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A scientific and methodological model for developing educators functional literacy through the integration of AI technologies

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Abstract – This study offers an interpretation of a scientific and methodological model for the development of educators' functional literacy under conditions of integrating artificial intelligence technologies into educational practice. The relevance of the research is обусловлена because contemporary AI systems extend beyond the framework of instrumental digitalization and, consequently, transform the structure of professional pedagogical thinking by redistributing cognitive and analytical functions between the educator and algorithmic systems. Under these conditions, educators' functional literacy can no longer be understood merely as an extension of digital competence and therefore requires conceptual reconsideration. In particular, recent international reviews emphasize that artificial intelligence is transforming the traditional "educator–student" relationship into a new triadic configuration of "educator–AI–student," thereby necessitating a fundamental rethinking of the educator's professional roles. However, to date, only a limited number of educational systems have clearly articulated which specific competencies educators must possess in the age of AI or how they should be prepared for this role. This gap underscores the urgent need for a new conceptual model that moves beyond the conventional notion of digital literacy.

The purpose of this study is to conceptualize educators' functional literacy as a dynamic, multilevel system of professional thinking and to develop a model for its development within an AI-mediated educational environment. The methodological foundation of the research is grounded in the ideas of pedagogical subjectivity, distributed cognition, and critical pedagogy.

We propose a matrix-based model that integrates three levels of functional literacy development (adaptive, integrative-operational, and reflective-projective) with four functional blocks of pedagogical activity. The study demonstrated that the development of functional literacy is associated not with the intensity of AI usage but with the qualitative deepening of pedagogical judgment, reflection, and professional responsibility. The practical significance of the proposed model lies in its applicability to the design of professional development programs and to the evaluation of educational practices involving the use of artificial intelligence.

Keywords: educators' functional literacy; artificial intelligence in education; pedagogical subjectivity; scientific-methodological model; AI integration; pedagogical reflection

1. Introduction

The rapid integration of artificial intelligence technologies into educational practice has clearly become one of the most significant factors in the transformation of contemporary universal pedagogy. Unlike earlier stages of digitalization, which were associated primarily with the automation of routine operations and the expansion of access to information resources, artificial intelligence affects the very structure of educators' professional thinking by redistributing cognitive functions between human actors and machine systems. Under these conditions, the central issue is no longer technical proficiency in using AI tools but rather the preservation and development of pedagogical subjectivity, responsibility, and meaningfulness in educational activity.

Within international and national discourse, the concept of functional literacy is traditionally used to denote a specialist's ability to act effectively in professional and socially significant situations through the integration of knowledge, skills, and reflective dispositions. In pedagogical research, educators' functional literacy is typically associated with readiness to apply professional competencies in changing educational contexts, adapt to new requirements, and ensure the quality of instruction [1]. However, we argue that under conditions of active AI adoption, this concept requires substantial rethinking. In particular, a simple expansion of functional literacy through digital or technological components proves methodologically insufficient, as it fails to capture the profound transformations in the nature of pedagogical labor.

Notably, contemporary AI systems are capable of performing analytical, predictive, and generative functions that were previously considered the exclusive domain of educators' professional judgment. This circumstance produces a dual effect. On the one hand, AI reduces the operational workload and expands the pedagogical toolkit. On the other hand, it amplifies the risks of formalizing instruction, losing semantic control, and substituting pedagogical decision-making with algorithmic recommendations. As several scholars have emphasized, the use of AI in education is not a neutral process, as it transforms the epistemological foundations of learning, modes of knowledge interpretation, and the distribution of responsibility for educational outcomes [2]; [3].

In this context, educators' functional literacy cannot be considered a static set of skills or a linear extension of

digital competence. In contrast, it acquires the character of a dynamic, multilevel system that includes the capacity to design educational processes within a hybrid "educator–AI–student" environment, critically evaluates algorithmic decisions, and consciously manages the meanings, goals, and value foundations of learning. From this perspective, it becomes evident that the development of educators' functional literacy under conditions of AI integration extends beyond the scope of the applied methodology and emerges as a subject of scientific and methodological analysis.

