Overcoming Barriers to Integrating Digital Technologies into the Professional Practice of Physics Teachers (a Case Study of General Education Schools in Kazakhstan)

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This is to certify that the Master's Thesis of
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List of Tables

Table 2.1. Comparative Overview of Conceptual Models of Digital Transformation in Education……. 25

Table 2.2. Comparative Analysis of Pedagogical Models of Technology Integration..... 29

Table 2.3. Pedagogical Functions of Digital Tools in Physics Education..... 34

Table 2.4. Comparative Overview of International Frameworks for Teachers' Digital Competence……... 28

Table 2.5. Empirical Evidence on Digital Technology Use in Kazakhstani Schools…….. 52

Table 3.1. Structure of the Survey Instrument…… 59

Table 3.2. Overview of Qualitative and Contextual Data Sources……. 62

Table 4.1. Demographic and Professional Profile of Respondents..... 68

Table 4.2. Perceived Usefulness of AI Across Instructional Tasks..... 72

Table 4.3. Group Comparison Results by Teaching Format, Degree, and Experience..... 74

List of Figures

Figure 2.1. Multilayered Typology of Barriers to Digital Integration in Education..... 43
Figure 2.2. Contextual Map of Digital Integration Barriers in Physics Education. 46
Figure 2.3. Policy Ecosystem of Educational Digitalization in Kazakhstan..... 49
Figure 2.4. Adapted Conceptual Framework for Digital Integration in Physics Education in Kazakhstan..... 55
Figure 4.1. Frequency of AI Use in Physics Teaching..... 70
Figure 4.2. Most Frequently Used AI Tools..... 71
Figure 4.3. Reported Barriers to AI Integration..... 72

List of Appendices

Appendix A. Survey Questionnaire for Physics Teachers..... 92

Appendix B. Semi-Structured Interview Guide for Physics Teachers..... 96

Table of Contents

Abstract…..……. ix

Аңдатпа…...…… x

Аннотация…...…… xi

1. Introduction……...…... 12

1.1 Relevance of the Study and Problem Statement…….. 12

1.2 Purpose and Objectives of the Research…….. 13

1.3 Research Questions……. 15

1.4 Theoretical and Practical Significance…… 16

1.5 Scientific Novelty……... 18

1.6 Structure of the Dissertation……... 19

2. Literature Review on the Integration of Digital Technologies into Education……. 22

2.1 Theoretical Foundations: Digital Technology and Pedagogical Models…. 22

2.2 Teachers' Digital Competence: International Studies and Barriers……. 35

2.3 The Kazakhstani Context: Policy, Standards, and Empirical Studies…….. 47

3. Research Methodology and Empirical Basis……...……. 57

3.1 Research Design and Methodological Approaches……. 57

3.2 Data Collection Methods and Research Participants……... 58

3.2.1 Survey Method…… 58

3.2.2 Interview Method……. 60

3.2.3 Document Analysis…….. 61

3.3 Data Processing, Analysis Techniques, and Ethical Considerations…… 63

3.3.1 Quantitative Data Analysis……..... 63

3.3.2 Qualitative Data Analysis……. 65

3.3.3 Ethics and Informed Consent…… 66

4. Research Findings and Scientific Analysis……...…… 68

4.1 Survey Results and Quantitative Analysis……..... 68

4.2 Interview Results and Qualitative Content Analysis……... 75

4.3 Comparison and Interpretation of Results with Theoretical Frameworks... 77
5. Conclusion……...……. 87
List of References…… 85
Appendices…….. 92

List of Abbreviations

AI	Artificial Intelligence
ICT	Information and Communication Technology
ICT-CFT	ICT Competency Framework for Teachers
TPACK	Technological Pedagogical Content Knowledge
SAMR	Substitution, Augmentation, Modification, Redefinition
ICAP	Interactive, Constructive, Active, Passive Framework
DigCompEdu	Digital Competence Framework for Educators
PhET	Physics Education Technology
STEM	Science, Technology, Engineering, and Mathematics
LMS	Learning Management System
VR	Virtual Reality
SPSS	Statistical Package for the Social Sciences
OECD	Organisation for Economic Co-operation and Development
UNESCO	United Nations Educational, Scientific and Cultural Organization
IITE	Institute for Information Technologies in Education
MoES RK	Ministry of Education and Science of the Republic of Kazakhstan
MoSHE RK	Ministry of Science and Higher Education of the Republic of Kazakhstan
SCES	State Compulsory Education Standard
APA	American Psychological Association

Abstract

This dissertation examines the barriers to integrating digital technologies into the professional practice of physics teachers in general education schools in Kazakhstan. The study focuses on the gap between national digitalisation policies and actual classroom implementation, especially in physics, where visualisation, modelling, experimentation, and conceptual reasoning are essential.

The research used a non-experimental descriptive-analytical mixed-methods design. Quantitative data were collected through an online survey of 151 physics teachers, while qualitative data were obtained from semi-structured interviews with six teachers and document analysis. The findings show that digital and AI-related tools are already present in teaching practice, but their use remains selective, uneven, and dependent on teacher competence, training, infrastructure, curriculum flexibility, and institutional support. Teachers valued digital technologies most for visual modelling, lesson preparation, and explaining complex physics concepts.

The study contributes theoretically by adapting digital integration models to physics education and practically by offering recommendations for teachers, schools, training programs, and policymakers.

Keywords: digital technologies, physics education, teacher competence, digital integration, barriers, Kazakhstan, mixed methods

Аңдатпа

Бұл диссертация Қазақстанның жалпы білім беретін мектептеріндегі физика мұғалімдерінің кәсіби тәжірибесіне цифрлық технологияларды енгізуге кедергі келтіретін факторларды зерттеуге арналған. Зерттеу ұлттық цифрландыру саясаты мен мектептегі нақты қолдану тәжірибесі арасындағы алшақтыққа назар аударады. Физика пәнінде визуализация, модельдеу, эксперимент және ұғымдық ойлау маңызды болғандықтан, цифрлық технологияларды қолдану пәндік-педагогикалық тұрғыдан негізделуі тиіс.

Зерттеу аралас әдістерге негізделген эксперименттік емес сипаттамалық-аналитикалық дизайн арқылы жүргізілді. Сандық деректер Қазақстанның әртүрлі өңірлерінен қатысқан 151 физика мұғаліміне арналған онлайн сауалнама арқылы жиналды. Сапалық деректер алты мұғаліммен өткізілген жартылай құрылымдалған сұхбаттар және құжаттарды талдау арқылы толықтырылды. Нәтижелер цифрлық және жасанды интеллектке негізделген құралдардың мұғалімдер тәжірибесінде қолданылып жатқанын, бірақ олардың қолданылуы әлі де таңдамалы, біркелкі емес және мұғалім құзыреттілігіне, дайындыққа, инфрақұрылымға, оқу бағдарламасының икемділігіне және мектеп қолдауына тәуелді екенін көрсетті.

Зерттеу теориялық тұрғыдан цифрлық интеграция модельдерін физика біліміне бейімдеуге, ал практикалық тұрғыдан мұғалімдерге, мектептерге, даярлау бағдарламаларына және саясаткерлерге ұсыныстар беруге үлес қосады.

Түйін сөздер: цифрлық технологиялар, физика білімі, мұғалім құзыреттілігі, цифрлық интеграция, кедергілер, Қазақстан, аралас әдістер

Аннотация

Данная диссертация посвящена изучению барьеров интеграции цифровых технологий в профессиональную практику учителей физики в общеобразовательных школах Казахстана. Исследование рассматривает разрыв между национальной политикой цифровизации и реальной практикой использования цифровых инструментов на уроках. В физике особенно важны визуализация, моделирование, экспериментирование и понятийное мышление, поэтому цифровые технологии должны быть связаны с предметной методикой преподавания.

В исследовании использован неэкспериментальный описательно-аналитический дизайн с применением смешанных методов. Количественные данные были собраны с помощью онлайн-опроса 151 учителя физики из разных регионов Казахстана. Качественные данные получены посредством полуструктурированных интервью с шестью учителями и анализа документов. Результаты показали, что цифровые и AI-инструменты уже используются в педагогической практике, однако их применение остается выборочным, неравномерным и зависит от компетентности учителей, подготовки, инфраструктуры, гибкости учебной программы и институциональной поддержки.

Теоретическая значимость исследования состоит в адаптации моделей цифровой интеграции к физическому образованию, а практическая значимость — в разработке рекомендаций для учителей, школ, программ подготовки педагогов и образовательных политиков.

Ключевые слова: цифровые технологии, физическое образование, компетентность учителя, цифровая интеграция, барьеры, Казахстан, смешанные методы

1. Introduction

1.1 Relevance of the Study and Problem Statement

In recent decades, the accelerating digital transformation has profoundly influenced educational systems worldwide, reshaping how knowledge is transmitted, acquired, and applied. The integration of digital technologies into formal schooling, ranging from interactive simulations and virtual laboratories to digital assessment tools, has become not merely a trend but a normative expectation in the modernization of teaching practices. Within this global shift, the subject of physics, by virtue of its reliance on abstract modeling and empirical experimentation, is particularly well-positioned to benefit from digital tools that can simulate complex phenomena, visualize invisible processes, and foster active student engagement. The reality on the ground in many national contexts reveals a persistent and often widening gap between the potential of digitalization and its practical enactment in the classroom.

In Kazakhstan, a country committed to modernizing its education system through strategic initiatives such as the Digital Kazakhstan program (Ministry of Digital Development, 2018) and ongoing updates to the State Compulsory Education Standards (MoES RK, 2020), there has been measurable progress in terms of digital infrastructure development and policy alignment. Empirical observations indicate that these macro-level advancements do not always translate into meaningful pedagogical change at the micro-level. In the domain of secondary school physics education, the integration of digital technologies remains uneven, fragmented, and at times superficial (Katayev et al., 2023). Teachers often face a constellation of challenges, including insufficient professional development, inadequate access to reliable equipment, limited time for curricular adaptation, and, crucially, a lack of confidence in their digital-pedagogical competence.

While international frameworks such as UNESCO's ICT Competency Framework for Teachers (UNESCO, 2018) and OECD's TALIS reports (OECD, 2019) underscore the importance of digital literacy and pedagogical adaptation, these global models must be interpreted through the lens of local contexts. In Kazakhstan, current

research into subject-specific digital integration remains limited, particularly with respect to physics educators. The few existing studies tend to adopt a generalist approach to digitalization, overlooking the distinctive cognitive, methodological, and epistemological demands of teaching physics (Sadu et al., 2022). This lack of targeted inquiry has resulted in a situation where policymakers and school administrators possess insufficient data to design interventions that are responsive to the unique barriers encountered by physics teachers in their professional practice.

The prevailing understanding of «barriers» often focuses disproportionately on material or infrastructural deficits, while underestimating the complex interplay of psychological, organizational, and curricular factors that influence technology adoption. Teachers' digital competence must be reconceptualized not simply as technical proficiency but as a multidimensional construct involving critical judgment, instructional design, and the capacity to align digital tools with learning outcomes. Without this nuanced understanding, initiatives aimed at digital integration risk becoming technocratic in nature, prioritizing tools over pedagogy and innovation over sustainability.

Given these unresolved tensions, this study addresses an urgent research gap by examining the specific obstacles physics teachers in Kazakhstan encounter when attempting to embed digital technologies into their instructional routines. Through a mixed-methods approach encompassing survey research, semi-structured interviews, and document analysis, the study aims to generate a context-sensitive, evidence-based understanding of how digital integration unfolds in practice. The relevance of this investigation lies in its potential to inform national education strategies, support teacher professional development, and contribute to a more coherent and pedagogically grounded model of digital transformation in the teaching of physics.

1.2 Purpose and Objectives of the Research

The accelerating pace of digital transformation in education has generated heightened expectations regarding the role of technology in enhancing the quality and accessibility of instruction across disciplines. Physics education today is undergoing

significant change. It offers strong potential for digital enhancement through simulations, modeling tools, and virtual experiments. At the same time, it remains pedagogically challenging. This is because physics relies heavily on abstract concepts, experimental logic, and the need for clear conceptual visualization. While Kazakhstan has made strategic investments in national programs such as «Digital Kazakhstan» and has updated its State Compulsory Educational Standards to include ICT integration, current practices in secondary school physics classrooms often lag behind policy intentions. This disconnect between reform rhetoric and implementation realities underpins the rationale for the present research.

The primary purpose of this study is to investigate the nature and scope of barriers that impede the effective integration of digital technologies into the professional practice of physics teachers in general education schools of Kazakhstan. This goal arises from an important recognition. Simply providing digital tools does not guarantee their meaningful use. Successful integration depends on teachers' digital-pedagogical competence. It also requires strong institutional support. Digital resources must be adaptable to the didactic needs of each subject. The study aims not only to identify the challenges but to understand their underlying causes and the broader systemic conditions that enable or constrain digital innovation in physics instruction.

To address this overarching aim, the research pursues several interrelated objectives:

1. It seeks to examine how physics teachers perceive and engage with digital technologies within their professional context, including the attitudes, beliefs, and expectations that shape their practices.

2. It aims to analyze the institutional and curricular conditions that influence the availability, accessibility, and pedagogical relevance of digital tools in the teaching of physics.

3. The study investigates how national policies and school-level administrative strategies either facilitate or hinder the development of subject-specific digital competence among teachers.

4. The research aspires to propose a set of grounded, context-sensitive recommendations for overcoming identified barriers, thereby contributing to the development of a more coherent model for digital pedagogy in science education.

By focusing on the physics discipline, where technological enhancement is both theoretically promising and practically problematic, this study contributes to filling an important gap in the literature. Existing international research often treats digital integration as a generic challenge, without sufficient attention to the epistemological and methodological particularities of individual subjects. In the Kazakhstani context, such differentiation is especially lacking, with few studies addressing the unique challenges faced by science educators in technology-rich or resource-constrained environments. Consequently, this research positions itself at the intersection of subject didactics, digital transformation, and educational policy, seeking not only to diagnose barriers but also to inform practice and decision-making in ways that are directly responsive to the needs of teachers and learners in the physics classroom.

1.3 Research Questions

This study is focused on examining the barriers that hinder the effective integration of digital technologies into the professional practice of physics teachers in general education schools in Kazakhstan. Given the subject-specific characteristics of physics education, as well as the institutional and curricular conditions within which teachers operate, the research adopts a contextualized approach to the analysis of digital technology use. The study seeks to explore these barriers not in isolation, but as interrelated factors shaped by teachers' professional competence, school-level support structures, and curriculum requirements.

The research is guided by the following central research question: What specific barriers do physics teachers in Kazakhstan's general education schools encounter when integrating digital technologies into their professional practice, and how do these barriers reflect the interaction between individual digital-pedagogical competence, institutional context, and curricular expectations?

To further elaborate this inquiry, the study addresses the following secondary research question: How do physics teachers perceive the pedagogical value of digital technologies in relation to the subject-specific content and cognitive demands of physics education?

These research questions provide a structured framework for investigating the pedagogical, institutional, and disciplinary dimensions of digital technology integration in physics teaching. They also serve as a basis for the selection of research methods and data analysis procedures, enabling an empirically grounded examination of teachers' practices, perceptions, and the conditions influencing digital transformation at the classroom level.

1.4 Theoretical and Practical Significance

The integration of digital technologies into education has evolved from being a peripheral innovation to a structural necessity in the 21st century. While global academic discourse increasingly emphasizes models of digital pedagogy, such as TPACK (Technological Pedagogical Content Knowledge) and DigCompEdu (European Framework for the Digital Competence of Educators), a critical gap persists in their application to discipline-specific contexts, particularly in the exact sciences. These models often provide a generalized framework for assessing and developing teachers' digital competence but they frequently underrepresent the distinct epistemological and methodological requirements of teaching physics. The present study addresses this limitation by focusing on the subject-specific realities of integrating digital tools into physics education in general secondary schools of Kazakhstan, thereby contributing to the theoretical refinement of digital pedagogy within STEM disciplines.

The research advances theoretical understanding by reconceptualizing digital competence not merely as a set of technical or procedural skills but as an embedded dimension of disciplinary teaching practice. In the case of physics, this involves interpreting abstract concepts, modeling physical processes, conducting experiments, and fostering scientific reasoning, activities that demand digital tools tailored to high

levels of cognitive engagement. By foregrounding the professional agency of physics teachers within institutional, curricular, and cultural constraints, the study contributes to a more nuanced theoretical model of technology adoption. It challenges the linear, tool-driven assumptions of many integration frameworks and proposes a more dynamic, context-sensitive view, one that recognizes the role of teacher belief systems, school leadership, and national policy in shaping digital practices.

