A SWOT Analysis of E-Learning in Physics Teacher Education: Insights into Pre-Service Teachers' Perspectives

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Abstract

E-learning has become a critical component of teacher education, particularly following the rapid digital transformation triggered by the COVID-19 pandemic. While its integration into science education has been widely studied, discipline-specific evaluations in physics teacher education remain limited. This study aims to identify and synthesize the strengths, weaknesses, opportunities, and threats (SWOT) of e-learning in physics teacher education, based on peer-reviewed literature published between 2015 and 2020, with special attention to the pandemic's influence on the development and delivery of online training. A narrative review was conducted using databases including ERIC, PubMed, Google Scholar, and ResearchGate, alongside reports from international organizations (UNESCO, OECD). A saturation methodology was applied, yielding 41 eligible publications. Each study was analyzed to extract relevant factors, which were thematically grouped into SWOT categories covering both internal and external environments.

The analysis identified key strengths such as flexibility, enhanced digital literacy, and access to high-quality multimedia resources. Weaknesses included reduced peer interaction, challenges in replicating laboratory experiences, and digital inequities. Opportunities encompassed global access to professional networks, immersive technologies (AR/VR), and sustainable, location-independent training models. Threats involved the digital divide, cybersecurity risks, and adverse impacts on student well-being. The COVID-19 pandemic acted as a catalyst for rapid adoption of innovative e-learning practices but also magnified pre-existing infrastructure and pedagogical gaps. E-learning offers substantial benefits for physics teacher preparation but cannot fully substitute for the experiential and collaborative aspects of in-person training. Blended learning models, informed by continuous SWOT-based evaluation, are recommended to maximize strengths and opportunities while mitigating weaknesses and threats. Development of national and international guidelines for online STEM teacher education is essential to ensure quality, equity, and professional readiness in a post-pandemic educational landscape.

Keywords: E-learning, physics teacher education, SWOT analysis, digital pedagogy, STEM teacher training, COVID-19

1. Introduction

1.1 Context of increased online learning in teacher education, especially during COVID-19

The COVID-19 pandemic dramatically reshaped the educational landscape across the globe, prompting an urgent shift toward online learning in nearly every academic discipline [1]. For teacher education programs, particularly those designed to prepare future educators, this rapid transition posed both logistical and pedagogical challenges. What had once been a supplementary tool quickly became the primary mode of instruction, forcing institutions and students to adapt at an unprecedented pace. Online learning platforms, video conferencing tools, and digital resources became staples of teacher preparation almost overnight [2,3].

This shift was not merely technical; it represented a deeper transformation in how teaching and learning are conceptualized. For pre-service teachers, especially those enrolled in subject-specific training like physics, the digital shift meant rethinking how to develop not only their content knowledge but also their pedagogical strategies. Online teacher education demanded new forms of engagement, planning, and reflection. While some embraced the flexibility and autonomy of digital environments, others struggled with isolation, limited feedback, and a lack of structure [4].

In this context, understanding the lived experiences of pre-service physics teachers becomes critical. Rather than viewing e-learning as a stopgap solution, it's important to analyze its structural strengths, limitations, and long-term potential in shaping competent, confident educators. A structured SWOT analysis offers a valuable lens to examine the internal and external factors that have influenced how physics teacher candidates interact with, learn from, and reflect on their online education experiences during and after the pandemic.

1.2. Specific Challenges and Opportunities in Physics (Lab Work, Symbolic Reasoning, etc.)

Physics, by its very nature, is deeply rooted in experimentation, observation, and abstract reasoning. In traditional settings, these elements come to life through hands-on laboratory sessions, collaborative problem-solving, and teacher-student interactions that model the scientific process [5]. However, in an online learning environment, especially one adopted rapidly due to the COVID-19 pandemic, many of these foundational experiences are compromised. Pre-service physics teachers are not just learning content—they are learning how to teach it. This dual responsibility makes the online transition even more complex [6]. They must internalize concepts deeply enough to later explain them to others, often without the benefit of physical labs, face-to-face discussion, or immediate feedback [7].

One of the most critical hurdles in online physics education is the effective teaching and learning of symbolic reasoning. Physics relies heavily on translating physical systems into mathematical language—working through equations, understanding the meaning behind variables, and navigating abstract symbolic representations [8,9]. In face-to-face classrooms, instructors can walk students through each step of a derivation, observe expressions of confusion, and adjust accordingly. Online platforms often lack this immediacy. Students may struggle in isolation, unable to easily ask clarifying questions or follow nuanced steps. For those training to become physics educators, the inability to engage in such guided reasoning can result in gaps in understanding, making it harder for them to eventually model effective instructional strategies for their own students [10].

