
126. Arguedas-Matarrita, C.; Orduña, P.; Concari, S.; Elizondo, F.U.; Rodriguez Gil, L.; Hernandez, U.; Carlos, L.M.; Cunejo-Villalobos, M.; da Silva, J.B.; Garcia Zubia, J.; et al. Remote experimentation in the teaching of physics in costa rica: First steps. In Proceedings of the 2019 5th Experiment@ International Conference (exp.at'19), Madeira, Portugal, 12–14 June 2019.
127. Alves, G.R. Contributions of remote labs to engineering education. Keynote address. In Proceedings of the ICOASE 2019, 2nd International Conference on Advanced Science and Engineering, Duhok, Iraq, 2–4 April 2019.
128. McKagan, S.B.; Perkins, K.K.; Wieman, C.E. Reforming a large lecture modern physics course for engineering majors using a PER-based design. *AIP Conf. Proc.* **2007**, *883*, 34–37.

129. Ablanque, J.; Seidel, L.; Losada, J.C. Virtual laboratory: Assessment of a b-learning experience for teaching physics in engineering (Abstract). *Geophys. Res. Abstr.* **2009**, *11*, 7394.
130. Simpson, J.; Fernandez, E. Student performance in first year, mathematics, and physics courses: Implications for success in the study of electrical and computer engineering. In Proceedings of the FIE 2014, 44th IEEE Frontiers in Education Conference, Madrid, Spain, 22–25 October 2014.
131. Jebaraj, P.G.; Mohanasundaram, K. Development, validation and effectiveness of e-Contents in teaching physics to engineering students. *Int. J. Adv. Res. Soc. Sci. Humanit.* **2016**, *4*, 26–32.
132. Hari, Z.; Anuar, A.; Mokhtar, M.Z.; Mokhtar, R. Evaluating engineering students performance in physics courses during foundation studies. In Proceedings of the ICEE 2016, 6th IEEE International Conference on Engineering Education, Kuala Lumpur, Malaysia, 7–8 December 2016; pp. 214–217.
133. Kattayat, S.; Josey, S. Implementation of digital platform in teaching physics: Concepts applied to engineering education and student's performance—An exploratory study. In Proceedings of the ASET, 2018 International Multi-Conference on Advances in Science and Engineering Technology, Abu Dhabi, UAE, 6 February–5 April 2018.
134. Bagner, J.L. Teaching Physics to Engineers: An. Evaluation of PHY 103/104. Senior Thesis, Princeton University, Princeton, NJ, USA, 1998.
135. Shaw, C.L. Advanced Engineering Tutorials in College Physics. Master's Thesis, Montana State University, Bozeman, MT, USA, July 2016.
136. Tobias, S. *Revitalizing Undergraduate Science: Why Some Things Work and Most Don't*; Research Corporation: Tucson, AZ, USA, 1992.
137. Petroski, H. *The Essential Engineer: Why Science Alone Will Not Solve Our Global Problems*; Knopf: New York, NY, USA, 2010.

© 2019 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).