On a practical level, the study offers timely and locally relevant insights for multiple stakeholders involved in Kazakhstan's ongoing educational modernization. For education policymakers, it highlights the discrepancy between digital strategy documents, such as the «Digital Kazakhstan» initiative and the State Program for Education Development, and the actual conditions under which teachers operate in schools. These findings may inform more targeted policy interventions that go beyond infrastructural provision to include context-appropriate professional development and curriculum adaptation. For school administrators, the study identifies organizational factors, such as leadership style, scheduling flexibility, and internal culture, that either support or inhibit sustainable digital integration. The research holds value for practicing physics teachers, offering them a reflective framework to better understand their own experiences with digital tools, and to locate these experiences within broader pedagogical and institutional narratives.

The empirical findings of the study are expected to support the development of a practical resource: a set of methodological recommendations, tailored specifically to physics education, that address identified barriers and support the meaningful use of digital technologies. This resource can be used to design professional learning programs that are aligned with subject content, responsive to local school realities, and grounded in current international research. In this way, the study aims not only to theorize digital pedagogy in the context of physics education but also to contribute concretely to its realization in the classroom, thereby supporting a more coherent and sustainable approach to digital transformation within Kazakhstan's secondary education system.

1.5 Scientific Novelty

The scientific novelty of this study is rooted in its interdisciplinary and context-sensitive approach to analyzing how digital technologies are integrated into the teaching of physics in public schools in Kazakhstan. While global research has extensively addressed digitalization in education, most existing studies remain generalized across disciplines or focused on technologically advanced countries. The present work concentrates specifically on the subject of physics, known for its high level of abstraction, reliance on modeling and experimentation, and demand for conceptual visualization, and examines how digital tools interact with its unique didactic structure. This disciplinary focus is rarely operationalized in research conducted in the post-Soviet or Central Asian educational space, which significantly enhances the regional and thematic originality of the study.

One of the principal contributions lies in the development of an analytical framework that categorizes barriers to digital integration not merely as infrastructural or technical deficits but as multi-layered systemic constraints. These include cognitive misalignments between digital tools and disciplinary logic, institutional mismatches between teacher expectations and administrative support, and epistemic tensions in the adaptation of virtual environments to experimental physics instruction. Such a framework enables a shift from conventional deficit-based models to a more holistic conceptualization of resistance to technology, wherein pedagogical meaning, not just access, becomes central.

The study introduces methodological innovation by applying a discipline-specific mixed-methods design, combining survey data with qualitative interviews and document analysis, while maintaining a tight focus on a single subject domain. In doing so, the research captures not only general tendencies but also the nuanced experiences of physics teachers working within the constraints of the national curriculum. For example, the study includes analysis of how teachers use platforms such as PhET Interactive Simulations, GeoGebra, or virtual labs integrated into e-learning systems,

highlighting subject-specific adoption patterns often absent from broader ICT integration literature.

Equally significant is the study's contribution to the underexplored empirical base concerning Kazakhstan's education system. Despite ambitious digital transformation initiatives such as the «Digital Kazakhstan» program and the State Program for Education Development, academic literature on the real conditions of digital pedagogy in Kazakhstani subject classrooms remains sparse. A preliminary scan of international databases reveals a noticeable deficit of peer-reviewed publications addressing the integration of digital tools in physics education across Central Asia.

The originality of this dissertation lies in its subject-specific theorization, contextual framing, and empirically supported critique of mainstream models of digital integration. It contributes not only to a deeper understanding of how digital technologies intersect with physics pedagogy but also to the global conversation about the conditions under which educational reforms achieve meaningful classroom impact, particularly in national systems undergoing systemic modernization.

1.6 Structure of the Dissertation

The structure of this dissertation reflects the internal logic of the research process and is aligned with the requirements of a problem-oriented inquiry situated within the contemporary context of educational digitalization. It is designed to provide a coherent, progressive, and methodologically grounded framework for exploring the integration of digital technologies into the teaching of physics in general secondary schools in Kazakhstan. Each chapter contributes to the gradual unfolding of the research argument, from the articulation of the problem to the synthesis of empirical results and formulation of evidence-based recommendations.

The introductory chapter establishes the relevance of the research and defines the conceptual space in which the study is located. It presents the problem statement, research objectives and questions, and discusses the theoretical, practical, and scientific significance of the topic. This is followed by a comprehensive literature review in Chapter 2, which examines global and local scholarship on digital pedagogy, teacher

digital competence, and models of technology integration such as TPACK, SAMR, and DigCompEdu. Special attention is given to how these frameworks align with the realities of physics education in Kazakhstan. Many of these frameworks were developed in Western or generalized contexts. It is important to examine whether they correspond to local disciplinary and institutional conditions. It is equally important to identify where they fail to correspond. This chapter also addresses the lack of subject-specific research on digital transformation in STEM education, thereby framing the niche that the current study seeks to fill.

Chapter 3 is devoted to the research methodology and provides a detailed justification for the mixed-methods design. It outlines the tools and procedures used to collect and analyze data, including surveys, semi-structured interviews, and document analysis. The choice of methods is explained not only from a practical standpoint, but also in light of the research aim to capture both the general patterns and the deeper meanings underlying teachers' digital practices. Ethical considerations, sampling procedures, and data validation strategies are also addressed to ensure transparency and academic rigor.

Chapter 4 presents the results of the empirical investigation. Quantitative findings from the survey are used to map out the frequency, typology, and perceived value of digital technology use among physics teachers. These are then complemented by qualitative insights derived from interviews, allowing for a contextualized interpretation of barriers, enabling factors, and pedagogical attitudes. The analysis is situated within the broader theoretical frameworks introduced earlier, and particular attention is given to subject-specific dynamics, for instance, how digital simulations are used or not used in teaching abstract topics such as electromagnetism or quantum phenomena.

The final chapter synthesizes the main findings and interprets them in relation to the research questions and objectives. It offers practical recommendations for teacher professional development, school administration strategies, and policy-level adjustments. The chapter reflects on the limitations of the study and outlines directions

for future research, particularly in developing locally sensitive, subject-specific models of digital pedagogy. The structure as a whole is not only sequential but also reflective, ensuring that theoretical and empirical components are continuously linked, and that each stage contributes meaningfully to the overall research trajectory.

2. Literature Review

2.1 Theoretical Foundations: Digital Technology and Pedagogical Models

Digital transformation in education has shifted from a technical enhancement narrative to one grounded in pedagogical restructuring, epistemological inquiry, and systemic reform. Early conceptualizations were often premised on the assumption that the mere introduction of digital tools would inherently improve educational outcomes. Okojie, Olinzock, and Okojie-Boulder (2006) challenged this instrumentalist view by emphasizing that the meaningful integration of technology must be rooted in pedagogical purpose. They argue that technology becomes educationally valuable only when its use aligns with specific learning objectives, theoretical underpinnings, and disciplinary methods. This shift in focus, from tools to teaching, has laid the foundation for more complex, theory-informed approaches to digital transformation, which position the educator as an active designer of technology-mediated learning rather than a passive adopter of digital innovations.

Against the backdrop of growing global enthusiasm for educational technology, recent critiques have emerged to temper overconfidence in the transformative promises of digital tools. Facer and Selwyn (2021), writing for UNESCO, propose the concept of "non-stupid optimism" to describe a critical yet hopeful stance toward the future of digital education. They caution against narratives that treat digital transformation as inevitable, depoliticized, and universally beneficial. They argue for a contextualized and reflective approach that foregrounds ethical, cultural, and social dimensions. In regions such as Kazakhstan, where educational reforms are often influenced by imported frameworks and global benchmarks, this perspective is particularly relevant. It invites educators and policymakers to interrogate the assumptions underlying digitalization efforts and to engage with transformation as a site of contested values, priorities, and identities.

One of the central challenges in evaluating digital transformation lies in determining what constitutes "enhancement." Kirkwood and Price (2014) interrogate

the widespread but vague claim that digital tools “enhance” teaching and learning. Through a comprehensive review, they demonstrate that without a clear articulation of pedagogical goals, the use of technology can result in superficial change or even pedagogical regression. For example, they argue that the mere digitization of traditional tasks, such as delivering lectures or assigning worksheets, does not equate to transformation. True enhancement involves fostering deeper understanding, promoting learner autonomy, and enabling novel forms of interaction that were previously impossible. This insight is especially critical in physics education, where technological tools must be evaluated not by their novelty but by their ability to support the cognitive processes involved in conceptual modeling, abstract reasoning, and experimental logic.

Further enriching the theoretical landscape, Tang, Huang, and Yan (2025) offer a systems-level framework for understanding digital transformation in higher education, which is equally applicable to general education. They argue that digital change is most effective when it is embedded within three interrelated domains: strategic vision, pedagogical innovation, and organizational culture. Their framework moves beyond linear models of change and instead conceptualizes transformation as an iterative, context-sensitive process shaped by leadership practices, faculty engagement, and infrastructural capacity. Importantly, they also identify barriers to successful implementation, such as fragmented leadership, teacher overload, and resistance to change, all of which resonate with the realities of education systems undergoing modernization, including Kazakhstan. Their work provides a necessary reminder that technological tools alone cannot catalyze transformation; rather, institutional readiness and pedagogical coherence are equally vital.

Complementing this systems-oriented perspective, Väätäjä and Ruokamo (2021) propose a multi-dimensional model of digital pedagogy that synthesizes technological, cognitive, and social dimensions of teaching and learning. They reject the view of digital pedagogy as merely the digital replication of existing instructional methods and instead conceptualize it as a reimagining of pedagogical relationships, learning environments, and knowledge construction. Their model emphasizes learner agency,

the affordances of digital tools, and the intentional design of learning experiences. These components interact dynamically, shaping the conditions under which meaningful digital learning occurs. In science education, particularly physics, this model aligns well with inquiry-based and student-centered approaches, which require learners to actively construct understanding through exploration, simulation, and reflection.

Technological overviews, such as that by Haleem et al. (2022), further contextualize the discussion by examining emerging digital technologies and their implications for pedagogy. From artificial intelligence to virtual reality and adaptive learning systems, the authors outline both the potential benefits and inherent challenges of digital adoption. They emphasize that without thoughtful integration, digital tools risk exacerbating educational inequities or creating new layers of complexity for educators. Their findings support a growing consensus that successful digital transformation is contingent not on the mere availability of tools, but on the presence of robust professional development, curriculum alignment, and inclusive design principles. These insights are particularly significant in resource-variable settings, where implementation often outpaces pedagogical support.

A subject-specific perspective is provided by Allanazarov (2025), who explores how digital technologies intersect with the unique demands of physics education. He asserts that physics, as a discipline grounded in abstraction, modeling, and empirical reasoning, poses distinct challenges and opportunities for digital pedagogy. Tools such as simulations and virtual laboratories can enrich conceptual understanding, but only if they are epistemologically aligned with the logic of the subject. Allanazarov warns that generic or poorly contextualized technologies may undermine learning by oversimplifying complex phenomena or detaching students from experimental reasoning. His work underscores the necessity of discipline-sensitive integration, where digital tools are adapted not only to curricular objectives but also to the cognitive architecture of the subject.

Table 2.1. *Comparative Overview of Conceptual Models of Digital Transformation in Education*

Model	Core Premise	Dimensions Considered	Limitations
Pedagogical Alignment Model	Technology should serve pedagogical objectives and be aligned with content.	Pedagogy, content, technology	Lacks subject-specific examples and empirical validation.
"Non-Stupid Optimism" Perspective	Advocates critical optimism, embedding digital transformation in sociopolitical context.	Policy, ethics, historical context	Too abstract; lacks concrete implementation strategies.
Critique of Enhancement Rhetoric	Questions vague claims of "enhancement" and calls for alignment with learning goals.	Learning outcomes, instructional design	Limited focus on disciplinary specificity.
Systemic Change Framework	Digital transformation must integrate strategy, pedagogy, and institutional culture.	Strategic vision, innovation, institutional readiness	Contextual scope focused mainly on higher education.
Digital Pedagogy Dimensions Model	Digital pedagogy involves cognitive, social, and technological interplay.	Learner agency, digital tools, intentional design	Limited focus on subject-specific instructional strategies.
Emerging Tech Impact Review	Explores the role of AI, VR, and adaptive tools in shaping educational practice.	Technological innovation, equity, usability	Lacks connection to curriculum and teacher practice.
Physics-Specific Integration Framework	Emphasizes epistemological alignment of digital tools with physics instruction.	Visualization, modeling, experimental logic	Theoretical in nature; empirical grounding remains minimal.

Note: This table is author-generated based on synthesis and interpretation of the cited literature.

The continuously evolving discourse on digital education has yielded a range of pedagogical models aimed at explaining how teachers can effectively integrate

technology into their instructional practices. One of the most influential among these is the Technological Pedagogical Content Knowledge (TPACK) model, conceptualized by Koehler and Mishra (2009). This framework proposes that proficient teaching with technology requires an intricate synthesis of three core knowledge domains: content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK). Rather than treating these domains as separate or additive, TPACK emphasizes their dynamic interplay, suggesting that the most effective educational strategies emerge when teachers can fluidly navigate the intersections between them. While the model has been widely adopted in teacher education and research, its practical application has generated debate. As noted in Schmid et al. (2024), much of the empirical work invoking TPACK struggles to operationalize its constructs with consistency or measurable outcomes. Although the model's conceptual depth is undisputed, its use in real-world classrooms often lacks clarity, which limits its transformative potential. This highlights a broader issue in the field: conceptual models that appear robust in theory often fail to translate seamlessly into practice without context-sensitive adjustments.

In response to such critiques, Gatete (2025) revisits the TPACK model and proposes a refined, contextually extended version tailored to the demands of the digital age. While acknowledging the foundational value of TPACK, Gatete argues that the original framework does not sufficiently address the complex realities educators now face, particularly regarding data ethics, digital citizenship, and socio-cultural literacy. He introduces a fourth dimension, contextual and ethical knowledge, designed to encompass the new competencies required for navigating digitally mediated educational environments. This includes awareness of algorithmic bias, data privacy, and platform politics, all of which increasingly affect how teachers choose and apply digital tools. The relevance of Gatete's work is especially clear in subject-specific domains like physics, where tools such as simulations or modeling software must align with both disciplinary epistemologies and institutional constraints. His proposal thus moves the discourse beyond a static triadic model toward a more fluid, responsive framework that can evolve alongside the rapidly shifting educational landscape.

Parallel to TPACK, the SAMR model, Substitution, Augmentation, Modification, Redefinition, has gained popularity for its intuitive classification of technology use in terms of transformational potential. Originally introduced by Ruben Puentedura, and later critically reviewed by Hamilton, Rosenberg, and Akcaoglu (2016), SAMR organizes digital tool integration into four ascending levels, encouraging teachers to progress from simple substitution of traditional tasks toward redefining learning experiences. Its simplicity has also drawn criticism. Hamilton et al. argue that SAMR risks promoting a deterministic view of technology in which "higher" levels are seen as inherently superior, regardless of pedagogical context. This perspective can be particularly problematic in content-heavy and cognitively complex subjects like physics, where augmentation, such as replacing physical lab tools with virtual simulators, may offer the optimal balance of accessibility, safety, and conceptual clarity. The SAMR model's lack of theoretical underpinning and absence of subject specificity weaken its utility as a stand-alone guide for digital pedagogy. Rather than serving as a prescriptive hierarchy, SAMR may be better understood as a descriptive lens through which to reflect on and evaluate design decisions.

Broadening the scope, the European Commission's DigCompEdu framework (Redecker & Punie, 2017) offers a comprehensive approach to educator digital competence that extends beyond instructional design. It identifies six domains of professional practice, including digital resources, assessment strategies, and learner empowerment, while embedding technology integration within wider institutional and ethical concerns. Unlike TPACK and SAMR, which primarily focus on the teacher's cognitive architecture and instructional behavior, DigCompEdu views educators as agents of digital culture who shape how learning communities engage with technology. This is especially relevant in systems undergoing policy-driven digital reforms, such as Kazakhstan, where the quality of digital integration is as much about systemic alignment and professional capacity-building as it is about individual tool usage. The framework's generalist orientation can be both a strength and a limitation: while it facilitates broad applicability across educational levels and disciplines, it may lack the

granularity required for fields like physics education, where integration decisions must consider epistemic demands such as experimental reasoning and abstract modeling.

In addition to teacher-focused models, learner-centered perspectives have also gained prominence. The ICAP framework by Chi and Wylie (2014) shifts the analytical lens from teacher actions to student cognitive engagement, positing that learning outcomes improve as learners move from Passive to Active, Constructive, and Interactive modes of engagement. The framework is especially useful in digital contexts, where superficial interactivity often masks passive consumption. ICAP challenges educators to evaluate not only whether technology is used, but how it supports deeper forms of thinking and learning. In physics education, for instance, simulations may be cognitively passive if students merely observe animations without interpreting or manipulating variables. Interactive activities that require prediction, experimentation, and argumentation can activate higher-order thinking aligned with disciplinary goals. ICAP complements models like TPACK by providing a means of assessing whether pedagogical strategies are successfully fostering deep engagement in digital environments.