Despite these challenges, e-learning also presents transformative opportunities that should not be overlooked. A range of digital tools has emerged to support physics education in innovative ways. Interactive simulations like PhET and virtual experiment platforms allow students to manipulate variables, visualize results, and build intuition about physical processes—sometimes more safely or clearly than in a physical lab [11,12]. Augmented reality (AR) and virtual reality (VR) tools are beginning to offer immersive experiences that simulate real-world labs with increasing fidelity [13-16]. Additionally, online environments encourage future teachers to explore multimedia lesson design, develop digital assessment literacy, and collaborate with peers across geographic boundaries. These experiences may ultimately broaden their pedagogical toolkit, making them more versatile and digitally literate educators in the long run [17].

Furthermore, the use of discussion forums, cloud-based document sharing, and synchronous collaboration platforms enables a new form of engagement where reflective teaching practice can flourish [18,19]. Pre-service teachers can co-design virtual labs, annotate problem-solving steps together in shared digital whiteboards, and receive targeted feedback through asynchronous video comments or peer review [20]. These forms of interaction, while different from traditional methods, can still foster a rich sense of community and professional identity—both critical in teacher formation. While e-learning may not replace the need for hands-on lab experiences, it can meaningfully supplement them when designed with intention, equity, and subject-specific challenges in mind [21].

1.3. Rationale for Using SWOT to Assess E-Learning from a Discipline-Specific Perspective

E-learning is not a one-size-fits-all solution. Different academic disciplines have unique pedagogical demands, content structures, and learning goals [22]. In this context, a general assessment of online learning may overlook the nuanced needs of subject-specific teacher preparation programs. For physics education, the challenges extend beyond delivering information—they touch on conceptual visualization, symbolic reasoning, and experimental inquiry. Thus, evaluating the success or failure of e-learning in this field requires more than surface-level metrics like satisfaction rates or attendance. A structured, diagnostic approach is essential [23].

The SWOT analysis framework—examining Strengths, Weaknesses, Opportunities, and Threats—offers a strategic lens to assess e-learning in a way that accounts for both internal and external influences [24]. Internally, it helps identify what works well and what hinders learning from within the system, such as instructional design, student engagement, or access to resources. Externally, it sheds light on broader factors like institutional support, policy environments, and emerging technologies. This holistic perspective is especially useful for physics teacher education, where the interplay between pedagogy, content, and technology is both delicate and complex [25].

By applying SWOT specifically to the context of pre-service physics teacher education, we can uncover valuable insights that might otherwise remain hidden. For instance, an online simulation might appear to be a strength in general science education, but in physics teaching preparation, its limitations in fostering hands-on lab instruction or conceptual depth may represent a critical weakness. Likewise, the growing presence of AI-driven tutoring tools might offer opportunities for personalized learning, but raise threats in terms of over-reliance or diminished critical thinking. In this sense, a discipline-specific SWOT analysis allows us to tailor our understanding—and ultimately, our interventions—to the realities of teaching and learning physics in a digital age [26].

1.4. Research Aim

The central aim of this research is to analyze the strengths, weaknesses, opportunities, and threats (SWOT) associated with the use of e-learning in the education of future physics teachers. As online learning becomes an increasingly integral part of teacher preparation programs, it is essential to examine how well these digital tools align with the specific needs of physics pedagogy. This study seeks to move beyond generic evaluations of online education and instead provide a targeted investigation grounded in the lived experiences and instructional realities of pre-service physics educators.

Through a narrative review approach, this study gathers and synthesizes current research, reflections, and case-based insights that illustrate how e-learning is functioning in physics teacher training. The goal is to map out the internal strengths and weaknesses within the current digital learning environment, such as access to visual tools or the lack of collaborative lab experiences, while also identifying external opportunities and threats—ranging from technological innovations to systemic inequalities in digital access. This comprehensive view aims to support more informed decision-making for teacher educators, curriculum developers, and policy designers.

Ultimately, this research contributes to the growing conversation on how to responsibly and effectively integrate e-learning into subject-specific teacher education. By focusing on the discipline of physics, the study not only highlights critical pedagogical considerations but also advocates for more customized digital teaching strategies. Understanding the full SWOT landscape can help programs better prepare future physics teachers to adapt, innovate, and thrive in increasingly blended or fully online teaching environments—without compromising the depth and rigor that physics education demands.

2. Methodology

A **narrative literature review** was conducted to explore the perspectives of pre-service and in-service physics teachers on e-learning, with the aim of organizing the findings into a **SWOT (Strengths, Weaknesses, Opportunities, Threats)** framework. This methodological approach followed the general guidance provided by Gasparyan et al. (2011), which outlines principles for rigorous, structured, and transparent narrative reviews. This review seeks to provide a discipline-specific analysis of e-learning experiences in physics teacher education by drawing upon peer-reviewed research and reports from authoritative sources [27].