Despite the growing body of literature addressing the use of artificial intelligence in education, a substantial proportion of existing studies remain descriptive or instrument oriented, focusing on individual digital solutions, platforms, and services. Moreover, comprehensive scientific and methodological models capable of systematically describing the development of educators' functional literacy and identifying its levels, structural components, and formative principles within AI-mediated pedagogical practice are lacking. Notably, a similar concern is being articulated at the international level: experts increasingly emphasize the need to develop comprehensive educator competency frameworks for working in AI-mediated educational environments. In the absence of such reference frameworks, educators are often compelled to rely on intuition, which in turn fosters formalism and the imitative use of technologies rather than their meaningful pedagogical integration. Consequently, the model proposed in this study addresses an identified methodological gap and responds to an urgent need for a systematic articulation of educators' professional development in the digital age. We contend that the absence of such models complicates the design of professional development programs, hinders the assessment of educators' professional growth, and contributes to the spread of formalistic and imitative uses of AI in educational processes.

Consequently, the aim of this study is to develop a scientific and methodological model for the development of educators' functional literacy in the context of AI integration. To achieve this aim, we seek to conceptualize functional literacy as a multilevel system, identify its key structural blocks, and substantiate methodological principles that ensure meaningful and pedagogically responsible use of artificial intelligence. The proposed model is oriented not toward replacing educators' professional thinking with algorithmic solutions but toward its enhancement and qualitative development within a digitally hybrid educational environment.

2. Theoretical findings

The theoretical examination of educators' functional literacy development under conditions of artificial intelligence integration necessitates engagement with several interrelated fields of inquiry: theories of functional literacy and competence, contemporary approaches to educator professionalism, and interdisciplinary studies analyzing the impact of AI on the cognitive and epistemological foundations of human activity. It is evident that only through the synthesis of these perspectives does it become possible to methodologically position functional literacy not as a narrow skill-based construct but rather as a systemic property of professional pedagogical activity.

Historically, the concept of functional literacy emerged as a response to the gap between the formal acquisition of knowledge and the individual's actual capacity to act effectively in complex life and professional situations. In particular, UNESCO documents [4] and OECD frameworks define functional literacy as the ability to apply knowledge and skills to problem solving within changing social, economic, and cultural contexts. Accordingly, within pedagogy, this concept has gradually evolved, acquiring professionally oriented character and becoming associated with educators' readiness for flexible, context-sensitive, and reflective action.

Contemporary research emphasizes that educators' functional literacy fundamentally differs from subject-specific or technological competence. It encompasses the capacity to interpret educational situations, make decisions under conditions of uncertainty, and align pedagogical actions with the long-term developmental goals of learners [5]. Thus, functional literacy should be understood not as the sum of discrete skills but as an integrative quality of professional thinking manifested in concrete pedagogical practices.

A significant contribution to this perspective is the concept of pedagogical subjectivity. Research on educator professionalism underscores that a key indicator of professional maturity lies in the ability to act as the author of pedagogical decisions rather than as a mere executor of external prescriptions or algorithms [6]. It is precisely at this point that fundamental methodological tension arises in relation to the integration of AI technologies into education. By offering ready-made analytical conclusions, recommendations, and generative outputs, artificial intelligence systems objectively intervene in the space of pedagogical choice and may shift the center of decision-making from the educator to the algorithm.

Theoretical work in the field of educational technologies further stresses that AI should not be regarded as a neutral tool but rather as a sociotechnical system that embeds specific models of knowledge, values, and assumptions into educational practice [7]. For example, machine learning algorithms rely on statistical regularities and probabilistic inferences that do not always align with pedagogical goals oriented toward personal development, critical thinking, and learner autonomy. In this sense, AI not only expands educators' functional capacities but also transforms the epistemological status of pedagogical knowledge, shifting the emphasis from interpretation and understanding toward optimization and prediction.