The review by Chai, Koh, and Tsai (2013) reinforces the necessity of context-aware applications of these models. Their meta-analysis of TPACK literature finds that many studies neglect to tailor the framework to specific subjects or cultural environments, thereby limiting its effectiveness. They advocate for a shift toward co-design approaches in which researchers collaborate with practitioners to adapt models in real-time to localized needs. In this view, pedagogical models should not be treated as fixed structures, but as evolving frameworks responsive to feedback and grounded in empirical realities. For Kazakhstan's educational landscape, where digital reforms often emerge from centralized initiatives, this insight is vital. Without subject-specific adaptation and bottom-up validation, even the most theoretically robust models risk becoming top-down prescriptions disconnected from the lived realities of classrooms, particularly in specialized subjects like physics that involve unique representational systems and experimental methods.

Table 2.2 provides a comparative overview of the main pedagogical models discussed in this section, demonstrating how each addresses various aspects of technology integration, from teacher knowledge to student engagement. The table also demonstrates that while these models individually make valuable contributions, their combined application, adapted to specific subject areas, such as physics, offers the most pedagogically coherent approach to meaningful digital transformation.

Table 2.2. *Comparative Analysis of Pedagogical Models of Technology Integration*

Model	Focus Area	Key Components	Strengths	Limitations
TPACK	Teacher knowledge	Technology, Pedagogy, Content (and their intersections)	Integrates multiple knowledge domains; flexible	Hard to operationalize; lacks context sensitivity
Extended TPACK	Teacher knowledge + Contextual awareness	Adds ethics, data literacy, sociocultural dimensions	Responds to 21st-century challenges	Still developing; limited empirical application
SAMR	Level of technology use	Substitution → Augmentation → Modification → Redefinition	Simple, intuitive; useful for reflection	Lacks theoretical grounding; hierarchical oversimplification
DigCompEdu	Digital competence of educators	6 competence areas incl. engagement, assessment, empowerment	Broad systemic view; policy-aligned	Generalist; limited subject-specific application
ICAP	Learner engagement	Passive, Active, Constructive, Interactive modes	Direct link to cognitive outcomes	Less focus on teacher role or instructional design

Note: Table 2.2 is author-generated based on synthesis and critical interpretation of the cited literature.

The landscape of pedagogical models for technology integration is rich yet complex, offering educators various conceptual tools to navigate digital teaching. While TPACK provides a foundational understanding of teacher knowledge, its limitations in context sensitivity have inspired new models such as Gatete's expansion and DigCompEdu's institutional perspective. SAMR offers a straightforward framework but oversimplifies pedagogical nuance, while ICAP re-centers attention on student cognition and engagement. Each model contributes valuable insights, but none is sufficient in isolation. For digital integration to be meaningful, particularly in physics education within contexts like Kazakhstan, educators must adopt a critical, adaptive approach, drawing selectively from multiple models and tailoring their application to disciplinary logic, institutional culture, and learner needs.

The integration of digital technologies into physics education requires a distinctly subject-oriented pedagogical approach, grounded in the epistemological and cognitive characteristics unique to the discipline. Unlike many other subjects in the school curriculum, physics is conceptually dense, abstract in nature, and heavily reliant on mathematical modeling and empirical validation. These attributes create instructional demands that go beyond generic digital tool use, necessitating pedagogical strategies and technologies that can simulate invisible phenomena, support conceptual visualization, and replicate or enhance experimental inquiry. As such, effective digital pedagogy in physics cannot rely solely on general models of technology integration but must be aligned with the representational forms, reasoning patterns, and investigative practices that define the subject. The literature reviewed in this section reveals that when digital tools, particularly simulations, are thoughtfully embedded within instructional frameworks that reflect the disciplinary logic of physics, they can significantly improve both learning outcomes and student engagement.

A foundational empirical contribution to this area was made by Finkelstein et al. (2005), who investigated whether computer simulations could replace physical equipment in introductory physics laboratories without compromising learning quality. Their findings revealed that students who used simulations performed as well as, or in

some instances better than, those in traditional labs, particularly in terms of conceptual understanding. The authors emphasized that simulations, when designed to reflect the underlying scientific models, allow learners to focus on the relationships and mechanisms at play rather than on operational details or procedural constraints. This shift from physical manipulation to cognitive modeling challenges traditional assumptions about the irreplaceability of real laboratory experiences. Their research also advanced the argument that educational value in physics experimentation lies not in the tangibility of instruments but in the epistemic engagement with physical systems, an insight that has since informed much of the research on digital learning environments in physics.

Building on these insights, Banda and Nzabahimana (2021) conducted a comprehensive literature review focused on the impact of PhET simulations on students' conceptual development. The review concluded that such simulations are particularly effective in facilitating the understanding of complex, abstract concepts, especially those involving processes that are difficult to observe directly, such as electromagnetic fields or wave propagation. The authors noted that the pedagogical impact of simulations was strongest when they were incorporated into inquiry-based learning contexts that encourage students to make predictions, manipulate variables, and reflect on outcomes. This approach aligns with constructivist learning theories and supports cognitive engagement at the "constructive" and "interactive" levels as described in the ICAP framework (Chi & Wylie, 2014). Their work thus reinforces the view that technology integration in physics must go beyond functional substitution and be strategically embedded in instructional designs that activate higher-order thinking and epistemic reasoning.

In a subsequent empirical study, Banda and Nzabahimana (2023) further explored the impact of PhET simulations on both academic performance and student motivation among secondary school learners in Malawi. Their findings revealed notable gains in both domains, suggesting that digital simulations can serve not only as effective tools for cognitive development but also as catalysts for learner

engagement and confidence. This dual impact is particularly significant in contexts where physical laboratories are under-resourced or inaccessible. By offering immersive, low-cost alternatives to traditional experiments, simulations make it possible for students to experience inquiry processes that would otherwise be unavailable. The study also highlighted the critical mediating role of the teacher: without pedagogical guidance and scaffolding, the educational potential of simulations may be diminished. This insight underscores the necessity of viewing digital tools not as self-sufficient solutions but as components within a broader pedagogical system that includes curriculum alignment, teacher expertise, and assessment strategies.

The question of how students interact with simulations at the conceptual level is further addressed by Batuyong and Antonio (2018), whose study examined the use of PhET-based activities in teaching electromagnetism. Their findings demonstrate that interactive simulations can help students bridge the gap between formal equations and intuitive understanding by enabling them to visualize forces, fields, and motion in real time. Students reported that these tools allowed them to test ideas, identify misconceptions, and develop deeper insight through exploration and feedback. The study emphasized that simulations were not merely visual aids but environments for active sense-making and hypothesis testing. This repositions the role of digital tools in physics instruction, from supplementary media to dynamic cognitive scaffolds, and reflects a broader shift toward student-centered, exploratory learning designs in STEM education.

The comparative effectiveness of virtual and real laboratories has also been a focus of research, particularly in higher education. Farrokhnia and Esmailpour (2018) investigated learning outcomes among undergraduate students studying DC circuits and found that a hybrid model combining real and virtual experimentation produced the most comprehensive results. While real labs were valuable for developing procedural and hands-on skills, virtual labs were more effective in enhancing conceptual clarity and minimizing cognitive overload. These findings suggest that neither format is inherently superior; rather, each offers unique pedagogical advantages

that, when combined, provide a more holistic learning experience. In the context of physics education, where conceptual understanding and experimental practice are equally essential, hybrid approaches appear particularly promising. They also resonate with contemporary calls for instructional flexibility and the thoughtful integration of technology to support differentiated learning pathways.

Turning to the local context of Kazakhstan, Kushekkaliev and Anesova (2025) offer an important perspective on the realities of implementing digital pedagogy in secondary school physics classrooms. Their study points to persistent challenges such as limited access to resources, lack of teacher training, and curriculum rigidity, which inhibit the effective adoption of digital tools despite increasing awareness of their potential benefits. They emphasize the need for localized digital content that aligns with national educational standards and reflects the linguistic and cultural context of Kazakhstani learners. Without such alignment, even the most promising technologies risk becoming misaligned with classroom realities, thus undermining their educational impact. Their analysis supports the argument that digital pedagogy must be not only subject-specific but also context-sensitive, shaped by the interplay between systemic conditions, teacher agency, and curricular frameworks.

Allanazarov (2023) provides a comprehensive overview of digital tools used in physics education, including simulations, video resources, online testing platforms, and virtual labs. He argues that while the proliferation of digital tools offers new pedagogical possibilities, their effectiveness depends on careful selection, coherent integration, and thoughtful instructional design. In particular, he warns that excessive or fragmented tool use, uncoordinated with curricular goals, can result in cognitive overload and reduced learning efficacy. He advocates for a strategic approach in which each tool is mapped to specific pedagogical functions, such as conceptual visualization, formative assessment, or experimental modeling. His perspective echoes broader educational research that cautions against tool-centric implementation and instead promotes the design of digital learning ecosystems that support student cognition, engagement, and epistemic growth.

As synthesized in Table 2.3, different digital tools fulfill distinct pedagogical roles within physics education. Their effectiveness depends not only on technological design but also on how well they align with specific disciplinary goals, such as visualizing non-observable phenomena, conducting experimental reasoning, or supporting conceptual modeling. A tool like PhET, for example, is not merely a visualization aid but an inquiry environment that supports hypothesis testing and dynamic feedback, especially in abstract domains like electromagnetism and wave motion.

Table 2.3. *Pedagogical Functions of Digital Tools in Physics Education*

Digital Tool / Method	Key Function in Physics Pedagogy	Disciplinary Focus	Pedagogical Strengths	Limitations / Requirements
PhET Simulations	Visualization of abstract processes	Electromagnetism, Waves, Mechanics	Enhances conceptual understanding; supports interactive inquiry	Requires scaffolding; alignment with learning goals
Virtual Labs	Experiment modeling	Circuits, Motion, Energy	Safe, cost-effective; supports data interpretation	Limited tactile skills; needs prior conceptual prep
Video Demonstrations	Observational learning	Kinematics, Optics	Supports flipped learning; aids in pre-lab prep	Passive if not followed by active tasks
Online Assessments	Formative and summative feedback	All topics	Immediate feedback; tracks progress	Needs calibration for conceptual depth

Comprehensive Platforms (e.g., LMS with simulations)	Integrated content delivery	Mixed topics	Structured progression; combines tools	Risk of cognitive overload without design coherence

Note: Table 2.3 is author-developed based on interpretation of the reviewed literature.

Digital pedagogy in physics is most impactful when it reflects the disciplinary demands of the subject, namely, abstraction, experimentation, and modeling. The reviewed literature consistently shows that digital simulations, particularly when implemented through inquiry-based approaches and supported by pedagogical scaffolding, can significantly enhance both conceptual understanding and student motivation. The success of these interventions is contingent on a range of contextual factors, including teacher capacity, curricular flexibility, and the availability of localized resources. In countries like Kazakhstan, where educational modernization is often driven by national policy initiatives, it is essential that digital transformation efforts in physics education go beyond infrastructure development to include subject-specific design, teacher empowerment, and culturally responsive practices.

2.2 Teachers' Digital Competence: International Studies and Barriers

The emergence of digital competence as a core component of modern teaching has reshaped international educational policy and research agendas, prompting a re-examination of what it means to be a digitally competent educator in the 21st century. Far from being a static list of technical skills, digital competence is now increasingly conceptualized as a dynamic and multidimensional construct that integrates technological knowledge with pedagogical reasoning, reflective practice, and ethical awareness. At the global level, organizations such as UNESCO and the European Commission have developed comprehensive frameworks aimed at guiding both teacher education and professional development initiatives. These frameworks serve

not only as aspirational blueprints but also as strategic instruments for aligning national education systems with the evolving demands of digitally enriched learning environments.

UNESCO's ICT Competency Framework for Teachers (ICT-CFT) (2018) offers a policy-oriented model that articulates three progressive approaches to ICT integration in education: technology literacy, knowledge deepening, and knowledge creation. Each level corresponds to different systemic goals, ranging from equipping teachers with basic operational skills to enabling them to innovate pedagogical practices and foster collaborative learning. The framework is notable for situating teacher digital competence within broader processes of curriculum reform, assessment modernization, and institutional change. Despite its comprehensiveness, it remains abstract and policy-heavy, making classroom-level operationalization challenging, especially in subject-specific domains such as physics, where digital tools must be carefully matched to conceptual and experimental content.

Complementing UNESCO's macro-level focus, the DigCompEdu framework (Redecker, 2017) offers a more practice-oriented model that disaggregates digital competence into six interrelated areas: professional engagement, digital resources, teaching and learning, assessment, learner empowerment, and facilitating learners' digital competence. Designed for applicability at both the individual and institutional levels, DigCompEdu includes progression stages that range from novice to innovator, thereby supporting both diagnostic self-assessment and structured professional growth. Caena and Redecker (2019) argue that DigCompEdu is well-aligned with the realities of contemporary classrooms, particularly in hybrid and digitally mediated environments. Unlike ICT-CFT, which focuses on systemic change, DigCompEdu emphasizes pedagogical intentionality, enabling educators to make informed decisions about technology use in specific teaching contexts. The successful adoption of DigCompEdu still hinges on teacher training programs and institutional support systems capable of translating its principles into localized practice, something that remains unevenly distributed globally.

Empirical studies reinforce the importance of embedding such frameworks into teacher education. The OECD's TALIS 2018 report (OECD, 2019) reveals that while teachers across countries increasingly recognize the value of digital technologies, a significant proportion still report low confidence in their ability to integrate these tools effectively. The disparity is particularly pronounced when examined across different socioeconomic and infrastructural contexts, with teachers in well-resourced systems reporting greater preparedness than those in lower-income settings. This evidences a persistent gap between policy ambition and classroom reality. The report indicates that digital competence development is rarely embedded into ongoing professional learning in a systematic way, leading to ad hoc and often superficial implementations.

Research on pre-service and in-service training further illustrates the fragmented nature of digital competence development. Napal Fraile et al. (2018), analyzing teacher training in European contexts, emphasize that while digital tools are present in curricula, they are often introduced without sufficient pedagogical framing. As a result, prospective teachers may gain exposure to technology but lack a deep understanding of how to use it meaningfully to support learning. Benali, Kaddouri, and Azzimani (2018), in a study of Moroccan English teachers, arrive at similar conclusions, noting that despite favorable attitudes toward technology, teachers frequently encounter barriers such as insufficient infrastructure, lack of support, and minimal subject-specific guidance. These findings underscore that digital competence must be cultivated not only through access to technology but through sustained, context-sensitive professional development grounded in instructional relevance.

Recent contributions have called for a critical re-evaluation of existing frameworks to ensure their adaptability to diverse educational ecosystems. Rakisheva and Witt (2023), in a systematic literature review, highlight both convergence and fragmentation in the way digital competence is defined and operationalized. While there is broad agreement on core areas, such as digital resource evaluation, online collaboration, and data literacy, there is less consensus on how these competencies should be taught, assessed, or contextualized. The authors argue that successful

framework adoption depends on flexibility, allowing for adaptation to local cultures, languages, and subject-specific pedagogies. They also caution against over-technocratic interpretations of competence that prioritize tool mastery over pedagogical depth, a critique particularly relevant for content-heavy subjects like physics, where the integration of technology must be epistemologically grounded.

International research frames teacher digital competence as a critical and evolving dimension of professional practice, shaped by global imperatives yet deeply contingent on local implementation. Frameworks such as UNESCO's ICT-CFT and DigCompEdu offer complementary visions: one oriented toward systemic reform, the other toward classroom-level pedagogy. Both require robust support systems, coherent teacher education, and cultural adaptability to be effective. For educational systems like Kazakhstan's, which are actively pursuing digital modernization, these frameworks offer valuable guidance, but their success depends on how well they are localized, embedded into teacher training, and aligned with disciplinary realities.

Table 2.4. *Comparative Overview of International Frameworks for Teachers' Digital Competence*

Framework	Focus Level	Core Structure	Key Strengths	Limitations
ICT-CFT	Macro (policy level)	3 approaches: Technology Literacy, Knowledge Deepening, Knowledge Creation	Aligns with system-wide educational reform; globally recognized	Abstract; difficult to operationalize at classroom level
DigCompEdu	Micro (classroom & teacher level)	6 areas: Professional Engagement, Digital Resources, Teaching & Learning, Assessment, Learner Empowerment, Facilitating Learners' Digital Competence	Practice-oriented; includes progression levels; adaptable	Requires strong institutional support for implementation

TALIS Findings	Comparative survey data	Teacher self-perception and training experience	Empirical evidence across countries; policy-informing	No specific competence model; descriptive, not prescriptive
Critical Review	Meta-level	Comparative synthesis across frameworks	Highlights convergence and gaps; calls for local adaptability	No unified model; relies on secondary literature

Note: Table 2.4 is author-developed based on the synthesis and critical interpretation of the cited frameworks and literature.

As summarized in Table 2.4, the reviewed international frameworks differ in their focus, structural complexity, and applicability. While UNESCO's ICT-CFT provides a global policy orientation, DigCompEdu offers a detailed progression model grounded in classroom practice. The OECD's TALIS data further contextualize these frameworks through large-scale teacher self-reporting, while Rakisheva and Witt's meta-review underscores the necessity of adapting such frameworks to local and disciplinary conditions.