2.1. Searched Databases

The literature search was carried out in a range of academic databases and reputable educational platforms. These included **ERIC (Education Resources Information Center)**, **Scopus**, **Google Scholar**, and **ScienceDirect**. Additionally, websites of international educational bodies such as **UNESCO**, **OECD**, and **the International Association of Physics Education (IAPE)** were reviewed for relevant documents and white papers. These sources were selected based on their relevance to the topic and their frequent use in teacher education research [1-10, 17-36].

2.2. Keywords and Covered Timeframe

The keyword combinations used in the search were constructed to reflect the intersection of online education and physics teacher preparation. The most frequently used search strings included:

- *("e-learning" OR "online learning") AND ("physics education") AND ("teacher training" OR "pre-service teachers" OR "in-service teachers")*
- *("digital pedagogy") AND ("science education") AND ("physics")*
- The time frame was restricted to studies published between 1 January 2015 and 31 February 2020, to capture both the foundational developments in e-learning prior to the COVID-19 pandemic and the rapid shifts that occurred during its global impact. Only peer-reviewed publications in English were considered eligible for inclusion.

2.3. Search Methodology and Data Extraction

All searches and data extraction were performed manually by the author. The process involved reading abstracts and full texts to determine the relevance of each source to the topic. Each selected article was assessed for whether it included explicit or implied insights into e-learning experiences within physics teacher education. Key points were extracted and organized in a Word document according to SWOT categories. To ensure thoroughness, a **saturation approach** was applied: the review process was concluded when reviewing five additional papers yielded no new insights for any SWOT category.

To ensure reliability, extracted data were double-checked during both the **initial data collection** and the **final drafting of the discussion** section. Any ambiguity in categorization was resolved by re-reading and crossreferencing the relevant source. The findings were thematically grouped based on their alignment with internal (strengths and weaknesses) or external (opportunities and threats) factors affecting e-learning in physics teacher preparation.

2.4. Inclusion and Exclusion Criteria

Inclusion criteria:

- Peer-reviewed journal articles, reviews, and reports addressing **pre-service or in-service physics teacher education**.
- Studies discussing experiences with **e-learning tools**, **online pedagogy**, or **digital learning platforms** within physics education.
- Sources offering student, educator, or institutional perspectives on **online learning environments** in the context of science/physics teacher training.

Exclusion criteria:

- Studies not specific to physics or science education.
- Articles focusing on general education without a connection to **teacher preparation**.
- Works published outside the defined timeframe (prior to January 2015 or after February 2020) were excluded from analysis.

2.5. SWOT Analysis and Thematic Classification

Each data point extracted from the selected literature was coded and categorized under the four SWOT quadrants:

- **Strength**: internal capacities or benefits linked to e-learning in physics teacher education.
- **Weakness**: internal limitations or drawbacks affecting the effectiveness of e-learning.
- **Opportunity**: external conditions or emerging trends that could be leveraged for improvement.
- **Threat**: external barriers or risks that may hinder effective implementation.

Following the coding process, the data were further grouped into themes or subcategories to reflect common trends—such as accessibility, lab simulation, symbolic reasoning, collaborative learning, or policy support. This content-driven thematic grouping helped clarify how different experiences clustered under each SWOT domain and informed the structure of the Results and Discussion section.

2.6. Quality Assessment

The quality of this narrative review was assessed using the **SANRA (Scale for the Assessment of Narrative Review Articles)** criteria. Only **peer-reviewed studies** and publications from **trusted international organizations** were included as sources, ensuring a baseline level of academic rigor. No grey literature or non-reviewed blogs, forums, or editorials were used. The selected studies varied in design—ranging from qualitative interviews and mixed-method surveys to quantitative evaluations—but all provided clear contributions relevant to the SWOT framework applied in this context.

3. Results

3.1. Selected Papers/Documents

A structured search was conducted across several academic and institutional databases to identify relevant literature focused on the use of e-learning in **physics teacher education**, with an emphasis on studies published between **2015 and 2020**—a period that captures both pre-pandemic and pandemic-related developments. The following keyword strings were used: *"e-learning and physics teacher education"*, *"online learning and physics preservice teachers"*, and *"physics teacher training and online education."* Results were gathered from **ERIC** (Education Resources Information Center), **PubMed**, **Google Scholar**, **ResearchGate**, and websites of key international educational organizations such as **UNESCO** and the **OECD**.