From the perspective of distributed cognition theory, the use of AI can be conceptualized as a redistribution of cognitive functions between humans and the technological environment [8]. However, within the educational context, this redistribution is inherently asymmetrical, as responsibility for pedagogical consequences, interpretation of results, and ethical dimensions of teaching remain

primarily with the educator. Consequently, functional literacy under AI conditions involves not only the ability to interact with intelligent systems but also the capacity to critically reflect on the limits of their applicability, uncover implicit assumptions, and prevent the substitution of pedagogical judgment with algorithmic recommendations. Notably, contemporary research highlights the critical importance of developing what is commonly referred to as *algorithmic literacy* among educators—that is, the capacity to understand the underlying principles of algorithmic systems, to critically evaluate automated recommendations, and to retain professional responsibility for pedagogical decision-making. Algorithm literacy is increasingly conceptualized as an integral component of educators' professional competence in the digital age [9], and its development within our model is directly supported through critical-reflective and ethical-pedagogical components.

The distinction between digital literacy and functional pedagogical literacy is particularly important in this context. Digital literacy typically focuses on the ability to use technologies, evaluate digital resources, and ensure the technical correctness of information practices [10]. Educators' functional literacy in AI-mediated environments extends beyond these boundaries, encompassing the ability to design educational processes in which technologies are subordinated to pedagogical aims rather than the reverse. As Biesta emphasized, genuinely pedagogical decision-making is always associated with value-based choice, which cannot be fully algorithmized.

Thus, the theoretical foundations of this study rest upon three key propositions.

First, we conceptualize educators' functional literacy as an integrative and dynamic quality of professional activity manifested in the ability to act meaningfully under conditions of uncertainty.

Second, the integration of AI technologies is interpreted as a factor of cognitive redistribution that intensifies demands on educators' reflection, interpretation, and responsibility.

Third, the development of functional literacy in an AI-mediated educational environment explicitly requires a scientific and methodological model capable of linking levels of professional development, structural components of pedagogical activity, and principles of meaningful technology use.

On these theoretical foundations, we present a scientific and methodological model for the development of educators' functional literacy under conditions of AI integration—one that is oriented toward preserving and strengthening pedagogical subjectivity amid the digital transformation of education.

3. Results

3.1. Description of the Scientific and Methodological Model for the Development of Educators' Functional Literacy under AI Integration

To clarify the internal structure and logic of the proposed scientific and methodological model, Figure 1 schematically presents the levels and functional blocks of educators' functional literacy development under conditions of artificial intelligence integration.

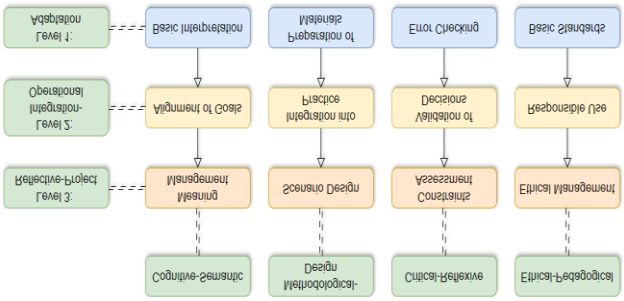

Figure 1. Scientific and methodological model for the development of educators' functional literacy under AI integration

The block diagram presented in Figure 1 visualizes the scientific and methodological model of educators' functional literacy development in the context of artificial intelligence integration, focusing not on operational details but on the structural foundations of educators' professional development. Notably, the intentional minimalism of the scheme is principled in nature and reflects a deliberate commitment to conceptual clarity. Within this logic, each element of the model possesses independent methodological status and does not require additional visual elaboration.

At the core of the scheme lies a matrix logic formed by the intersection of a vertical dimension representing levels of professional development and a horizontal dimension representing functional blocks of pedagogical activity. This structure enables us to conceptualize educators' functional literacy as a multidimensional phenomenon that cannot be reduced either to a linear trajectory of professional growth or to a set of isolated competencies. Through the visual economy of the diagram, we aim to emphasize that the development of functional literacy is not a matter of accumulating skills but rather of qualitatively increasing the complexity of professional thinking. This is the most critical aspect of our model.