The integration of digital technologies into educational practice, while increasingly prioritized in policy and reform discourse, continues to be hindered by a diverse set of interrelated barriers. Scholarly literature over the past two decades has extensively examined these challenges, producing increasingly nuanced typologies that aim to systematize understanding and guide strategic interventions. The most enduring distinction remains the classification of barriers into first-order (extrinsic) and second-order (intrinsic) types. Contemporary research critiques the reductive nature of this binary, highlighting the dynamic interplay between individual, institutional, curricular, and systemic factors. This section synthesizes international perspectives on the

evolving typology of barriers, with particular attention to how such frameworks inform context-sensitive digital integration in education.

Hew and Brush's (2007) seminal review provides a foundational structure for categorizing integration barriers into six domains: resources, knowledge and skills, institutional support, teacher attitudes and beliefs, assessment practices, and subject-specific constraints. Their model emphasizes that technical access alone does not ensure meaningful technology use; instead, pedagogical transformation requires cultural and institutional alignment. Importantly, they note that certain barriers, such as limited content-specific tools or rigid curricula, may be especially acute in disciplines like physics, where technology must support abstract reasoning and modeling rather than rote content delivery. The lasting relevance of this framework lies in its holistic perspective, bridging infrastructural issues with pedagogical and epistemological concerns.

Building upon this, Bingimlas (2009) reiterates the utility of the first-order versus second-order distinction but underscores the interdependence of these categories. While first-order barriers include hardware availability, internet connectivity, and training access, second-order barriers reflect teachers' values, confidence, and openness to pedagogical change. The entanglement of these barriers is particularly visible in STEM education, where even well-resourced environments may see low adoption rates if teachers perceive digital tools as misaligned with disciplinary rigor. Bingimlas emphasizes that addressing only external factors, without fostering belief change and instructional support, leads to limited and unsustainable outcomes.

Buabeng-Andoh (2012) extends the discussion by examining the influence of systemic and policy-level contexts. His review highlights how school leadership, national curriculum frameworks, and accountability systems shape teachers' perceived autonomy and risk tolerance in adopting digital methods. Even when individual teachers are motivated and skilled, structural constraints, such as time allocation, assessment pressures, or lack of policy coherence, can significantly inhibit integration. In physics education where conceptual understanding is cumulative and assessment-

driven, rigid syllabi may discourage exploratory or simulation-based learning, even when digital tools are available and valued.

A more integrated and culturally responsive perspective is presented by Tosuntaş, Çubukçu, and İnci (2019), who propose a five-dimensional model of barriers: personal, institutional, technological, instructional, and cultural. Their qualitative data reveal that factors such as fear of failure, hierarchical school culture, and the absence of collaborative communities often contribute to teacher hesitation. This is particularly relevant in subjects like physics, where traditional authority structures and content transmission norms dominate classroom practices. The authors argue that digital integration is not only a technical shift but a cultural transformation, requiring changes in how knowledge is constructed, shared, and evaluated within disciplinary communities.

Contrary to assumptions that technological access has rendered first-order barriers obsolete, Abedi and Ackah-Jnr (2023) demonstrate that material constraints remain a significant impediment in many contexts. Their multi-stakeholder study confirms that infrastructure limitations, intermittent power supply, and insufficient technical support continue to undermine teacher motivation and capacity. They highlight a cyclical relationship wherein persistent first-order barriers erode confidence and reinforce second-order resistance. This dynamic is observable in resource-constrained physics classrooms, where repeated technical disruptions may lead teachers to revert to analog methods, thereby limiting student exposure to visualization or modeling technologies critical for abstract conceptualization.

Joshi and Khatiwada's (2024) systematic review introduces a multilayered framework that categorizes barriers into technological, individual, institutional, and curricular layers. Of particular interest is their emphasis on curriculum as both a barrier and enabler of digital integration. In rigid, exam-oriented systems, the lack of flexibility to adapt teaching methods to include simulations or interactive tools restricts innovation. This insight holds strong implications for physics education, where conceptual depth and experimental logic are often difficult to reconcile with time-

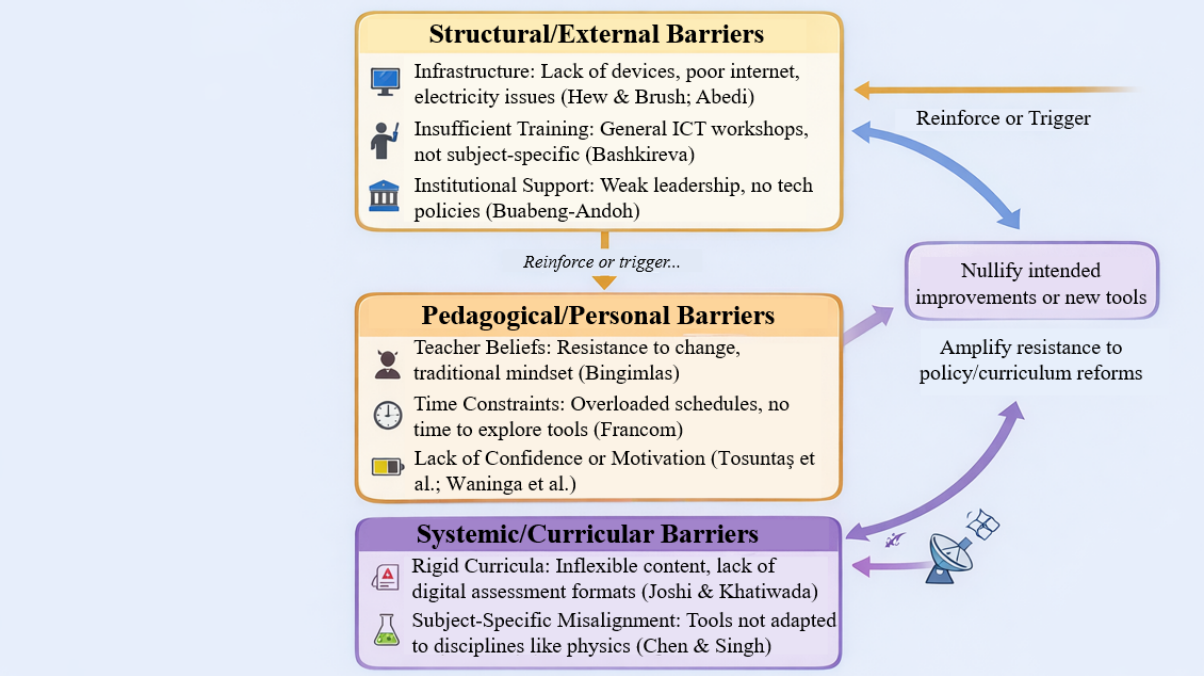
bound, assessment-driven instruction. The authors advocate for curricular redesign that embeds digital pedagogy into learning standards, thereby legitimizing its use and creating space for subject-specific adaptations.

Adding a temporal dimension, Francom (2020) analyzes how teachers' perceptions of barriers evolve over time. His longitudinal study shows that while some access issues have diminished, new challenges, such as time constraints, professional burnout, and the absence of sustained institutional commitment, have emerged as dominant obstacles. Teachers report feeling overwhelmed by the need to continuously update their digital skills without sufficient planning time or peer support. In physics teaching, where the integration of simulations or modeling tools often demands significant preparation and content alignment, such temporal pressures can make digital innovation unsustainable unless long-term support structures are in place.

Figure 2.1 presents a multi-level typology of barriers to digital integration in education. The diagram illustrates the interdependence of structural, pedagogical, and systemic issues, creating a complex ecosystem of resistance to technology use.

In synthesizing these perspectives, it becomes evident that barriers to digital integration are not static or uniform but multifaceted and context-dependent. Early typologies, while still relevant, must now be understood within broader systemic, cultural, and curricular ecosystems. For physics education in particular, where the didactic demands are complex and the cognitive load of learners is high, integration barriers intersect with deeper questions of epistemology and pedagogy. This study adopts a multidimensional understanding of these barriers, recognizing that overcoming resistance requires not only resolving technical limitations or shifting teacher attitudes, but also reimagining how digital tools align with disciplinary knowledge, instructional goals, and institutional priorities.

Figure 2.1. Multilayered Typology of Barriers to Digital Integration in Education



Note: Visual developed by the author based on an analysis of seven international studies.

The integration of digital technologies in science education, particularly in physics, presents a distinctive constellation of challenges that extend beyond general ICT barriers. Unlike many other subjects, physics requires the development of abstract conceptual reasoning, the use of visual models, and the manipulation of experimental systems, all of which pose unique demands on digital pedagogy. While technology has the potential to enhance physics instruction through simulations, data visualization, and virtual laboratories, international research demonstrates that these tools are often underutilized or misaligned with curricular structures and classroom realities. The literature consistently emphasizes that digital integration in physics is not merely a matter of access but involves deeper epistemological, pedagogical, and cultural dimensions that shape both teacher practices and student experiences.

Pokhrel (2024) highlights that physics teachers often recognize the instructional value of digital simulations, particularly for visualizing non-observable phenomena

such as electromagnetic fields or wave interactions. He also finds that integration is limited by a lack of specialized training, misalignment with assessment-driven curricula, and a prevailing perception of physics as a discipline that is resistant to pedagogical innovation. These factors discourage risk-taking and experimentation with digital formats, reinforcing a cycle in which traditional didactic methods persist. Yehya, Barbar, and Abou Rjeily (2018) offer similar insights from Lebanese secondary schools, where physics teachers reported difficulty finding subject-specific digital content, as well as confusion over how to evaluate learning outcomes produced through digital means. The authors emphasize the need for curricular reform that legitimizes digital instruction as a valid component of scientific teaching and assessment.

From a sociocultural perspective, Waninga et al. (2024) draw attention to the intersection of technological and gender-based barriers in physics teacher education. Their study in Ugandan training institutions reveals that female pre-service teachers face lower digital confidence and less mentorship support, particularly in physics, which remains culturally coded as abstract and male-dominated. This dynamic suggests that digital exclusion in physics education is reinforced not only by infrastructural or pedagogical deficits but by entrenched perceptions of who belongs in the discipline. Addressing such barriers requires inclusive training strategies that empower underrepresented groups to engage with both the content and tools of physics education. These findings also raise critical questions about equity and representation in STEM digitalization initiatives.

Chen and Singh (2025) add a cognitive dimension to the analysis by exploring how physics educators often struggle to align digital tools with the epistemological structures of the discipline. Their research shows that while educators have access to a wide array of technologies, many lack the pedagogical frameworks necessary to select tools that reinforce scientific reasoning rather than distract from it. This is particularly problematic in physics, where conceptual clarity is paramount, and the misuse of simulations or animations can lead to misconceptions. The authors advocate for a

“design-first” model of integration, where technology serves pedagogical goals grounded in the logic of disciplinary thinking.

In contexts of geographic or socioeconomic marginalization, Levy et al. (2025) report that digital instruction in science frequently fails to replicate the experimental and relational dimensions of classroom-based physics learning. Their study on distance learning models in underserved regions reveals that students often perceive virtual physics education as impersonal and disconnected, leading to disengagement. For physics, a subject that relies heavily on hands-on experimentation and peer interaction, this mode of delivery requires adaptation. The authors recommend blended approaches that integrate low-tech, locally contextualized materials with digital content to maintain engagement and experiential depth in resource-constrained settings.

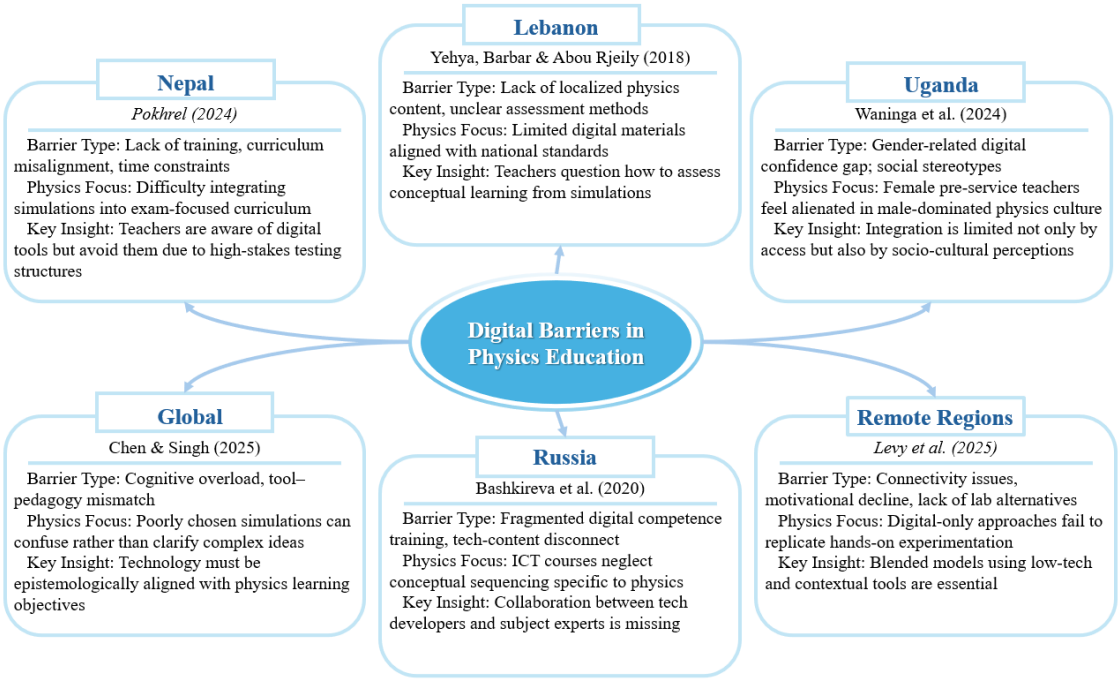
Bashkireva et al. (2020) emphasize the foundational role of digital competence among science educators as a prerequisite for effective integration. Their study critiques the generic nature of ICT training in many teacher preparation programs, arguing that without subject-specific digital pedagogies, tools are often perceived as externally imposed or irrelevant. They point to the lack of collaboration between content specialists and technology designers as a structural barrier, especially in disciplines like physics where learning progression depends on precise sequencing and representation of concepts.

Figure 2.2 provides a context map summarizing country-specific research on barriers to integrating digital technologies into physics teaching.

In synthesizing these perspectives, it becomes clear that digital barriers in physics education are multifaceted and deeply embedded in the disciplinary, institutional, and sociocultural fabric of teaching. Unlike general ICT challenges, physics-specific barriers involve not only access and training but also legitimacy, curricular alignment, cognitive design, and inclusion. This study builds on these insights to examine how such barriers are experienced by physics teachers in Kazakhstan’s general education schools, with a focus on how digital integration interacts with national curricular standards, teacher preparation, and subject-specific

instructional norms. Understanding these layered dynamics is essential for developing informed strategies that support both technological and pedagogical innovation in physics education.

Figure 2.2. Contextual Map of Digital Integration Barriers in Physics Education



Note: Visual developed by the author based on the reviewed literature.

Chapter 2.2 has provided a multi-dimensional exploration of the factors influencing the integration of digital technologies by teachers, emphasizing both global frameworks and subject-specific realities. The section critically examined international models of digital competence, outlined the evolving typologies of barriers, ranging from structural and pedagogical to systemic, and highlighted how these challenges manifest uniquely in the context of science and physics education. It demonstrated that effective digital integration is not solely dependent on access to technology but requires alignment with teacher beliefs, institutional structures, curricular flexibility, and discipline-specific pedagogical strategies. These insights collectively justify the need

for context-aware and subject-sensitive approaches to digital transformation in education, particularly for complex domains like physics.

2.3 The Kazakhstani Context: Policy, Standards, and Empirical Studies

Kazakhstan's commitment to digitalizing its education system has been articulated through a range of legislative and strategic policy instruments that aim to align the country with global technological and pedagogical trends. The foundational legal document in this regard is the 2015 Law “On Informatization,” which outlines the principles and mechanisms for ICT integration across sectors, including education. This law established the state’s responsibility in ensuring digital infrastructure, regulating information security, and creating the necessary conditions for informatization at all levels of education. Its highly technocratic orientation tends to emphasize infrastructure over pedagogy, leaving underdeveloped the question of how digitalization should translate into subject-specific teaching strategies. For disciplines such as physics, where digital tools must support conceptual modeling and experimental thinking, this gap presents a significant limitation for practical implementation.

In response to the need for curriculum-level reforms, the Ministry of Education and Science issued Order No. 348 in 2022, which introduced mandatory subjects such as “Digital Literacy” and “ICT” into the state education standards. These additions mark a formal recognition of digital competence as a core component of general education. Yet, the standards provide limited guidance on how digital skills should be pedagogically embedded within specific subjects, particularly in science education. While the flexibility given to schools to interpret the standards is commendable, it also results in highly uneven application, especially in under-resourced or rural settings where digital readiness varies considerably. For physics education, the lack of centralized recommendations on how to integrate simulations, virtual labs, or modeling tools means that digitalization often remains peripheral rather than transformative.