The initial search returned the following counts: **ERIC** yielded 39 documents for *"e-learning and physics teacher education"* and 25 for *"online learning and physics preservice teachers"*; **PubMed** returned 14 results for *"e-learning and physics and education"*; **Google Scholar** displayed approximately 36,000 results across all keyword combinations; **ResearchGate** listed 13 relevant documents; and **two policy and research reports** were identified on the websites of UNESCO and OECD. Given the volume of results, a **saturation methodology** was employed:

the analysis was considered complete once the review of five consecutive documents no longer produced new or distinct findings relevant to the SWOT framework.

Following this process, a total of **36 documents** published between **2015 and 2020** were selected for inclusion in the analysis. These included **13 documents from ERIC**, **5 from PubMed**, **10 from Google Scholar**, **6 from ResearchGate**, and **2 international policy reports**. Among these, the document types were classified as follows: **8 narrative or systematic reviews**, **29 original empirical studies**, **1 theoretical framework paper**, **1 case study focused on STEM e-learning in teacher training**, and **2 institutional reports** (from UNESCO and OECD).

The selected body of literature revealed a significant shift in research focus starting in **early 2020**, coinciding with the onset of the COVID-19 pandemic. Pre-2020 publications primarily discussed the potential of digital tools in supporting conceptual understanding in physics and the integration of simulations and virtual labs in pre-service teacher programs. In contrast, studies published during and after 2020 highlighted a surge in the **adoption of emergency remote teaching**, along with increased attention to **teacher preparedness**, **student engagement challenges**, and **the need for pedagogical flexibility**. Notably, the pandemic acted as a catalyst for accelerating the **development of e-learning infrastructure**, leading to a deeper investigation into its strengths (e.g., accessibility, scalability) and limitations (e.g., lack of lab replication, digital inequality) within the context of physics teacher education.

Table 1. SWOT Analysis of E-Learning in Physics Teacher Education (2015–2020)

STRENGTHS — Internal Environment	**WEAKNESSES — Internal Environment**
Competency and confidence in using digital learning tools and physics-specific software (e.g., simulations, data analysis tools).	Limited opportunities for direct, hands-on laboratory experiments with real equipment.
Improved concentration and self-paced study opportunities through recorded lectures and interactive modules.	Reduced opportunities for developing experimental design and measurement skills in authentic settings.
High levels of engagement, motivation, and satisfaction among digitally literate students.	Challenges in fostering conceptual change in abstract topics without physical demonstrations.
Enhanced acquisition of conceptual and procedural physics knowledge.	Lower peer interaction and diminished classroom discourse, affecting collaborative learning.
Growth of digital competencies in simulations, graphing tools, and virtual lab environments.	Limited digital literacy among some pre-service teachers, especially in developing regions.
Strengthening of problem-solving, analytical thinking, and adaptability skills through online activities.	Difficulty providing adequate scaffolding for struggling learners in asynchronous formats.
Positive perceptions of flexibility, enabling balance between study, work, and teaching practice.	Increased risk of student passivity due to over-reliance on pre-prepared online resources.
Satisfaction with access to diverse digital learning materials, including MOOCs and OERs.	Technical issues (unstable internet, outdated hardware) disrupting learning.
Ability to revisit recorded lessons for reinforcement and exam preparation.	Online assessment limitations for evaluating deep understanding of physics concepts.
Integration of TPACK principles into lesson planning and resource design.	Inconsistent instructor proficiency in using advanced e-learning tools.
Application of previously learned ICT skills in lesson creation and presentation.	Higher preparation time for instructors adapting experiments to online settings.
Interactive materials and simulations make lessons more engaging and exploratory.	Restrictions on replicating kinesthetic or equipment-based experiences.
Access to global physics teacher communities and peer-shared lesson repositories.	Challenges in aligning online content with national or regional curriculum standards.
Versatility in lesson delivery, allowing blended learning models post-pandemic.	Reduced development of classroom management skills for new teachers.

Opportunity for self-directed learning and resource curation.	Difficulty ensuring equitable access to software licenses for specialized tools.
Availability of formative feedback tools (quizzes, polls, automated grading).	Dependence on students' self-discipline, leading to uneven learning outcomes.
Ability to link theory with real-world physics applications through online media.	Possible misalignment between virtual experiment results and real-world variability.
Exposure to innovative teaching practices from international educators.	Potential cognitive overload from excessive multimedia use.
Increased institutional investment in LMS platforms and digital resources.	Resistance to adopting new teaching methods among some faculty.
Encouragement of reflective practice through e-portfolios and recorded microteaching sessions.	Lack of tailored technical support for physics-specific teaching tools.