The vertical axis of the diagram reflects the level-based dynamics of professional development, beginning with the adaptive level and culminating in the reflective-projective level.

The adaptive level denotes an initial form of educator–AI interaction, in which technologies are perceived as auxiliary tools and are incorporated into pedagogical practice without a profound transformation of professional judgment.

The integrative-operational level captures the transition to more deliberate use of AI in educational practice, where technologies begin to influence planning, organization, and assessment of learning.

The reflective-projective level, located at the top of the scheme, symbolizes a mature form of functional literacy in

which the educator consciously manages the meanings, boundaries, and pedagogical consequences of AI use.

The horizontal axis of the diagram defines four functional blocks representing key dimensions of pedagogical activity in an AI-mediated educational environment.

The cognitive–meaningful block captures the educator's capacity to maintain educational goals and interpret AI outputs within a pedagogical meaning-making framework.

The methodological–design block reflects the project-based nature of pedagogical activity and emphasizes that AI integration occurs through the construction of educational scenarios rather than through the mechanical application of tools.

The critical–reflective block highlights the necessity of verifying, validating, and interpreting algorithmic decisions, thereby preventing the substitution of pedagogical judgment with technological expediency.

Finally, the ethical–pedagogical block introduces the value dimension of the model, emphasizing the educator's responsibility for the consequences of AI use with respect to learners' autonomy, fairness, and subjectivity.

Notably, in our version of the model, each element is presented in a maximally condensed semantic form. This choice underscores the analytical rather than descriptive nature of the model. In other words, the diagram does not aim to explain the content of functional literacy but rather to define its structural coordinates, which are subsequently elaborated in the textual analysis. This relationship between the visual and textual levels allows us to avoid redundancy and ensures high cognitive transparency of the model.

The trajectory of professional thinking development depicted in the scheme is of particular methodological importance. This trajectory does not imply rigid linearity of professional growth but rather indicates a dominant direction of increasing pedagogical rationality under conditions of AI integration. At the same time, the model explicitly allows for asymmetrical development of functional blocks and potential regressions, which corresponds to the real dynamics of professional practice in contexts of technological uncertainty.

Overall, the block diagram functions as a conceptual framework for the study. It does not replace theoretical or methodological explanations but delineates the boundaries and internal logic of the proposed scientific and methodological model. We argue that the scientific value of the model lies precisely in its structural rigor, as it enables educators' functional literacy to be understood not as a collection of discrete skills but as a holistic system of professional thinking formed under conditions of artificial intelligence integration.

Thus, the proposed scientific and methodological model of educators' functional literacy development under AI integration is grounded in an understanding of pedagogical activity as a complex, reflective, and value-laden professional practice. In contrast to instrumental or competency-based models focused on mastering individual technologies, our model is based on the need for systemic alignment of pedagogical goals, cognitive processes, and technological affordances within a hybrid educational environment. Methodologically, the model draws on the concepts of pedagogical subjectivity, distributed cognition, and professional development as nonlinear, stage-based processes.

Accordingly, the foundation of the model is the conception of educators' functional literacy as a multilevel system in which development is not reduced to the accumulation of experience in using AI tools but is associated with a qualitative transformation in pedagogical thinking and decision-making. Within this logic, AI integration is understood not as a technological innovation in itself but as a methodological challenge requiring educators to rethink the boundaries of their professional agency and responsibility.

3.2. Model Structure: Levels and Functional Blocks

Overall, the proposed scientific and methodological model has a matrix structure and includes two interrelated dimensions: levels of functional literacy development and functional blocks of pedagogical activity. This structure enables us to describe not only the content of functional literacy but also the dynamics of its formation throughout professional growth.

The first dimension of the model is interpreted through levels of functional literacy development. We identify three levels that qualitatively reflect distinct modes of educator interaction with AI technologies.