This national picture is further nuanced by international assessments such as the UNESCO IITE (2025) report, which critically evaluates Kazakhstan’s progress in

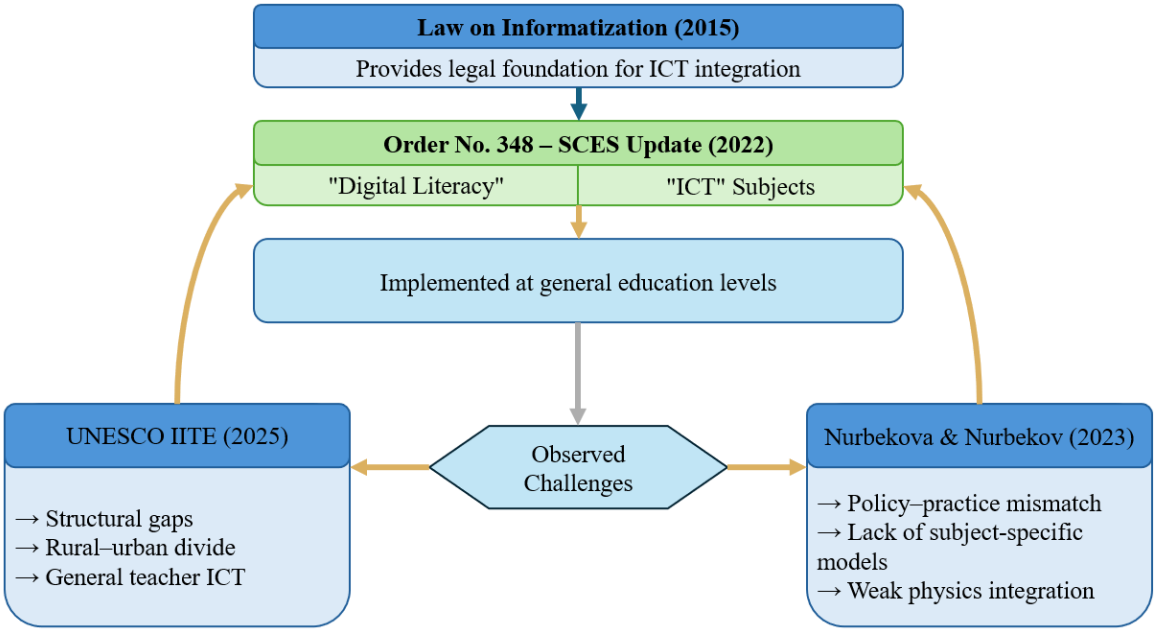
developing ICT skills within its education sector. The report acknowledges achievements such as widespread connectivity in urban schools and the institutionalization of digital subjects, but it also identifies persistent challenges: rural–urban disparities in access, inconsistent teacher training in digital pedagogy, and insufficient evaluation mechanisms for measuring authentic digital competencies. Importantly, UNESCO emphasizes the need for a shift from infrastructure provision toward the cultivation of meaningful, context-sensitive digital teaching practices, particularly within STEM fields like physics, where abstract reasoning and experimentation are central to learning.

Complementing this external view, Nurbekova and Nurbekov (2023) offer a national scholarly critique, highlighting the discrepancy between macro-level policy initiatives and micro-level classroom realities. Their study reveals that while Kazakhstan has made significant strides in digital education reform, implementation is hindered by outdated equipment, inadequate technical support, and limited subject-specific teacher training. Particularly in physics education, digital tools are often perceived as supplementary rather than integral due to a lack of alignment between national strategies and disciplinary epistemologies. The authors argue that without clearer frameworks connecting national standards to the cognitive and methodological requirements of subjects like physics, the potential of digital transformation will remain unrealized in actual teaching practice.

Figure 2.3 provides a schematic overview of the national policy ecosystem for educational digitalization in Kazakhstan. These sources illustrate that while Kazakhstan has laid a solid legislative and structural foundation for educational digitalization, significant gaps remain in bridging policy with pedagogical application. The legal recognition of digital competencies and the inclusion of ICT subjects into curricula are important milestones. Effective implementation, especially in complex and abstract disciplines like physics, requires policies that not only provide infrastructure but also support teacher capacity, offer subject-specific integration models, and promote equity in access and application. This study builds on these

insights by examining how national policies are perceived and operationalized by physics teachers in general education schools in Kazakhstan, with the aim of identifying the conditions under which digital tools can enhance rather than merely supplement disciplinary teaching.

Figure 2.3. Policy Ecosystem of Educational Digitalization in Kazakhstan



Note: Visual developed by the author based on legal sources and scholarly analysis.

Empirical research on the use of digital technologies in Kazakhstani schools provides a multifaceted view of how national policy ambitions translate into pedagogical realities. While legislative frameworks and curricular reforms have underscored the importance of digital integration, studies indicate that actual classroom practices often fall short of systemic goals, particularly in subject-specific contexts such as physics education. The literature reflects both structural achievements, including infrastructure expansion and formal digital literacy instruction, and persistent challenges related to teacher preparedness, curricular alignment, and the depth of digital pedagogy.

Abdullaeva and Zhanatbekova (2025) offer a rare subject-specific exploration focused on the didactic purposes of ICT in physics lessons. Their findings highlight a utilitarian use of digital tools, primarily to visualize complex phenomena or demonstrate experiments, rather than as instruments for inquiry-based or constructivist learning. Although digital simulations are recognized for their illustrative potential, their integration often lacks alignment with deeper learning outcomes such as critical thinking or scientific reasoning. This suggests a gap between tool availability and pedagogical application, exacerbated by limited methodological training among physics teachers and the absence of subject-tailored digital strategies in curriculum documents.

Expanding this discussion, Abiltayeva et al. (2025) examine the perceptions of pre-service biology teachers, revealing a generally positive disposition toward digital tools but a lack of confidence in embedding them meaningfully into instructional design. Despite differences between biology and physics, both disciplines require visualization and experimental thinking, making the findings transferable in key aspects. Amiresheva et al. (2025) further contextualize teacher readiness using the TPACK framework, showing that while future teachers possess basic technological and content knowledge, the pedagogical integration of these domains remains underdeveloped. Interestingly, science-related disciplines exhibited slightly higher self-reported confidence, yet without corresponding instructional coherence, a gap that is especially problematic for physics, where abstract reasoning demands a high degree of conceptual scaffolding.

Kerimbayeva et al. (2024) contribute a broader institutional and communicative lens, arguing that digital competence must extend beyond tool operation to include digital collaboration, media interaction, and ethical engagement. Their findings suggest that while teacher candidates can navigate digital platforms, they often lack the strategic awareness to design meaningful learning experiences. This critique aligns with Yeleussiz and Qanay (2025), who demonstrate that despite supportive policies, media literacy and critical digital use remain inconsistently embedded in school

practices. Teachers report a lack of clear frameworks for integrating media literacy into disciplinary instruction, especially in subjects like physics where curricular rigidity and high-stakes assessments may limit pedagogical flexibility.

Historical studies by Sapargaliyev (2012) and Nurmukhametov et al. (2015) offer important longitudinal context. Both works emphasize that Kazakhstan's early e-learning initiatives prioritized access and infrastructure over pedagogy, leading to fragmented development. Although dated, these studies underscore that longstanding barriers, such as digital inequality, low institutional support, and insufficient teacher training, persist into the present, particularly in rural or resource-constrained settings. The implications for physics education are significant, as the subject often relies on laboratory infrastructure, modeling software, and continuous feedback, all of which require stable digital ecosystems and informed instructional design.

The empirical literature reveals a national context in which digitalization is both a policy mandate and a pedagogical challenge. While schools are increasingly equipped with digital resources, their pedagogical integration remains inconsistent, especially in content-heavy and cognitively demanding subjects like physics. A recurring theme is the limited ability of teachers, both pre-service and in-service, to align technological tools with subject-specific learning goals. This study builds on these findings by focusing on how digital technologies are used by physics teachers in Kazakhstani general education schools, aiming to identify not only the structural barriers but also the instructional opportunities that emerge in practice.

As summarized in Table 2.5, empirical studies across Kazakhstan highlight consistent challenges in translating digital access into meaningful educational practice. Contemporary research into Kazakhstan's digital education reforms reveals a widening gap between national ambitions and pedagogical realities at the subject level. While infrastructure development and digital literacy have become policy priorities, the empirical literature indicates that classroom-level integration, particularly in science and physics education, remains under-theorized and inconsistently applied. Kuchumova and Mukhamejanova (2025) argue that one of the structural challenges

lies in the absence of a research-based culture within teacher education. Though digital tools are formally introduced in training programs, their pedagogical application is often fragmented or superficial.

Table 2.5. *Empirical Evidence on Digital Technology Use in Kazakhstani Schools*

Applied Framework	Focus Area	Discipline	Key Findings	Barriers Identified
Didactic Goals of ICT	ICT usage in physics lessons	Physics	ICT supports visualization, but lacks integration into inquiry-based learning	Limited methodological training; absence of subject-specific integration models
TPACK	Pre-service teacher digital readiness	Science education	Basic technological and content knowledge present, but weak pedagogical linkage	Deficiency in structured instructional design for digital integration
Digital Integration Attitudes	Teacher perceptions of ICT in practice	Biology	Positive attitudes toward technology, uncertainty in instructional embedding	Inadequate confidence and experience in integrating ICT into lessons
Networked Communicative Culture	Digital literacy and collaboration	Cross-discipline	Functional skills are present; lacks strategic and reflective use	Insufficient emphasis on ethical, communicative, and collaborative dimensions
Media Literacy Policy	Policy-to-practice translation	Cross-discipline	Weak curricular embedding of digital/media literacy into subject teaching	Absence of clear guidelines and institutional support
Historical ICT Development	E-learning evolution and adoption stages	General education	Initial focus on infrastructure over pedagogy	Sustainability concerns; limited

				relevance to classroom realities
Distance Education Constraints	Online learning infrastructure and practice	General education	Infrastructure developed, but pedagogy underutilized	Low teacher engagement; lack of localized digital resources

Note: Table 2.5 is author-developed based on comparative analysis of the reviewed empirical literature.

This is especially problematic for physics educators, who require a solid methodological grounding to leverage digital technologies for abstract conceptual learning and experimental modeling. Without research-informed instructional strategies, digital tools risk being reduced to peripheral add-ons, rather than functioning as integral elements of physics pedagogy.

This misalignment is further reflected in the findings of Nurbekova and Nurbekov (2023), who note that Kazakhstan's policy frameworks often emphasize digital access and infrastructure over subject-sensitive implementation. Their critique underscores a systemic oversight: while policies support generalized ICT integration, they rarely address how digital tools can be meaningfully aligned with the epistemological structures of individual disciplines. In physics education, this is particularly critical. The rigid nature of national curricula and assessment regimes often constrains innovation, leaving teachers with little flexibility to adapt technologies to their instructional contexts. One of the key research gaps is not simply the presence or absence of digital tools, but the lack of scaffolding that would allow teachers to use them in discipline-relevant ways that enhance student understanding of complex scientific phenomena.

Maimakova et al. (2025) add a forward-looking dimension to this discussion by exploring the integration of artificial intelligence (AI) into education. While AI offers promising applications, such as personalized feedback and adaptive content delivery,

its current implementation in Kazakhstan is still nascent. The authors argue that in the absence of foundational pedagogical infrastructure and digital fluency among educators, AI risks being deployed in inequitable or pedagogically incoherent ways. Particularly in subjects like physics, where the logic of learning is built upon sequential conceptual development, any technological enhancement must be tightly integrated with subject-matter pedagogy. This highlights the necessity of a conceptual framework that links emerging technologies to classroom-level practice in a coherent and evidence-based manner.

The issue of teacher readiness is further illuminated by Yermekova et al. (2025), who apply the DigCompEdu framework to assess the digital competence of future educators. Their study finds that while many pre-service teachers demonstrate basic operational skills, higher-order competencies, such as digital assessment strategies, learner empowerment, and content-specific tool selection, remain underdeveloped. The study lacks disciplinary disaggregation, which obscures how such competencies differ across subjects like physics, where visualization, simulation, and experimental modeling play central roles. This omission points to another significant research gap: the absence of subject-specific metrics or benchmarks for evaluating digital competence within the broader national framework.

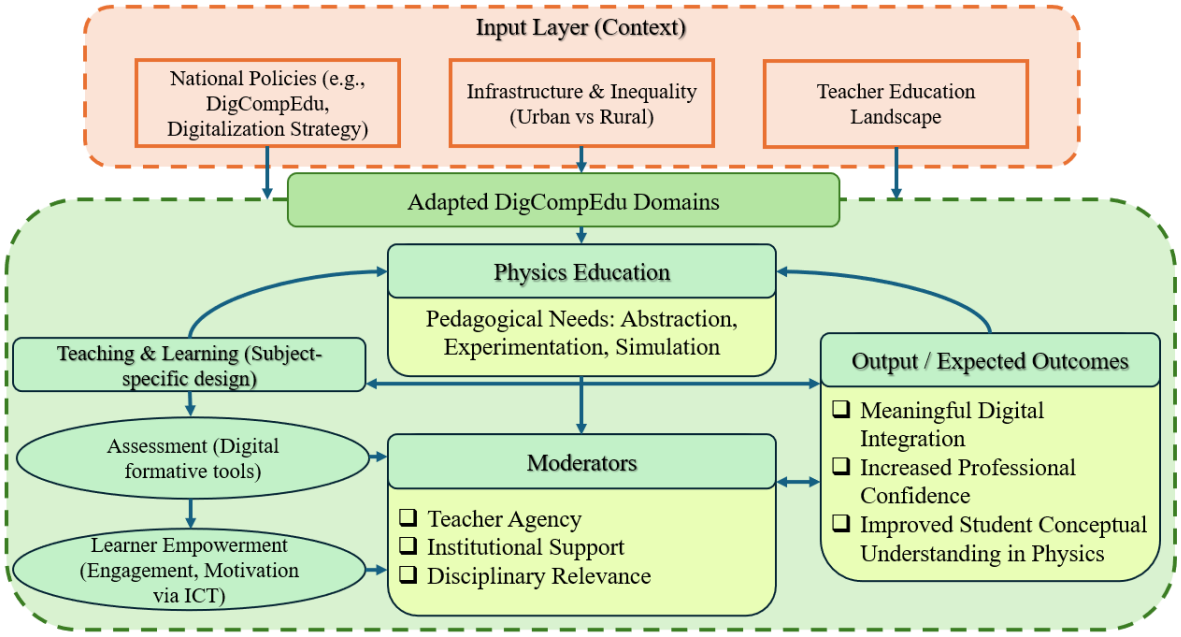
Nurbayev's (2021) policy analysis draws attention to the socio-spatial disparities that persist between urban and rural schools in Kazakhstan. These inequities are particularly consequential in physics education, where access to physical labs is limited and digital tools could serve as viable alternatives, if deployed effectively. The literature reveals little targeted inquiry into how infrastructure disparities affect subject-specific digital practices. Addressing these gaps requires more than policy reform; it demands localized, empirical research that explores how digital integration unfolds within the pedagogical realities of different school environments and subject areas.

As illustrated in the adapted conceptual model (Figure 2.4), this study synthesizes policy context, disciplinary pedagogy, and teacher competence into a

unified analytical framework that guides the exploration of digital integration practices among physics educators.

In light of these findings, the present study proposes a conceptual framework adapted from DigCompEdu, with particular emphasis on the domains of teaching and learning, assessment, and learner empowerment. These domains are contextualized within the specific pedagogical demands of physics education in Kazakhstan's general education system. The framework also accounts for structural and contextual variables, including policy coherence, institutional support, and geographic inequality, thus providing a multidimensional lens through which to examine digital integration. By situating this research at the intersection of national policy, teacher preparation, and subject-specific practice, the study aims to generate actionable insights into the conditions that enable or hinder the effective use of digital technologies in physics teaching.

Figure 2.4. Adapted Conceptual Framework for Digital Integration in Physics Education in Kazakhstan



Note: This conceptual framework is author-developed based on the adaptation of DigCompEdu to the disciplinary and contextual needs of physics education in Kazakhstan.

Chapter 2.3 has critically examined the national context of digital education in Kazakhstan, revealing both policy-level advancements and persistent implementation challenges. While legal frameworks and strategic initiatives such as the integration of ICT and digital literacy into state standards demonstrate a strong institutional commitment, empirical studies highlight uneven digital practices across schools, insufficient subject-specific teacher preparation, and marked rural-urban disparities. These gaps are particularly evident in disciplines like physics, where digital tools must support complex cognitive processes and experimental learning. The chapter concludes by proposing an adapted conceptual framework that bridges national policy, teacher competence, and disciplinary pedagogy, laying the foundation for the present study's exploration of digital technology integration in physics education.