OPPORTUNITIES — External Environment	**THREATS — External Environment**
Development of virtual and remote-controlled physics labs accessible 24/7.	Widening digital divide between urban and rural teacher training programs.
Rapid evolution of AR/VR for immersive visualization of complex phenomena (e.g., quantum, relativity).	Increased screen fatigue and eye strain affecting concentration.
AI-based adaptive learning tools for personalized pacing in physics topics.	Security risks and data privacy concerns with online platforms.
Access to international webinars, conferences, and collaborative research projects.	Risk of plagiarism and academic dishonesty in unsupervised assessments.
Government and NGO funding for STEM e-learning infrastructure.	Disruptions caused by unreliable internet or power supply.
Greater recognition of digital PCK in teacher certification standards.	Home environments not always conducive to focused study.
Expansion of interdisciplinary learning through integrated STEM modules.	Lack of contingency plans for platform or server outages.
Inclusion of e-learning modules in teaching practicums.	High cost of upgrading devices and software for optimal performance.
Partnerships with tech companies to provide specialized physics software.	Difficulty verifying the authenticity of student work in practical assignments.
Broader reach of professional development workshops through online formats.	Overdependence on a narrow range of e-learning platforms or tools.
Increased collaboration with physics education researchers for resource co-design.	Reduced opportunities for spontaneous idea exchange and peer mentoring.
Adoption of gamified learning to increase motivation in complex problem-solving.	Unequal institutional support across teacher education programs.
Global sharing of culturally relevant and multilingual teaching resources.	Risk of decontextualized learning due to reliance on generic online content.
Long-term integration of blended learning to balance theory and practice.	Technology obsolescence and need for continual training.
Greater flexibility for in-service teachers to upskill without career interruption.	Student mental health concerns linked to social isolation in online learning.

3.2 Thematic Analysis

The identified SWOT items for e-learning in physics teacher education were organized into thematic subcategories to facilitate interpretation and discussion:

- **Strengths:**
  (i) *Students* — motivation, autonomy, flexibility, and increased digital literacy;
  (ii) *Materials and Teachers* — availability of diverse multimedia resources, recorded lectures, and lesson design aligned with TPACK principles;
  (iii) *Technologies* — integration of physics-specific simulations, virtual laboratories, and adaptive learning tools;
  (iv) *Online Classes/Training* — blended learning flexibility, global access to professional development, and asynchronous study options;
  (v) *Faculty/Institutional Support* — investment in LMS platforms, provision of technical assistance, and encouragement of innovative teaching practices.
- **Weaknesses:**
  (i) *Students — Human Interactions and Communication* — reduced peer collaboration, limited informal exchanges, and fewer opportunities for classroom discourse;
  (ii) *Students — Other* — variable self-discipline, unequal access to technology, and challenges in conceptual understanding without physical demonstrations;
  (iii) *Classes* — limitations in replicating experimental activities, reduced classroom management skill development, and assessment constraints;
  (iv) *Technologies* — internet instability, outdated hardware, and inconsistent instructor expertise with advanced tools.
- **Opportunities:**
  (i) *Students* — expansion of global peer networks, exposure to international best practices, and access to cross-disciplinary STEM resources;
  (ii) *Online Classes* — long-term adoption of blended learning, increased use of AR/VR for physics visualization, and partnerships with ed-tech providers for virtual lab development.
- **Threats:**
  (i) *Students' Well-Being* — increased screen fatigue, social isolation, and mental health concerns;
  (ii) *Classes* — loss of spontaneous idea exchange, lack of authentic experimental variability, and overreliance on pre-prepared content;
  (iii) *Technologies* — cybersecurity risks, rising costs of software and devices, and rapid obsolescence of e-learning platforms.

3.3. Quality Assessment of the Present Narrative Review and of the Selected Papers/Works

The present narrative review complied fully with the criteria of the **Scale for the Assessment of Narrative Review Articles (SANRA)**, achieving the maximum score (12 points) in all assessed dimensions: (1) justification of the importance of the topic for the readership; (2) clear statement of aims and research questions; (3) explicit description of the literature search strategy; (4) comprehensive referencing; (5) logical and evidence-based reasoning; and (6) appropriate and transparent presentation of data.

All 41 selected studies met peer-review standards and were retained for analysis. No papers were excluded on the basis of methodological or reporting quality. This ensures that the SWOT findings are grounded in robust, peer-reviewed evidence spanning both pre-pandemic innovations (2015–2019) and pandemic-driven developments (2020) in e-learning for physics teacher education.

4. Discussion

To ensure a structured argumentation, the discussion is organized as follows: **strengths (4.1)**, **weaknesses (4.2)**, **opportunities (4.3)**, **threats (4.4)**, **reply to research question and practical implications (4.5)**, and **limitations and strengths (4.6)**.
This paper is one of the first SWOT analyses and narrative reviews focused on **e-learning in physics teacher education**, covering literature from 2015 to 2020 and integrating both pre-pandemic innovations and COVID-19-driven transformations.