The adaptive level is characterized by the initial incorporation of AI into pedagogical practice. At this stage, technologies are used primarily as auxiliary tools for preparing instructional materials, automating selected operations, or retrieving information. At this level, functional literacy is fragmented and largely shaped by external requirements or institutional expectations. A significant risk at this stage is the imitative use of AI, whereby pedagogical activity is formally modernized without undergoing substantive change.

The integrative-operational level is associated with the deliberate inclusion of AI in key pedagogical processes, including instructional planning, analysis of learning outcomes, and personalization of educational trajectories. At this stage, the educator begins to perceive AI as an element of the professional environment and structures interaction with it on the basis of pedagogical objectives. Functional literacy manifests in the ability to align algorithmic recommendations with the educational context and to adjust them in accordance with pedagogical goals. However, it should be noted that the risk of shifting emphasis from pedagogical judgment to technological efficiency remains present.

The reflective-projective level represents the highest stage of functional literacy development under AI integration. At this level, the educator is aware of the limits of the applicability of intelligent systems, critically analyzes their impact on educational processes, and acts as the author of pedagogical decisions. AI is used as a cognitive amplifier subordinated to pedagogical intent

rather than as a source of normative prescriptions. This level presupposes advanced professional reflection and the assumption of ethical responsibility for learning outcomes, which fundamentally distinguishes functional literacy from technical or digital competence.

The second dimension of the model is interpreted through functional literacy blocks reflecting key aspects of pedagogical activity in an AI-mediated environment.

The cognitive–meaningful block includes the ability to formulate educational goals, interpret AI outputs, and relate them to learners' developmental objectives. Here, functional literacy is expressed as the capacity to maintain the semantic integrity of the educational process amid algorithmic fragmentation of knowledge.

The methodological–design block reflects the ability to design lessons, tasks, and educational scenarios while accounting for both the capabilities and limitations of AI. This does not involve mechanical technology adoption but rather pedagogical design, in which AI serves as a means of realizing didactic intentions rather than replacing them.

The critical–reflective block is associated with evaluating the correctness, reliability, and pedagogical appropriateness of algorithmic decisions. It includes the ability to identify errors, distortions, and implicit assumptions embedded in AI systems, as well as to recognize their impact on learners' cognitive autonomy. This block is directly aligned with the principles of critical pedagogy and digital reflexivity.

The ethical–pedagogical block reflects educators' responsibility for the consequences of AI use in education, including issues of authorship, fairness, inclusivity, and the preservation of learners' subjectivity. As emphasized by a number of scholars, these dimensions cannot be fully formalized and require professional judgment grounded in educational values.

3.3. Principles of the scientific and methodological model

The functioning of the model is ensured by a set of principles that define its methodological coherence. Central among these is the principle of pedagogical subjectivity, which prioritizes educators' professional judgment over algorithmic recommendations. This emphasis resonates with the prevailing international position that underscores the central role of the educator in the age of AI: as it is often expressed metaphorically, *it is educators, not technologies, who should lead this transformation* of education. In other words, even under conditions of deep digitalization, priority remains with human pedagogical judgment (educators' decision-making), a principle that is explicitly embedded in our model through the notion of subjectivity. We deliberately proceed on the basis of the premise that the integration of AI technologies should enhance educators' professional autonomy rather than constrain it. Equally important is the principle of managed AI integration, according to which technologies are regarded as instruments for achieving educational goals rather than as autonomous drivers of change. The principle of reflexivity ensures continuous critical reflection on pedagogical practice, whereas the principle of responsibility emphasizes the value-laden nature of educational activity within a digitally hybrid environment.

Taken together, the proposed scientific and methodological model allows for a conceptual understanding of educators' functional literacy development as a process of qualitatively deepening professional thinking and pedagogical reflection. It provides a foundation for the design of professional development programs, the construction of educational courses, and subsequent empirical validation. Moreover, the model does not replace pedagogical activity with technological solutions but instead strengthens its methodological rigor and value-based integrity.