3. Research Methodology and Empirical Basis

3.1 Research Design and Methodological Approaches

This study uses a non experimental, descriptive analytical design within a mixed methods framework. It examines a naturally occurring educational issue, namely the barriers that physics teachers in Kazakhstan face when integrating digital technologies into their professional practice. The purpose is not to test an intervention. It is to understand how digital integration is experienced in real school settings and what limits its effective use. A non experimental design is appropriate because the study investigates existing conditions rather than changing them. The descriptive analytical orientation suits the aim of identifying recurring patterns and interpreting them in relation to broader pedagogical, institutional, and curricular factors.

A mixed methods approach was selected because the research problem is complex and cannot be captured through one type of evidence alone. Digital integration in physics teaching is not simply a matter of access to tools or frequency of use. It also involves teachers' digital pedagogical competence, the demands of subject specific instruction, school level support, and the policy context that shapes classroom practice. The literature reviewed in Chapter 2 shows that barriers to digital integration are layered and interconnected. In physics education, the issue is even more complex because the subject depends on abstraction, modelling, experimentation, and conceptual visualisation. For that reason, the study combines quantitative and qualitative methods in order to capture both broad patterns and the meanings teachers attach to them.

The quantitative component is based on survey research. The survey was used to identify patterns in teachers' use of digital and AI related tools, their views of pedagogical usefulness, and the difficulties they encounter in classroom practice. Its main function in the design is diagnostic. It provides a broad picture of how digital integration is perceived and enacted across a larger group of respondents. In this dissertation, artificial intelligence is treated as one of the most visible and rapidly developing forms of digital technology in school practice. Its inclusion does not narrow

the study to AI alone. It provides a focused empirical entry point for examining wider issues of digital integration in physics teaching.

The qualitative component includes semi structured interviews and document analysis. The interviews deepen the survey findings by exploring how teachers explain their choices, how they describe subject specific difficulties, and how they evaluate the possibilities and limits of digital tools in physics instruction. Document analysis places these accounts within the wider institutional and regulatory context of Kazakhstani schooling. This includes curriculum documents, digitalisation policies, and relevant methodological materials. Taken together, the three methods strengthen the study through methodological triangulation. They make it possible to examine digital integration in physics education as a practice shaped by teacher agency, disciplinary logic, institutional conditions, and national reform priorities.

3.2 Data Collection Methods and Research Participants

3.2.1 Survey Method

The survey was the main instrument used to collect quantitative data for this study. It was designed to document how physics teachers in Kazakhstan use digital technologies in their professional practice, how they judge their instructional value, and what obstacles they face when trying to incorporate them into teaching. In the overall research design, the survey provided the broad empirical base of the study. Its purpose was to identify recurring patterns across a larger group of teachers rather than to test the effect of a specific intervention.

The survey included 151 secondary school physics teachers from different regions of Kazakhstan. The sample brought together teachers working in public and private schools and reflected variation in professional experience and teaching format. Participants were recruited through purposive and snowball sampling. This strategy was chosen because the study required respondents who were actively teaching physics at the secondary level and who had direct experience with digital tools in educational settings. The goal was not to produce a statistically representative national sample. The

goal was to gather relevant evidence from teachers whose professional experience could speak directly to the problem under investigation.

Data were collected through a structured online questionnaire created in Google Forms. To make participation more accessible, the instrument was offered in Kazakh, Russian, and English. Its design was guided by the research questions, the conceptual focus of the dissertation, and the empirical materials already developed for the study. The questionnaire combined several types of items. These included demographic and professional background questions, frequency based items, Likert type evaluations, multiple response items, and open ended questions. This structure allowed the study to gather standardized data suitable for quantitative analysis while also leaving room for brief written comments that could support later interpretation. Some items focused specifically on artificial intelligence. In this dissertation, these items are treated as part of the wider field of digital technologies, since AI tools have become one of the most visible forms of digital innovation in school teaching practice.

The structure of the survey instrument is summarised in Table 3.1.

Table 3.1. *Structure of the Survey Instrument*

Section	Focus Area	Type of Items	Purpose in the Study
Section A	Demographic and professional information	Categorical items	To describe the profile of the respondents
Section B	Experience with AI and digital tools	Frequency and multiple-response items	To identify patterns of technology use
Section C	Perceived usefulness of AI	Likert-type scale items	To assess teachers' views on instructional value
Section D	Barriers and challenges	Multiple-response items	To identify perceived constraints to integration
Section E	Impact and future perspectives	Multiple-response and open-ended items	To examine expectations and possible pedagogical change

The questionnaire was organised into five main sections. The first section collected demographic and professional information such as gender, age, academic degree, teaching experience, school type, and instructional format. The second section focused on teachers' use of digital and AI related tools in physics teaching. The third section examined perceived usefulness across key instructional tasks, including lesson preparation, explanation of complex topics, assessment, feedback, and individual support. The fourth section addressed barriers to integration, including lack of knowledge, limited training, technical constraints, and institutional conditions. The fifth section invited open ended responses on teachers' experiences, concerns, and expectations regarding the future role of digital technologies in physics education. This structure made it possible to examine both actual use and perceived constraints, which were central to the aims of the study.

Before the main stage of data collection, the instrument went through a preliminary validation process. Three specialists in educational technology and science pedagogy reviewed the questionnaire to assess its face validity. A pilot test was then conducted with 10 respondents. Minor revisions were made to improve wording, clarity, and the order of items. The final version of the survey was distributed during the spring semester of 2025 and remained open for four weeks. Invitations were shared through email, professional networks, educational events, and online platforms used by teachers. These procedures supported the practical feasibility of the study and helped ensure that the instrument was appropriate to the educational context under investigation.

3.2.2 Interview Method

Interviews were included to extend the survey findings. The survey identified broad patterns in teachers' use of digital technologies and in their views of the barriers involved. It could not show how teachers made sense of those experiences in their own practice. For that reason, semi structured interviews were used to explore the practical and professional meanings behind the survey responses. Their purpose was to deepen

the study's understanding of digital integration in school physics rather than to generate a separate line of inquiry.

Six physics teachers were selected for the interview stage from among those who had completed the survey. Participant selection followed a variation based purposive sampling strategy. The aim was to capture relevant differences within the respondent group. Three criteria guided selection. These were teaching experience, school type, and level of digital technology use. This sampling logic matched the focus of the study, since the barriers under investigation were expected to vary across professional backgrounds and institutional settings.

The interviews followed a semi structured format. This format ensured a shared thematic focus while allowing participants to describe their experiences in detail. The interview guide included eight main questions. These questions addressed teachers' use of digital technologies, their views of pedagogical value, the barriers they faced, the role of school level support, the relationship between digital tools and curriculum requirements, and possible directions for future improvement. The guide was developed in line with the concerns outlined in the literature review, particularly the need to examine digital integration in physics as a subject specific practice shaped by competence, institutional conditions, and curricular demands.

Each interview was planned to last between 20 and 30 minutes and could be conducted either online or offline, depending on the participant's availability. With informed consent, the interviews were audio recorded to support accurate transcription. All transcripts were anonymised before analysis, and identifying details were removed from the working data set. The interview material was then prepared for qualitative content analysis. Within the design of the study, the interviews served an interpretive function. They were used to clarify and contextualise patterns already identified in the survey data.

3.2.3 Document Analysis

Document analysis was used in this study to provide policy, curricular, and institutional context for the teachers' accounts collected through the survey and

interviews. It was not treated as a primary empirical source in the same sense as those two methods. Its value lay in clarifying the formal expectations and regulatory frameworks within which physics teachers are expected to integrate digital technologies into their practice.

The qualitative and contextual data sources used in the study are outlined in Table 3.2.

Table 3.2. *Overview of Qualitative and Contextual Data Sources*

Data Source	Participants / Materials	Selection Logic	Main Focus	Role in the Study
Semi-structured interviews	6 physics teachers	Variation-based purposive sampling	Teachers' experiences, barriers, pedagogical value, institutional support	To deepen and explain survey patterns
Open-ended survey responses	Written comments from survey respondents	Included as supplementary qualitative data	Additional reflections on digital technology use	To support qualitative interpretation
Document analysis	Policy documents, standards, curriculum materials, ICT-related regulations, methodological documents	Relevance to digital integration in school physics	Policy support, curriculum fit, teacher training, institutional conditions	To provide policy and curricular context

The document corpus consisted of publicly available materials directly related to digital integration in general education and, where possible, to physics teaching in

particular. These materials included national digitalisation policy documents, the State Compulsory Education Standard, physics curriculum documents, regulations concerning ICT and digital literacy, and relevant methodological materials. Documents were selected for their direct relevance to the research topic and for their likely influence on teachers' classroom practice.

The analysis was guided by a set of predefined categories drawn from the conceptual focus of the dissertation and the issues identified in the literature review. These categories included policy support for digitalisation, teacher training and professional development, subject specific guidance for physics, infrastructure and access, curriculum flexibility, assessment demands, and institutional support. The documents were read closely and coded manually. Attention was given to policy statements, curriculum requirements, and methodological recommendations that addressed the place of digital technologies in school education and the conditions of their implementation.

Within the overall research design, document analysis served an interpretive function. The survey mapped broad patterns in teachers' reported practice, and the interviews explored how those patterns were experienced in everyday teaching. Document analysis added a formal layer of context. It helped distinguish between difficulties arising from individual practice and those linked to curriculum requirements, institutional expectations, or the limited availability of subject specific guidance. In this way, it strengthened the contextual grounding of the study and supported a more precise reading of the barriers to digital technology integration in physics education.

3.3 Data Processing, Analysis Techniques, and Ethical Considerations

3.3.1 Quantitative Data Analysis

The quantitative component of the study was based on the survey dataset and formed the main statistical strand of the empirical analysis. Its purpose was to describe patterns in teachers' reported use of digital technologies and to examine whether selected background variables were associated with differences in use, perceived

usefulness, and future expectations. This section outlines the analytical procedures applied to the survey data. The results of those procedures are presented separately in Chapter 4.1.

All survey responses were entered and processed in IBM SPSS Statistics 26. The data were coded in line with the structure of the questionnaire. Demographic and professional background variables were treated as categorical variables. Frequency items and scaled evaluation items were coded according to their response formats. Items that allowed more than one response were recoded into separate binary variables, with each option coded as selected or not selected. This procedure was used for items on AI tools, barriers, and projected forms of impact. Descriptive summaries for these items were based on frequencies and respondent based percentages. Open ended responses were excluded from the quantitative dataset and analysed separately as part of the qualitative strand.

The first stage of analysis used descriptive statistics. Frequencies and percentages were calculated for categorical variables and binary recoded items. Means and standard deviations were calculated for scaled variables in order to summarise central tendency and dispersion. Before group comparisons were carried out, the data were examined for distributional properties and test assumptions. Skewness and kurtosis were reviewed as initial indicators of distribution shape. These checks were followed by the Shapiro–Wilk test for normality and Levene's test for homogeneity of variance. The aim was to select statistical procedures that matched the characteristics of the data rather than to apply one model uniformly across all variables.

Inferential procedures were chosen according to variable type and assumption fit. Welch's ANOVA was used for selected group comparisons when conventional one way ANOVA was not the most appropriate option. Kruskal–Wallis tests were applied to variables with non parametric characteristics. Effect sizes were calculated alongside these tests in order to assess the magnitude of observed differences in addition to statistical significance. Eta squared and epsilon squared were used for this purpose, depending on the procedure applied. Multivariate analysis of variance was also used to

examine the combined effects of academic degree and teaching experience on selected dependent variables, followed by univariate ANOVA where appropriate. Taken together, these procedures provided a consistent statistical framework for analysing the survey data within the non experimental and descriptive analytical design of the study.

3.3.2 Qualitative Data Analysis

The qualitative component of the study was intended to extend and clarify the survey findings by examining how physics teachers understood digital technology integration in their own professional contexts. Its purpose was to explore how teachers described the instructional value of digital tools, the obstacles they encountered, and the institutional and curricular conditions that shaped their classroom decisions. In methodological terms, this section explains how the qualitative data were prepared and analysed. The substantive findings derived from this process are presented in Chapter 4.2.

The main qualitative dataset consisted of semi-structured interviews with six physics teachers. These participants were selected from the survey sample through variation-based purposive sampling, with attention to teaching experience, school type, and level of digital technology use. Each interview lasted approximately 20 to 30 minutes. With participants' consent, the interviews were audio recorded and then transcribed for analysis. All transcripts were anonymised before coding, and identifying details such as personal names and school references were removed from the working dataset. Open-ended survey responses were also reviewed as supplementary material, although the interviews remained the primary source of qualitative evidence.

The data were analysed using qualitative content analysis. The process began with repeated reading of the transcripts and open-ended responses in order to develop familiarity with the material as a whole. This was followed by manual coding of text segments containing relevant descriptions, evaluations, and reflections on digital technology use in physics teaching. Codes addressing related ideas were then grouped into broader categories. From these categories, recurring themes were identified and

organised in relation to the research questions. The analysis remained closely aligned with the interview guide, which focused on digital technology use, perceived pedagogical value, barriers to integration, teacher competence, institutional support, curriculum fit, student response, and possible directions for improvement.

This approach was selected because it allowed the analysis to move from individual accounts to broader thematic patterns without losing the practical context in which those accounts were produced. The aim was not to quantify teachers' responses, but to interpret the meanings embedded in their descriptions of practice. In this way, the qualitative analysis complemented the survey by adding explanatory depth and by relating teachers' experiences to the wider concerns of the dissertation, including professional competence, subject-specific demands in physics education, and the institutional conditions that shape digital integration.

3.3.3 Ethics and Informed Consent

Ethical considerations were addressed throughout the research process. This section outlines the procedures used to secure informed participation, protect confidentiality, and manage research data during both the survey and interview stages. In the dissertation structure, ethics and informed consent are presented as a distinct methodological subsection. Participant information and consent materials are included in the Appendix in accordance with the dissertation format.

Participation in the survey was voluntary and anonymous. The questionnaire was administered online, and respondents provided digital consent before proceeding to the survey items. They could discontinue participation at any point. The survey was designed to gather professional perspectives on the use of digital technologies in physics teaching, and the data were collected exclusively for academic purposes. The survey analysis did not require respondents to disclose their identities.

The interview stage followed the same principle of voluntary participation, but it involved a more explicit consent process because spoken responses were recorded and transcribed. Before each interview, participants were informed about the purpose of the study, how the data would be used, and their right to withdraw at any stage.

Consent for audio recording was obtained in advance. After transcription, all interview materials were anonymised. Personal names, school names, and other identifying references were removed from the working dataset and replaced with coded labels.

Data protection focused on restricted use and minimal disclosure. Survey responses were treated as anonymous records. Interview materials were analysed only in anonymised form after transcription. Only data relevant to the research questions were retained, and all materials were used solely for academic research. These procedures were intended to ensure that participation remained informed, voluntary, and secure throughout the study.

4. Research Findings and Scientific Analysis

4.1 Survey Results and Quantitative Analysis

This section presents the survey findings on digital technology integration in physics teaching, with AI related tools treated as the most visible strand captured by the questionnaire. The survey involved 151 physics teachers working in general education schools in Kazakhstan. Women made up 77.5% of the sample and men 22.5%. In terms of age, 32.5% were under 30, 22.5% were between 30 and 40, 14.6% were between 40 and 50, and 30.5% were over 50. Most respondents held a bachelor's degree (61.6%), while 37.1% reported a master's degree and 1.3% a doctoral degree. The sample also included teachers with different levels of professional experience. Those with less than five years of experience accounted for 36.4%, those with five to ten years for 10.6%, those with ten to twenty years for 18.5%, and those with more than twenty years for 34.4%. Most respondents worked in public schools (83.4%), and face to face teaching remained the dominant format (76.2%). In self assessment, 58.9% described their AI knowledge as intermediate, 31.1% as beginner, and 9.9% as advanced.

The demographic and professional profile of the respondents is presented in Table 4.1.