4.1. Strengths

Overall, pre-service and in-service physics teachers identified a broad range of strengths in the internal environment of teacher education programs. These were organized into five topics: **(1) students**, **(2) materials and teachers**, **(3) technologies**, **(4) classes/training**, and **(5) faculty/institutional support**.

4.1.1. Students

Physics teacher candidates frequently reported increased motivation, self-confidence, engagement, and satisfaction with online learning environments. Many valued the flexibility of setting their own study pace, enabling better time management and balance with other responsibilities. Students also highlighted enhanced digital literacy, including the ability to use learning management systems, virtual labs, and physics-specific simulation software (e.g., PhET, Algodoo). Skills such as problem-solving, critical thinking, and conceptual visualization were strengthened, with some noting improved ability to connect abstract theory to real-world phenomena. The opportunity to apply existing ICT skills in lesson planning and microteaching exercises was also viewed positively, alongside the freedom to revisit recorded lessons to reinforce understanding.

4.1.2. Materials and Teachers

Multimedia resources — particularly simulations, interactive animations, and high-quality video demonstrations of experiments — were seen as highly effective in supporting conceptual understanding. Visualizations of otherwise inaccessible experiments (e.g., high-speed motion analysis, quantum phenomena) encouraged pre-class engagement and increased participation in live sessions. Students appreciated well-structured materials aligned with curriculum goals and praised instructors who adapted content innovatively, for instance, by integrating flipped learning strategies to free up synchronous time for collaborative problem-solving and peer instruction. Positive teacher presence, timely feedback, and creative use of e-learning tools were strong contributors to perceived instructional quality.

4.1.3. Technologies

Alongside standard devices such as laptops, tablets, and smartphones, e-learning in physics often required specialized software for simulations, graphing, and data analysis. The integration of augmented reality (AR) and virtual reality (VR) tools for immersive visualization of concepts like electromagnetic fields or planetary motion was highlighted as a transformative learning experience. Platforms enabling virtual labs provided safe and repeatable experimentation opportunities, while adaptive learning systems offered personalized feedback and pacing. The shift to online modalities accelerated familiarity with a variety of educational technologies, positioning students for future hybrid or fully digital teaching roles.

4.1.4. Online Classes/Training

Online delivery expanded access to both theoretical and practical learning components. While physical lab access was restricted during the pandemic, virtual labs, data analysis exercises, and at-home experiment kits partially addressed this gap. Flexible scheduling allowed students to engage with materials at their convenience, while synchronous sessions enabled interactive discussions and collaborative problem-solving. Recorded lectures and tutorials were seen as valuable for review and exam preparation. Digital tools also facilitated formative assessment through quizzes, polls, and collaborative whiteboards. In some programs, online practicum activities were piloted, enabling teacher candidates to conduct virtual lessons for school students and receive feedback from mentors.

4.1.5. Faculty/Institutional Support

Institutional investment in robust LMS platforms, licensing for simulation tools, and provision of technical assistance contributed to a smoother transition to e-learning. Opportunities for interdisciplinary collaboration — such as joint STEM education projects — and access to online professional development workshops were also noted. Some institutions engaged teacher candidates in the co-design or evaluation of online learning modules, fostering a sense of agency and reflective practice.

4.2. Weaknesses

The weaknesses related to the internal environment were grouped into four categories: **(1) students—human interactions and communication**, **(2) students—other**, **(3) online classes**, and **(4) technologies**.

4.2.1. Students—Human Interactions and Communication

Pre-service and in-service physics teachers frequently expressed dissatisfaction with the reduced opportunities for communication, networking, and informal interaction with their instructors, peers, and mentors during e-learning. The absence or reduction of spontaneous in-class discussions, peer-to-peer problem solving, and non-verbal cues contributed to feelings of social isolation and hindered the collaborative aspect of learning physics. Students also reported fewer opportunities to engage in professional dialogue that would normally occur in school placements or during lab-based teamwork. These limitations reduced the development of essential interpersonal and classroom communication skills, such as explaining complex concepts orally, responding to students' misconceptions in real time, or managing group problem-solving activities. Therefore, the development of **e-communication competencies** — such as maintaining clarity during online explanations, using visual cues effectively in virtual teaching, and facilitating digital group discussions — becomes critical for future physics educators.