4. Discussion

Thus, the scientific and methodological model we propose for the development of educators' functional literacy under conditions of artificial intelligence integration provides not only a conceptual framework for analysis but also a foundation for practice-oriented methodological solutions within educator education and professional development systems. Its methodological implications clearly extend beyond localized recommendations regarding the use of individual digital tools and are oriented toward rethinking the logic of educators' professional development in an AI-mediated educational environment.

First and foremost, our model implies a departure from universalist and linear professional development programs in which the acquisition of AI technologies is interpreted as a single, standardized process. The matrix structure of the model enables us to construct differentiated educational trajectories that consider both the functional literacy development level of a given educator and the prevailing deficits within particular functional blocks. This means that methodological work should begin not with training in "how to use AI" but with a diagnostic analysis of the educator's professional profile that identifies the configuration of the cognitive–meaningful, methodological–design, critical–reflective, and ethical–pedagogical components of their activity.

At the adaptive level, the model's methodological implications are associated with cultivating an initial experience of AI interaction that is conscious and pedagogically appropriate. In this context, the central issue is not expanding the inventory of tools but rather developing the capacity to interpret AI-generated outputs and relate them to educational goals. Methodologically, this presupposes the inclusion in professional development programs of analytical and reflective tasks aimed at identifying the limitations of algorithmic decisions, as well as discussing the risks of formalistic and imitative uses of technologies. Notably, such an approach is fully consistent with international recommendations on the responsible adoption of AI in education, which emphasize the importance of developing a critical understanding of technologies at the earliest stages of their use.

In turn, the integrative-operational level sets different methodological emphases. Here, functional literacy is manifested in the ability to incorporate AI into the design of educational processes without losing pedagogical control or the semantic integrity of learning. Methodologically, this requires a shift from instructive training formats to project-oriented formats in which educators develop and analyze their own instructional scenarios involving AI. A substantial element of such programs is collective professional reflection, which enables educators to compare algorithmic recommendations with pedagogical experience and with the context of a specific educational environment. In this respect, our model is directly aligned with approaches developed within the concepts of professional learning communities and continuous educator development.

At the reflective–projective level, the methodological implications, as we argue, acquire a strategic character. At this stage, functional literacy development presupposes the ability of educators to act not only as users but also as critical moderators of AI-mediated educational practices. Methodologically, this is expressed through the inclusion in educational programs of modules devoted to pedagogical expertise in AI; the analysis of ethical dilemmas; and issues of fairness, transparency, and the preservation of learners' subjectivity. However, such modules cannot be reduced to normative instruction because they require discursive formats of work, case analysis, and philosophical–pedagogical reflection on the boundaries of technological rationality.

Moreover, the effective development of functional literacy requires organizational conditions that support horizontal knowledge exchange. In this context, it is both appropriate and necessary to foster professional communities of practice among educators engaging with AI. The collective discussion of AI use cases, the reflective analysis of successful solutions and encountered challenges, and the coconstruction of shared ethical norms for the educational use of AI contribute to a more conscious and responsible development of professional competence. International recommendations explicitly highlight the value of such networked communities: supporting collaboration among educators strengthens their agency and accelerates the diffusion of effective AI-related practices. Consequently, incorporating mechanisms of professional collaboration enhances the practical relevance of the proposed model by enabling its implementation not only through formal professional development courses but also through sustained professional learning.

We contend that our model is of particular importance for designing systems of assessment and self-assessment of educators' professional development. Specifically, unlike traditional checklists of digital competencies, the proposed approach allows the evaluation of functional literacy to be treated as a multidimensional and dynamic process. Methodologically, this opens up the possibility of developing formative assessment tools oriented not toward documenting the degree of AI proficiency but toward identifying educators' capacity to make meaningful pedagogical decisions under conditions of uncertainty. This approach is fully consistent with contemporary trends in professional competence assessment, where priority is increasingly given to reflective and contextual indicators of activity quality.