Table 4.1. *Demographic and Professional Profile of Respondents*

Variable	Category	n	%
Gender	Male	34	22.5
	Female	117	77.5
Age	Under 30 years	49	32.5
	30–40 years	34	22.5
	40–50 years	22	14.6
	50+ years	46	30.5

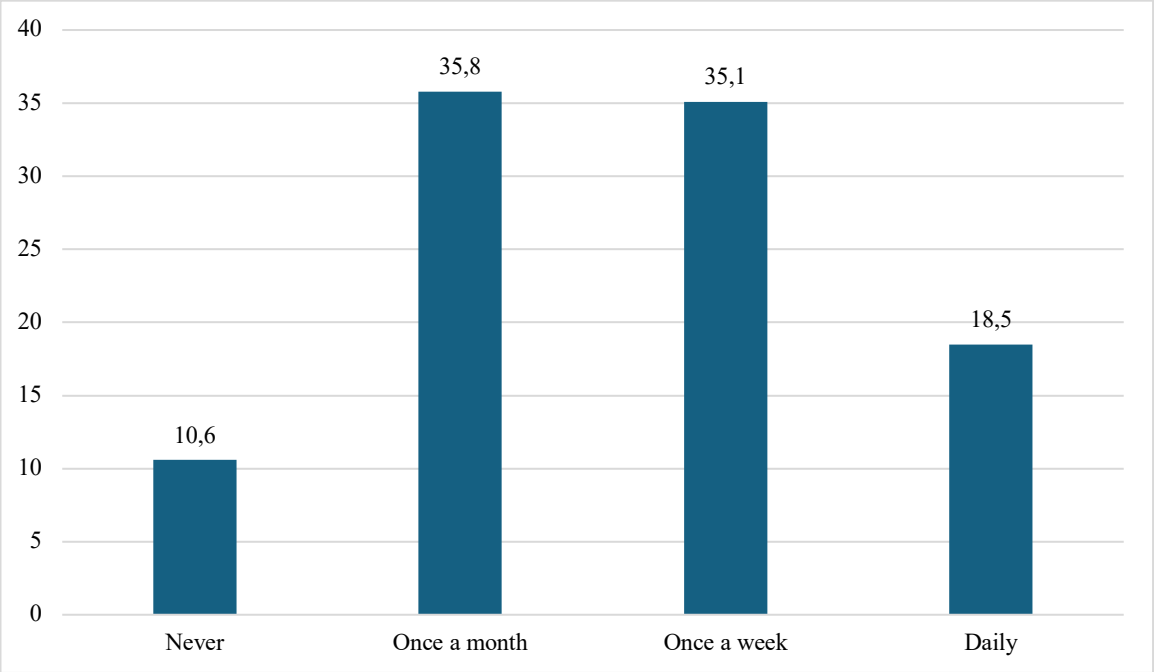
Highest degree	Bachelor’s degree	93	61.6
	Master’s degree	56	37.1
	Doctoral degree	2	1.3
Teaching experience	Less than 5 years	55	36.4
	5–10 years	16	10.6

Table 4.1. continued

Variable	Category	n	%
Teaching experience	10–20 years	28	18.5
	More than 20 years	52	34.4
School type	Public school	126	83.4
	Private school	25	16.6
Predominant lesson format	Traditional face to face	115	76.2
	Online	5	3.3
	Hybrid	31	20.5
Self assessed AI knowledge	Beginner	47	31.1
	Intermediate	89	58.9
	Advanced	15	9.9

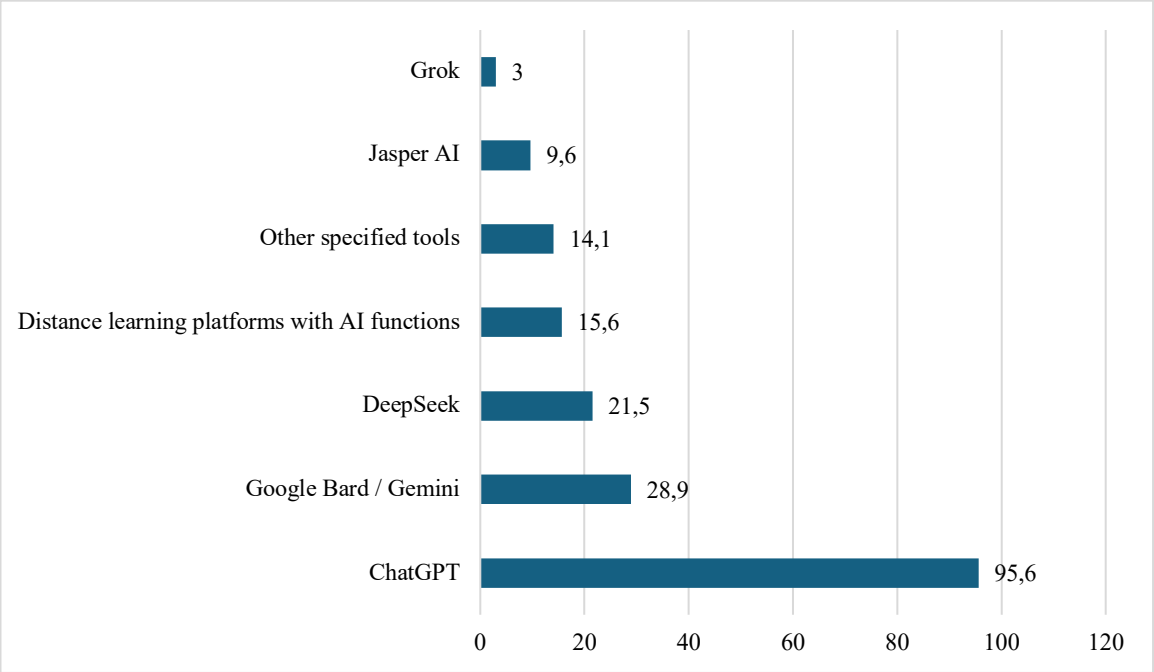
The responses show that AI had already entered routine teaching practice for most participants, though levels of use varied. Only 10.6% reported that they never used AI in teaching physics. The largest groups were those who used it once a month (35.8%) and once a week (35.1%). Daily use was reported by 18.5% of the sample. These figures suggest that AI use was no longer confined to a small experimental minority. For many teachers, it had become part of regular professional work, even if not on a daily basis. The distribution of use frequency is shown in Figure 4.1.

Figure 4.1. Frequency of AI Use in Physics Teaching



Use of AI tools was concentrated around a small number of platforms. Among the 135 respondents who answered the multi response item on tool use, ChatGPT was selected by 95.6% (n = 129). Google Bard or Gemini was selected by 28.9% (n = 39), and DeepSeek by 21.5% (n = 29). Distance learning platforms with AI related functions were chosen by 15.6% (n = 21), other specified tools by 14.1% (n = 19), Jasper AI by 9.6% (n = 13), and Grok by 3.0% (n = 4). The pattern is clear. Teachers' reported use was shaped by a narrow platform profile, with one tool dominating the field. The most frequently used AI tools are presented in Figure 4.2.

Figure 4.2. Most Frequently Used AI Tools

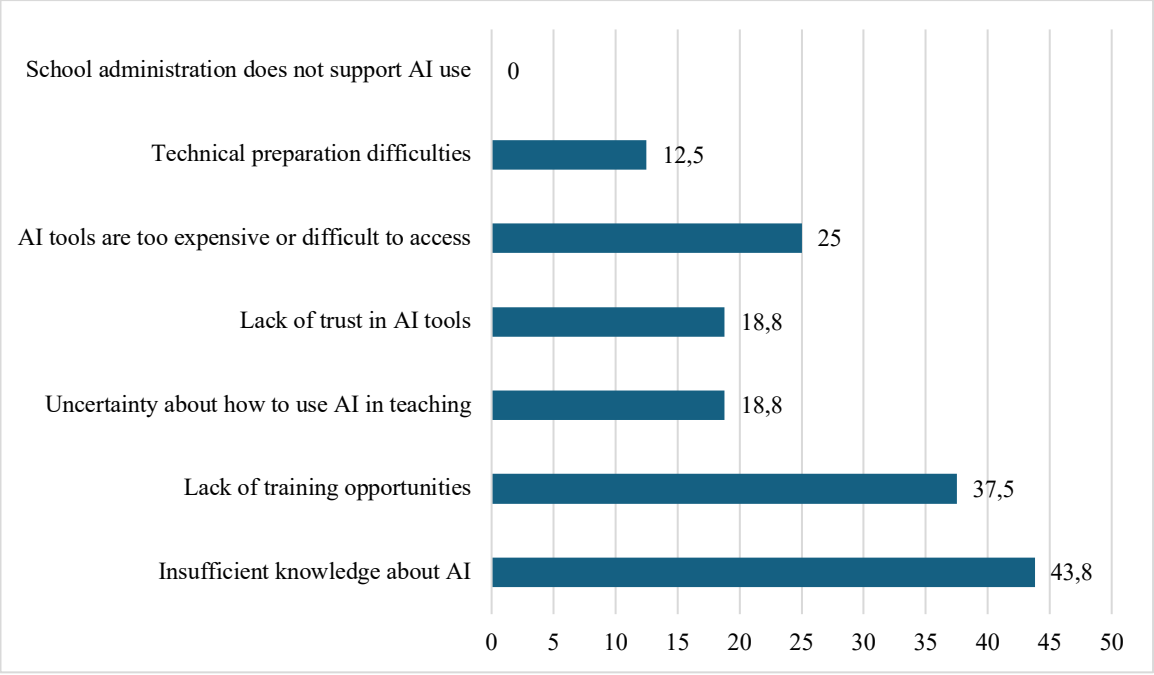


Teachers generally rated AI as more useful for preparation and explanation than for tasks requiring sustained instructional judgement. The highest mean values in the grouped descriptive indicators were recorded for teacher workload reduction (M = 0.623) and visual modeling (M = 0.609). These were followed by simplified explanation (M = .503) and technology integration (M = 0.503). Lower values were reported for interactive feedback (M = 0.437), material personalization (M = 0.397), assessment automation (M = 0.391), methodological change (M = 0.371), and content adaptation (M = 0.364). This distribution suggests that respondents saw the strongest value of AI in areas such as lesson support, visualisation, and explanation of difficult content. They were more reserved about its role in assessment, personalisation, or broader changes in teaching method. The distribution of perceived usefulness across instructional tasks is summarised in Table 4.2.

Table 4.2. *Perceived Usefulness of AI Across Instructional Tasks*

Instructional task or function	Mean	Rank
Teacher workload reduction	0.623	1
Visual modeling	0.609	2
Lesson automation	0.563	3
Simplified explanation	0.503	4
Technology integration	0.503	5
Personalized learning	0.444	6
Interactive feedback	0.437	7
Overreliance risk	0.411	8
Material personalization	0.397	9
Assessment automation	0.391	10
Methodological change	0.371	11
Content adaptation	0.364	12

Figure 4.3. Reported Barriers to AI Integration



The barriers item was answered by the subgroup of teachers who reported that they did not use AI, which consisted of 16 respondents. Within this group, the most frequently reported barrier was insufficient knowledge about AI (43.8%, n = 7). This was followed by lack of training opportunities (37.5%, n = 6). Smaller proportions reported uncertainty about how to use AI in teaching (18.8%, n = 3), lack of trust in AI tools (18.8%, n = 3), and technical preparation difficulties (12.5%, n = 2). No respondents in this subgroup identified school administration as a barrier. Within this small non user group, the main constraints were linked more to professional readiness than to formal institutional restriction. Reported barriers to AI integration are shown in Figure 4.3.

Responses to the future oriented items reveal a mix of practical expectation and caution. The most frequently selected future effect was reduced teacher workload, chosen by 62.3% of respondents (n = 94). This was followed by simplified explanation of complex topics at 50.3% (n = 76) and support for the implementation of new educational technologies at the same level (50.3%, n = 76). Personalised learning was selected by 44.4% (n = 67), while 41.1% (n = 62) expressed concern that students might become overly dependent on AI. Lower proportions selected automated student assessment (38.4%, n = 58) and broader methodological change in education (37.1%, n = 56). A similar pattern appeared in the item on methodological change in physics teaching. The most frequently selected option was the use of visual models for complex concepts (60.9%, n = 92), followed by lesson planning automation (56.3%, n = 85). Interactive feedback was selected by 43.7% (n = 66), adaptation of learning materials by 40.4% (n = 61), facilitation of new teaching methods by 39.7% (n = 60), and adaptation and updating of educational content by 36.4% (n = 55). These responses place explanation, visualisation, and planning support at the centre of teachers' expectations.

The comparative analysis adds a more differentiated picture to the descriptive results. At the overall level of AI use frequency, Welch's ANOVA showed no statistically significant difference across teaching formats, $F(2, 12.5) = 0.403$, $p = .677$,

η^2 = .012. Most format based comparisons were also non significant. One exception was material personalization, where the Kruskal–Wallis test indicated a significant difference across formats, $\chi^2(2) = 8.71$, $p = .013$, $\varepsilon^2 = .058$. Simplified explanation approached significance, $\chi^2(2) = 5.07$, $p = .079$, $\varepsilon^2 = .034$. Multivariate analysis showed no overall effect of academic degree on the combined dependent variables. Teaching experience, however, had a significant multivariate effect, Pillai's Trace = .170, F(9, 426.000) = 2.849, p = .003, partial η^2 = .057. The interaction between degree and experience was also significant, Pillai's Trace = .119, F(9, 426.000) = 1.962, p = .042, partial η^2 = .040. Follow up tests showed that experience significantly affected use frequency, $F(3, 142) = 4.708$, $p = .004$, $\eta^2 = .090$. The interaction between degree and experience significantly affected future impact, $F(3, 142) = 4.119$, $p = .008$, $\eta^2 = .080$, and future change, $F(3, 142) = 3.156$, $p = .027$, $\eta^2 = .063$. The main group comparison results are summarised in Table 4.3.

Table 4.3. *Group Comparison Results by Teaching Format, Degree, and Experience*

Comparison factor	Dependent variable	Statistical test	Test statistic	p	Effect size	Result
Teaching format	AI use frequency	Welch's ANOVA	$F(2, 12.5) = 0.403$	.677	$\eta^2 = .012$	Not significant
Teaching format	Material personalization	Kruskal–Wallis	$\chi^2(2) = 8.71$	.013	$\varepsilon^2 = .058$	Significant
Teaching format	Simplified explanation	Kruskal–Wallis	$\chi^2(2) = 5.07$	.079	$\varepsilon^2 = .034$	Marginal
Academic degree	Combined dependent variables	MANOVA (Pillai's Trace)	$F(6, 282) = 0.879$	.511	Partial $\eta^2 = .018$	Not significant
Teaching experience	Combined dependent variables	MANOVA (Pillai's Trace)	$F(9, 426) = 2.849$	.003	Partial $\eta^2 = .057$	Significant

Degree × experience	Combined dependent variables	MANOVA (Pillai's Trace)	F(9, 426) = 1.962	.042	Partial η^2 = .040	Significant
Teaching experience	Use frequency	ANOVA	F(3, 142) = 4.708	.004	η^2 = .090	Significant
Degree × experience	Future impact	ANOVA	F(3, 142) = 4.119	.008	η^2 = .080	Significant
Degree × experience	Future change	ANOVA	F(3, 142) = 3.156	.027	η^2 = .063	Significant

4.2 Interview Results and Qualitative Content Analysis

The interview findings add qualitative depth to the survey results by showing how teachers described digital technology use in their own school settings. Across the six interviews, digital tools were viewed as valuable, but their use was uneven and strongly shaped by local conditions. Teachers spoke about infrastructure, confidence, curriculum pressure, and the immediate demands of classroom teaching. No single pattern of integration emerged. Instead, participants described a practical and context-sensitive use of digital tools, selected according to what was available and what served a clear instructional purpose. All quotations in this section are presented in English translation by the researcher.

A first theme was selective, purpose-driven use. None of the participants described digital technology as something used in every lesson or across all parts of instruction. In better resourced contexts, teachers referred to simulations, virtual laboratories, data-logging tools, and learning management platforms. In rural or small-class settings, they relied more on videos, mobile applications, messaging platforms, and simple online tests. What mattered was not the sophistication of the tool, but its usefulness for a specific teaching task. T4 expressed this directly: "The digital tool must first serve the instructional purpose." T5 made a similar point from a more cautious perspective: "What matters to me is not a complex tool, but one that is useful for a real lesson."

A second and more widely shared theme concerned pedagogical value, particularly in relation to visualisation and explanation. This was the clearest area of agreement across the interviews. Teachers repeatedly linked digital tools to the ability to make abstract physical processes visible and easier to grasp. T1 remarked that "Simulation helps the student understand not the formula, but the phenomenon itself." T2 and T3 described the same value from different angles. T2 emphasised the usefulness of video when direct demonstration was difficult, while T3 highlighted the role of real-time data collection and analysis in strengthening the connection between theory and practice. Across these accounts, the strongest value of digital technology lay in supporting conceptual understanding, visual modelling, and student engagement in topics such as motion, force, electricity, and experimental work.

A third theme concerned barriers and constraints. Some of these were infrastructural, particularly in rural schools. T2 referred to slow internet and unstable electricity, while T6 noted that digital learning was not equally accessible because some families lacked home internet and device access. Other barriers were linked to time, training, and tool complexity. T1 and T5 both pointed to curriculum density and limited preparation time. T5 also suggested that some platforms were too complex to adopt easily within an already demanding schedule. These constraints were described not as isolated incidents, but as recurring conditions that shaped teachers' willingness and capacity to use digital tools consistently. As T1 put it, "If the technology is not ready, even a well-planned lesson loses strength."