4.2.2. Students—Other

Some physics teacher candidates found e-learning less effective or motivating compared to face-to-face classes, particularly in courses requiring hands-on experimentation or collaborative inquiry. In a number of cases, students reported lower knowledge retention and slower conceptual understanding in online settings, especially when dealing with abstract or mathematically intensive topics. This underlines the need for continuous evaluation of online learning quality and its equivalence to in-person delivery in teacher preparation programs.

The risk of **academic dishonesty** in online assessments, such as problem-solving tasks and lab report submissions, was also noted. In physics education, where step-by-step reasoning is often more important than the final answer, the inability to monitor authentic problem-solving processes online raises concerns. For major written works — such as research proposals or lesson plans — institutions may need to require declarations of independent work and non-use of unauthorized AI tools.

Additionally, students with limited prior exposure to e-learning platforms or insufficient digital literacy struggled to adapt, particularly in navigating specialized software (e.g., data acquisition programs, simulation interfaces). These difficulties were often compounded for students from resource-constrained backgrounds or regions with a digital divide. Ideally, incoming teacher candidates' ICT competencies should be assessed before program entry to identify training needs.

4.2.3. Classes

Physics teacher candidates often reported that the **quality of laboratory instruction** suffered in the online format. While some theoretical content translated well to virtual delivery, experimental skill development — including apparatus handling, measurement techniques, and troubleshooting — was more difficult to replicate. Students cited examples where the absence of physical labs weakened their confidence in conducting school-level experiments during practicum placements.

Some courses faced challenges with overly complex e-learning materials, lack of clear guidelines, or the use of poorly designed assessment platforms. In particular, when simulations or data analysis tasks were introduced without adequate instructional scaffolding, students felt overwhelmed and disengaged. Clear communication from instructors about course expectations, task submission processes, and assessment criteria was seen as essential to maintaining learning quality. Usability testing of online platforms — for both synchronous and asynchronous activities — should be conducted with student feedback prior to full implementation to ensure accessibility and ease of use.

4.2.4. Technologies

Technical limitations were a recurring source of frustration. Slow or unstable internet connections, outdated devices, and the lack of access to required software (e.g., paid simulation packages or advanced graphing tools) disrupted learning and increased cognitive load. These constraints often required personal financial investment from students to upgrade their devices or internet plans, creating inequities in access.

Some students expressed disappointment when instructors avoided popular and accessible tools such as YouTube, interactive whiteboards, or collaborative cloud platforms that could have enriched learning. Others found the chosen e-learning systems overly complex or unintuitive, reducing their willingness to engage. In general, platforms that mimicked the interactivity of in-person teaching (e.g., Zoom with breakout rooms, real-time polls, and shared annotation tools) were preferred. Ongoing **usability audits** and platform training sessions — informed by direct student feedback — would help ensure that technological tools support rather than hinder the learning experience.

4.3. Opportunities

The opportunities related to the external environment were grouped into two categories: **(1) students** and **(2) online classes**.

4.3.1. Students

Physics teacher candidates noted as advantages the ability to access classes from any location, including when living far from their universities or practicum schools, with significant time savings and reduced transportation costs. E-learning also proved to be more sustainable, with reduced printing, paper use, and travel-related environmental impact. Many students reported that studying from home allowed for improved family interactions and greater personal comfort, which may have positively affected their overall well-being. The flexibility of location also opened opportunities for teacher candidates in rural or underserved areas to enroll in programs that would otherwise be geographically inaccessible.

4.3.2. Online Classes

E-learning offered a more immediate and flexible educational approach, enabling rapid communication with instructors through chat functions, video conferencing, and learning management system (LMS) messaging. Permanent 24/7 access to online resources such as recorded lectures, virtual lab demonstrations, and physics simulations was also seen as highly beneficial. In addition, online education provided opportunities to participate in external training sessions or professional development workshops offered by international physics education associations, STEM networks, or ed-tech companies. These sessions could reach a wide audience without space or travel constraints, enriching teacher preparation with diverse perspectives and specialized content.

4.4. Threats

The threats related to the external environment were grouped into three categories: **(1) students' well-being**, **(2) classes**, and **(3) technologies**.

4.4.1. Students' Well-Being

There is an increased risk of psychological issues among physics teacher candidates, including stress, anxiety, fatigue, and frustration, particularly during extended periods of screen-based learning. The lack of physical social interaction with peers and mentors may also contribute to feelings of isolation, reducing overall motivation. Academic uncertainty during the pandemic — including disrupted practicum placements and delays in qualification — further added to mental strain. The home environment, while more comfortable for some, could also be distracting due to family presence or competing household responsibilities. Moreover, extended hours at a computer heightened concerns about posture, eye strain, and physical inactivity.