Finally, our model yields important implications at the institutional level of educational governance. This makes it possible to conceptualize AI integration not only as a technological innovation but also as a process requiring alignment among education policy, educator preparation programs, and the value foundations of the teaching profession. In this sense, the scientific and methodological model may be used as an analytical instrument in developing strategies for the digital transformation of education, preventing the reduction of pedagogical development to indicators of technological provision and efficiency.

Thus, the methodological implications of the proposed model consist of reorienting educator education from tool acquisition toward the development of professional thinking, reflection, and responsibility. Here, we wish to emphasize that, within this approach, the integration of AI into educational practice becomes not a threat to pedagogical subjectivity but rather a condition for its qualitative complication and renewal.

We wish to underscore that the scientific novelty of our study is defined not by the introduction of a new term or by describing yet another variant of AI technology use in education but by a methodological shift in understanding educators' functional literacy within an AI-mediated pedagogical reality. In this register, our work offers a new theoretical and methodological reading of educators' professional development that goes beyond the dominant instrumental and competency-based approaches.

First, fundamentally new is the reconceptualization of educators' functional literacy as a dynamic, multilevel system of professional thinking rather than as a set of skills or an expanded form of digital competence. In existing research, educators' functional and digital literacy are typically interpreted through the lens of operational readiness to use technologies, which reduces pedagogical activity to a repertoire of procedures and techniques. In our study, functional literacy is conceptualized as educators' ability to act meaningfully under conditions of cognitive uncertainty generated by AI while retaining control over the goals, meanings, and value foundations of the educational process. In doing so, we introduce a qualitatively different understanding of literacy—not as an instrumentarium but as a form of professional rationality.

The second aspect of scientific novelty is associated with introducing artificial intelligence into the model not as an external technological factor but as a methodological element of pedagogical activity. Unlike most studies that treat AI as an auxiliary tool for automation or personalization of learning, the present research conceptualizes AI as a cognitive agent that redistributes functions of analysis, prediction, and generation between the human and the algorithm. This makes it possible to reveal deep changes in the structure of pedagogical decision-making and to demonstrate that AI integration inevitably transforms the epistemological status of

pedagogical knowledge. The novelty of our approach lies in the fact that AI is considered not as a means of increasing efficiency but as a factor that intensifies the requirements for educators' professional reflection and responsibility.

A third substantial element of scientific novelty is the development of a scientific and methodological model that combines a level-based and functional-block logic of functional literacy development. Unlike linear models of professional growth that dominate pedagogical practice, our model reflects the nonlinear and asymmetrical character of professional development in a digitally hybrid environment. The intersection of development levels (adaptive, integrative-operational, and reflective-projective) with functional blocks of pedagogical activity enables functional literacy to be described as a structurally complex system amenable to analytical and methodological interpretation. Therefore, we argue that our model has no direct analog in existing research, as it simultaneously accounts for the cognitive, methodological, reflective, and ethical dimensions of pedagogical activity.

Notably, there is an emphasis on pedagogical subjectivity and responsibility as central elements of functional literacy in the AI era. Whereas a substantial portion of research focuses on the efficiency, adaptability, and scalability of AI solutions, the present study deliberately shifts the analytical focus toward the authorship of pedagogical decisions, the preservation of professional judgment, and value-based choice. This allows us to transcend the technocratic logic within which educators are treated as operators of digital systems and to return to the center of analysis the educator as a responsible subject of the educational process.

Finally, the scientific novelty of our research, as it appears to us, is expressed in the methodological potential of the proposed model, which extends beyond the scope of this article. Our model may serve as a foundation for developing diagnostic instruments, professional development programs, empirical studies, and comparative analyses across diverse educational contexts. In this sense, our study not only fills the identified theoretical gap between AI-related research and pedagogical theory but also establishes an open research framework oriented toward the further development of scholarly knowledge.