A fourth theme was the gap between expectations for digital use and the conditions that support it. Several participants indicated that digital integration was encouraged, but not always supported in a stable or systematic way. T1 noted that technical support in school was inconsistent. T6 described a setting in which the teacher had to deal with technical problems alone because no specialist was available. Curriculum fit emerged as a related concern. Teachers across different school types described the programme as overloaded, leaving little room for digital tasks that required additional time. T3 linked this to assessment pressure, arguing that a strong

focus on tests reduced opportunities for digitally supported inquiry. T4 raised a different but related concern, noting that frequent use of digital platforms did not necessarily mean that their educational value had been evaluated in a systematic way.

The final theme concerned future improvement. The suggestions offered by participants were practical and closely tied to classroom realities. Teachers did not call for abstract technological expansion. They asked for support that could be used directly in subject teaching. This included short practice-oriented training, ready-made task banks, curated lists of reliable tools, more Kazakh-language materials, and resources that could function offline in rural contexts. T6 captured this position clearly: “What we need most is not a complex platform, but an accessible solution.” T3, working in a specialised school context, placed greater emphasis on formal curriculum integration and teacher exchange, arguing that digital laboratories should be built into the programme rather than treated as optional additions. Despite these differences, the interviews converged on one point: teachers were generally open to digital technologies, but they wanted support that was realistic, subject-specific, and responsive to local school conditions.

Taken together, the interview findings sharpen the picture that emerged from the survey. They show that digital technology use in physics teaching is present, but uneven and selective. They also clarify why teachers valued visualisation, explanation, and lesson support more highly than broader methodological change. Most importantly, they show that barriers were experienced not simply as technical problems, but as part of the wider realities of school teaching, including curriculum overload, uneven access, limited training, and inconsistent institutional support.

4.3 Comparison and Interpretation of Results with Theoretical Frameworks

This section interprets the survey and interview findings as a connected body of evidence and relates them to the theoretical and conceptual foundations established in Chapter 2. Taken together, the findings show that digital technology integration is already present in the professional practice of physics teachers in Kazakhstan, but it

remains uneven, selective, and strongly dependent on context. The survey data indicated regular use of digital and AI related tools among a substantial proportion of respondents, while the interview data showed that such use was usually tied to specific instructional purposes rather than to a consistent transformation of classroom practice. This pattern is consistent with the study's broader argument that digital integration in physics should be understood not as a simple matter of access or adoption, but as a context-sensitive process shaped by teacher competence, institutional support, curriculum structure, and the disciplinary demands of physics itself.

A key conclusion of the study is that barriers to digital integration are multilayered. The survey identified insufficient knowledge, lack of training, and uncertainty about implementation among the most frequently reported barriers, while the interviews added detail on unstable internet, unequal access to devices, limited preparation time, curriculum overload, and inconsistent technical support. This pattern closely reflects the barrier literature reviewed in Chapter 2. Hew and Brush (2007) argue that technology integration barriers extend across resources, knowledge and skills, institutional support, assessment practices, and subject-specific constraints. Bingimlas (2009) likewise shows that first-order and second-order barriers are deeply interdependent, while Buabeng-Andoh (2012) emphasises the role of systemic and curricular conditions in shaping teachers' autonomy and risk-taking. The present findings support these perspectives. They suggest that barriers in physics education are not reducible to infrastructure. Rather, technical, pedagogical, institutional, and curricular constraints operate together and reinforce one another in practice.

The results also sharpen the discussion of teacher competence and professional confidence. Chapter 2 positioned TPACK and DigCompEdu as important reference points for understanding digital competence, while also noting that both frameworks require subject-specific adaptation in contexts such as physics education. The present findings support that position. Teachers did not describe competence simply as the ability to operate digital tools. Their confidence depended on whether a tool could be linked to a specific topic, a realistic teaching aim, and a manageable classroom routine.

In TPACK terms, the challenge was not technological knowledge in isolation, but the alignment of technological, pedagogical, and content knowledge in subject-specific teaching situations. In a similar way, the findings fit the DigCompEdu discussion in Chapter 2, particularly the areas of teaching and learning, digital resources, assessment, and learner empowerment. Teachers were generally more confident in using digital tools for explanation, lesson support, and resource preparation than for more complex areas such as assessment redesign or broader methodological change. This supports the argument that meaningful digital integration depends less on generic digital familiarity than on situated professional competence grounded in classroom practice and disciplinary logic.

The subject-specific character of physics is especially important in interpreting the perceived value of digital tools. Across both the survey and the interviews, teachers associated the strongest pedagogical value with visualisation, explanation of abstract concepts, simulations, and support for understanding processes that are difficult to observe directly. This pattern directly supports the Chapter 2 argument that digital integration in physics differs from general ICT use because it must respond to abstraction, modelling, and experimental reasoning. The findings are therefore consistent with studies that identify simulations and visual models as especially valuable in physics teaching when they are aligned with disciplinary understanding rather than used as generic enhancements (Banda & Nzabahimana, 2021, 2023; Allanazarov, 2025). At the same time, the weaker support for automated assessment and broad methodological transformation suggests that teachers regard digital technologies as most useful when they clarify concepts, support explanation, or enrich inquiry, rather than when they are presented as a wholesale replacement for established pedagogical practice. In this respect, the study reinforces the need for discipline-sensitive integration models rather than generalized digital prescriptions.

The findings also clarify the gap between policy ambition and classroom reality in Kazakhstan. Chapter 2 reviewed this issue in detail, showing that national policy has established a strong formal commitment to digitalisation, yet implementation remains

uneven across schools, especially in relation to subject-specific teacher preparation, rural access, and classroom-level support. The present study supports that reading. Survey data showed that digital and AI related tools had already entered school practice, but the interviews revealed important contextual differences in feasibility, access, and support. Teachers in better resourced schools described more varied and research-oriented uses, while teachers in rural or small-class settings spoke more often about limited infrastructure, unequal student access, and the need for accessible or offline resources. This pattern echoes the policy and empirical discussions in Chapter 2, particularly the critique by Nurbekova and Nurbekov (2023) and the UNESCO IITE (2025) report, both of which stress that formal policy commitment does not automatically produce meaningful pedagogical transformation at classroom level.

Taken together, the findings support the adapted conceptual framework proposed in Chapter 2, while also refining it in several ways. The framework positioned policy context, disciplinary pedagogy, teacher competence, institutional support, and geographic inequality as interconnected conditions of digital integration in physics education. The present study confirms the importance of all of these dimensions. It also makes their interaction more visible. Teacher competence matters, but it becomes effective only when teachers have access to tools that match the conceptual demands of physics. Institutional support matters, but only when it reaches everyday teaching in practical forms. Policy matters, but its effects are filtered through curriculum load, assessment pressure, and school-level realities. In this sense, the study suggests that meaningful digital integration in physics depends on alignment rather than isolated improvement. Where competence, support, curriculum flexibility, and disciplinary fit come together, digital tools begin to support explanation, inquiry, and more active learning. Where that alignment remains weak, digital technologies are used, but mostly in supplementary and seleфctive ways rather than as a stable part of physics pedagogy.

5. Conclusion

This dissertation examined the barriers that shape the integration of digital technologies into the professional practice of physics teachers in general education schools in Kazakhstan. The study was guided by the view that digital integration is not simply a matter of access to tools, but a pedagogical and institutional process shaped by teacher competence, curriculum demands, school conditions, and the disciplinary character of physics itself. Although the dissertation addressed digital technologies more broadly, the empirical strand captured this issue most clearly through AI-related and other reported digital practices, since these currently constitute one of the most visible forms of digital use in school teaching. By combining survey data, interviews, and document analysis, the study was able to examine both the distribution of reported practices and the conditions that support or constrain their meaningful use.

The main research question asked what barriers physics teachers in Kazakhstan encounter when integrating digital technologies into their professional practice, and how these barriers reflect the interaction of individual competence, institutional context, and curricular expectations. The findings show that these barriers are layered and closely interconnected. Technical difficulties remain significant, particularly in rural and small-school settings, where unstable internet, limited access to devices, and weak technical support continue to affect classroom practice. At the same time, the evidence shows that barriers are not primarily technical. Teachers also reported uncertainty about implementation, insufficient practical training, limited preparation time, curriculum overload, and pressure from existing assessment structures. These constraints combine in ways that make digital integration difficult to sustain, even when teachers are willing to use digital tools. The study therefore suggests that barriers to digital integration in physics teaching are best understood as a combination of technical, pedagogical, institutional, and curriculum-related factors rather than as isolated obstacles.

The secondary research question focused on how physics teachers perceive the pedagogical value of digital technologies in relation to the content and cognitive

demands of physics education. On this point, the findings were more consistent. Teachers attached the strongest value to tools that support visualisation, explanation of abstract concepts, lesson preparation, and the representation of processes that students cannot easily observe directly. This is especially significant in physics, where learning depends on modelling, conceptual interpretation, and experimental reasoning. The findings therefore indicate that digital technologies are valued most when they help make complex phenomena more accessible, visible, and teachable. By contrast, teachers were more cautious in their views of automated assessment, large-scale methodological change, and more ambitious forms of digital redesign. In practical terms, digital technologies were seen less as replacements for established pedagogy than as resources that can strengthen specific aspects of physics teaching.

The dissertation also makes a theoretical contribution. It supports the argument developed in Chapter 2 that teacher digital competence should not be reduced to technical proficiency. What matters is whether teachers can connect a tool to a specific topic, a clear pedagogical aim, and a realistic classroom context. In this respect, the findings support a discipline-sensitive reading of digital competence, one that brings technological, pedagogical, and content knowledge into direct relation. The study also strengthens the adapted conceptual framework proposed in the dissertation. Teacher competence, disciplinary pedagogy, institutional support, policy context, and geographic inequality all proved relevant, but their importance became clearest in interaction rather than in isolation. The findings show that digital integration becomes meaningful only when these dimensions align. Where that alignment is weak, digital tools remain supplementary. Where it is stronger, teachers are better able to use them to support explanation, inquiry, and more active forms of learning.

Several practical implications follow from this analysis. For physics teachers, the findings suggest that effective digital integration depends less on adopting many tools than on selecting those that serve clear instructional purposes, especially in visualisation, modelling, explanation, and manageable differentiation. For school leaders, the study points to the importance of stable technical support, realistic time

structures, and working conditions that recognise digital integration as pedagogical labour rather than as an additional formal requirement. For teacher education providers and professional development programmes, the evidence shows that generic ICT training is insufficient. Teachers need short, practice-oriented, and subject-specific forms of support that speak directly to physics teaching. For policymakers in Kazakhstan, the findings point to two linked priorities. Schools need better access to usable digital resources, including local-language and offline materials, particularly in rural settings. At the same time, national digitalisation efforts need stronger links to curriculum design, assessment practices, and subject-specific methodological guidance if digital integration is to move beyond partial and uneven implementation.

The study also has limitations that should be acknowledged clearly. The survey sample was relevant to the research problem but was not intended to produce nationally representative estimates. The interview component added important qualitative depth, though it was based on a relatively small number of participants. Much of the empirical evidence was self-reported, which means the study captured teachers' perceptions, judgments, and reported practices rather than direct observation of classroom use. The survey instrument also focused strongly on AI-related practices as a visible entry point into broader digital integration, which made the empirical analysis timely and concrete but did not capture the full range of digital tools used in physics teaching. Document analysis strengthened the contextual interpretation of the findings, though it did not function as a primary empirical strand in the same way as the survey and interviews. These limitations do not undermine the central conclusions of the dissertation, but they do define the scope within which those conclusions should be interpreted.

Future research could develop this work in several directions. Larger studies would make it possible to examine regional, institutional, and demographic variation in greater detail. Longitudinal research could show how teacher competence and digital practices develop over time as tools, expectations, and support structures change. There is also a clear need for classroom-based research that moves beyond self-report data and examines how digital tools influence student engagement, conceptual

understanding, and experimental reasoning in physics lessons. Further work is needed on subject-specific professional development models for physics teachers, particularly in relation to simulations, virtual laboratories, and assessment practices. Overall, this dissertation concludes that digital technologies already occupy a visible place in the professional practice of physics teachers in Kazakhstan, but their use remains selective and uneven. Their educational value is strongest when they respond to the conceptual and representational demands of physics. Their wider and more meaningful integration depends not on technology alone, but on the alignment of teacher competence, institutional support, curriculum flexibility, and the practical realities of school life.

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Appendix A

Survey Questionnaire for Physics Teachers

Title. Survey for Physics Teachers: AI and Digital Technologies in Teaching Practice

Introductory Note. This survey is intended for physics teachers and aims to explore their experience of using artificial intelligence in teaching, the challenges they face, and the opportunities they see for future practice. Your responses will be used for academic research purposes only. Participation is voluntary, and all responses will remain anonymous and confidential.

Instructions. Please answer all questions as accurately as possible. For some questions, you may select more than one option where indicated.

Section A. General Information

1. What is your gender?

• Male

• Female

2. What is your age?

• Under 30 years

• 30 to 40 years

• 40 to 50 years

• 50+ years

3. What is your highest level of education?

• Bachelor’s degree

• Master’s degree

• Doctoral degree

4. How many years have you been teaching physics?

• Less than 5 years

• 5 to 10 years

• 10 to 20 years

• More than 20 years

5. What type of school do you work at?

• Public school

• Private school

6. What is the predominant format of your lessons?

• Traditional face to face

• Online

• Hybrid

7. How would you assess your level of knowledge about artificial intelligence?

• Beginner

• Intermediate

• Advanced

Section B. Experience with AI

8. How often do you use AI in teaching physics?

• Never

• Once a month

• Once a week

• Daily

9. Which AI tools do you use?

Select all that apply.

• ChatGPT

• Google Bard or Gemini

• Grok

• DeepSeek

• Jasper AI

• Distance learning platforms with AI functions

• Other. Please specify: _____

Section C. Perceived Usefulness of AI

10. Rate the usefulness of AI on a scale from 1 to 5. *1 = absolutely useless, 2 = slightly beneficial, 3 = moderately beneficial, 4 = mostly beneficial, 5 = extremely effective*

Instructional task	**1**	**2**	**3**	**4**	**5**
Preparing lesson materials	○	○	○	○	○
Creating tests and assignments	○	○	○	○	○
Explaining complex topics	○	○	○	○	○
Automating grading	○	○	○	○	○
Providing individualized student support	○	○	○	○	○

Section D. Barriers and Challenges

11. Why do you not use artificial intelligence in teaching? *Select all that apply.*

• I do not have enough knowledge about AI

• I have not received training on how to use AI in teaching

• I do not know how to integrate AI into my lessons

• I do not trust AI tools

• AI tools are too expensive or difficult to access

• Technical preparation is difficult

• My school administration does not support the use of AI

• I do not see a clear benefit for teaching physics

• Students may become too dependent on AI

• Other. Please specify: _____

Section E. AI Impact and Future Prospects

12. How do you think AI will impact physics teaching in the future? *Select all that apply.*

• It will enhance personalized learning

• It will reduce teachers' workload

• It will simplify the explanation of complex topics

• It will introduce methodological changes in education

• It will automate student assessment

• It will facilitate the implementation of new educational technologies

• Students may rely too much on AI, which could weaken their critical thinking and problem solving skills

13. How can AI change the methodology of teaching physics? *Select all that apply.*

• It can adapt learning materials

• It can automate lesson planning

• It can use visual models to explain complex concepts

• It can provide interactive feedback

• It can adapt and update educational content

• It can facilitate the introduction of new teaching methods

Appendix B

Semi-Structured Interview Guide for Physics Teachers

Introductory note for participants. This interview is conducted as part of a master's dissertation on the barriers to integrating digital technologies into the professional practice of physics teachers in general education schools in Kazakhstan. The purpose of the interview is to explore teachers' experiences, perceptions, and challenges related to the use of digital technologies in physics teaching. Participation is voluntary. All responses will be kept confidential and used for academic purposes only. No real names or school names will be reported in the dissertation.

Interview Questions

1. Could you describe how you currently use digital technologies in your physics teaching practice?

2. Which digital tools or platforms do you use most often in physics lessons, and for what purposes?

3. In your experience, which areas of physics teaching benefit most from digital technologies?

4. What difficulties or barriers have you faced when trying to integrate digital technologies into your lessons?

5. To what extent do your own digital skills and professional preparation affect your use of digital technologies in teaching physics?

6. How do school-level conditions, such as infrastructure, internet access, administrative support, or timetable demands, influence your ability to use digital tools effectively?

7. How well do digital technologies fit the curriculum requirements and assessment practices in school physics?

8. What is your view on the use of artificial intelligence tools in physics teaching as part of broader digital integration?

9. In your opinion, how do students respond to the use of digital technologies in physics lessons?

10. What kinds of professional development or institutional support would help physics teachers integrate digital technologies more effectively?

11. Looking ahead, what changes would be necessary to improve the meaningful integration of digital technologies into physics teaching in Kazakhstan?

Optional Probing Questions

• Could you give a specific example from your teaching practice?

• Why do you think this difficulty occurs?

• How did your students respond in that situation?

• Was this challenge related to the subject content, the school environment, or your own preparation?

• What would have helped you handle that situation more effectively?