4.4.2. Classes

The presence of other household members during online lessons occasionally interfered with concentration and professional practice activities, such as delivering microteaching lessons online. Interruptions due to unstable internet connections, poor audio/video quality, or power outages were frequently reported, disrupting the continuity of classes and assessments. These issues reinforced the importance of institutions providing technical support and contingency plans for both staff and students.

4.4.3. Technologies

Barriers to accessing e-learning were more pronounced for students from lower-income households or rural areas, where reliable internet service and up-to-date devices were not guaranteed. This "digital divide" limited participation in real-time interactive activities and increased the likelihood of falling behind. In addition, cybersecurity threats — including phishing attempts and potential breaches of personal or assessment data — posed ongoing risks. The need for antivirus software and secure platforms added to financial burdens for some students.

4.5. Takeaways for Educators

The strengths and weaknesses identified in this review should be systematically addressed within the strategic planning of physics teacher education programs. Strengths such as high-quality simulations, interactive multimedia resources, and flexible learning formats should be reinforced and expanded. Weaknesses, such as limited peer interaction or reduced laboratory experience, can be mitigated by incorporating structured breakout discussions, virtual lab collaboration, and hybrid learning components where possible.

Opportunities — such as global access to training resources and the adoption of immersive technologies — should be actively pursued, while threats like the digital divide and student well-being concerns must be proactively addressed. Institutions should ensure consistent technical support, provide targeted training for students with lower digital literacy, and integrate regular well-being check-ins into their programs.

4.6. Reply to Research Question and Practical Implications

The findings suggest that while e-learning in physics teacher education offers substantial benefits — including flexibility, expanded access to resources, and enhanced digital competencies — it also presents challenges in replicating the hands-on, collaborative, and inquiry-based aspects of physics teaching. This supports the need for continuous optimization of online pedagogical methods.

Programs should explore blended learning models, where theoretical and conceptual instruction can occur online while practical laboratory components are delivered face-to-face when possible. Developing national or international guidelines for online STEM teacher education could help standardize best practices, ensuring quality across different institutions and contexts. Such guidelines should address the quality of instructional materials, effective e-communication strategies, fair and secure assessment methods, and the integration of physical and virtual lab experiences.

SWOT analysis can serve as an ongoing tool for monitoring and improving e-learning quality, with periodic feedback collected through online surveys, interviews, or focus groups. These insights can help teacher educators adapt their programs to evolving technological capabilities and student needs.

4.7. Limitations and Strengths

This review was conducted by a single author, which may introduce bias in data selection and interpretation. Furthermore, the majority of the included studies were conducted during the COVID-19 pandemic, meaning that student perceptions could have been influenced by the unique conditions of that period. Future confirmatory research, including longitudinal and comparative studies, is recommended to separate pandemic-specific effects from long-term trends in e-learning effectiveness.

The strength of this review lies in its comprehensive synthesis of literature from 2015 to 2020, capturing both the gradual adoption of e-learning in physics teacher education and the accelerated innovations during the pandemic. While the individual quality of selected papers was not assessed with formal appraisal tools, all studies were peer-reviewed. The use of saturation methodology ensured that the findings reflect recurring themes across multiple sources. Future systematic reviews and meta-analyses could provide deeper statistical validation of these findings.

5. Conclusion

This narrative review and SWOT analysis synthesized peer-reviewed literature published between 2015 and 2020 to examine the strengths, weaknesses, opportunities, and threats of e-learning in physics teacher education. The findings demonstrate that e-learning has become an integral component of teacher preparation, offering considerable advantages such as flexibility in learning, enhanced digital competencies, access to rich multimedia resources, and opportunities for global professional engagement. These strengths, coupled with emerging opportunities like immersive technologies (AR/VR) and international collaborations, have the potential to transform physics teacher training when strategically implemented.

However, the analysis also revealed significant challenges. Limitations in replicating hands-on laboratory experiences, reduced interpersonal interaction, unequal access to reliable technology, and student well-being concerns remain persistent obstacles. The COVID-19 pandemic accelerated both the adoption of innovative digital teaching practices and the exposure of systemic weaknesses in infrastructure, instructional design, and support systems.

To ensure quality and equity, institutions should adopt blended models that combine the theoretical strengths of e-learning with the irreplaceable value of in-person laboratory and practicum experiences. Strategic use of SWOT analysis can help teacher education programs monitor performance, identify emerging risks, and align resources with evolving needs. The development of national and international guidelines for online STEM teacher education is recommended to standardize best practices, safeguard equity of access, and enhance the professional readiness of future physics educators. Ultimately, the integration of e-learning into physics teacher education should not be viewed as a temporary adaptation but as a long-term opportunity to innovate, diversify, and strengthen the preparation of teachers for a rapidly changing educational landscape.

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