Thus, our study contributes to contemporary pedagogy and educational research by offering a new conceptualization of educators' functional literacy, a new methodological status of AI within pedagogical activity, and an original scientific and methodological model capable of functioning as a linking mechanism between theory, methodology, and educational practice in the age of artificial intelligence.

4.1. Limitations and Directions for Future Research

Despite the conceptual coherence and methodological grounding of the proposed scientific and methodological model for educators' functional literacy development under conditions of artificial intelligence integration, the present study has several limitations that should be understood not as shortcomings but as the natural boundaries of theoretical modeling at this stage of the field's development. Explicitly articulating these boundaries allows us to interpret the obtained results appropriately while simultaneously outlining promising directions for future research.

The first and most substantial limitation concerns the absence of empirical validation of the model. The model presented in this study is conceptual and methodological in nature and relies primarily on a synthesis of theoretical approaches from pedagogy, the philosophy of education, and research on AI in educational contexts. Although such an approach is justified and methodologically legitimate at the stage of developing framework models, it does not allow for a full assessment of the model's reproducibility and sensitivity to the diversity of institutional, cultural, and disciplinary contexts. In this context, future research should focus on empirical testing of the proposed levels and functional blocks, including the development of diagnostic instruments and scales that make it possible to operationalize educators' functional literacy in an AI-mediated environment.

The second limitation concerns the model's intentionally general character, which deliberately abstracts from disciplinary specificity and national education systems. On the one hand, this ensures the universality and transferability of the model. On the other hand, its applicability for analyzing particular subjects in which patterns of interaction with AI may differ substantially is limited. For example, pedagogical practices in the humanities, in science education, or in vocational and technical training entail different requirements for interpretation, ethics, and the design of AI solutions. We believe that a particularly promising direction for future research is adapting the model to subject-specific contexts, followed by comparative analysis of educators' functional literacy development trajectories.

The third limitation is related to the dynamism of AI technologies themselves, which evolve far more rapidly than educational theories and institutional practices do. The algorithms, architectures, and modes of AI application that were relevant at the time of the present study may have undergone significant changes in the short term. This creates a risk of technological reduction in the model if it is interpreted as rigidly bound to the current generation of AI tools. Moreover, this limitation points to an important advantage of the proposed approach—namely, its orientation not toward particular technologies but toward the functional and methodological foundations of pedagogical activity. Future research may therefore examine the model's robustness under conditions of shifting technological paradigms, including the emergence of more autonomous and adaptive AI systems.

Particular attention should also be paid to the issue of ethical and regulatory uncertainty surrounding the use of AI in education. Despite the inclusion of an ethical–pedagogical block in the model's structure, the relationship between educators' professional judgment and external regulatory frameworks—formed at the level of education policy and technology corporations—remains an open question. Future research may deepen this aspect, for example, by examining how normative documents, the

recommendations of international organizations, and local institutional policies influence the development of educators' functional literacy and the redistribution of responsibility within an AI-mediated educational environment.

Finally, a promising direction for further research lies in integrating the proposed model with theories of professional development and pedagogical agency. Empirical exploration of how different levels of functional literacy relate to educators' sense of professional autonomy, resilience, and pedagogical identity would deepen the understanding of the long-term effects of AI integration. In this context, of particular interest is the study of possible nonlinear development trajectories, including regressions, asymmetries, and zones of conflict between technological efficiency and pedagogical values.

In summarizing these limitations and future directions, we emphasize that the proposed scientific and methodological model does not claim completeness; rather, it should be viewed as an open research framework. Its further development presupposes dialog between theory and empirics, pedagogy and technologies, as well as between educators' professional autonomy and the growing role of intelligent systems in education. We are convinced that it is precisely in this dialog—and not in technological determinism—that the potential for forming genuinely functional literacy among educators in the age of artificial intelligence resides.

5. Conclusion

Thus, the present study was devoted to the conceptual and methodological examination of educators' functional literacy development under conditions of artificial intelligence integration, which is understood as one of the key challenges of contemporary educational transformation. In contrast to the instrumental and technocratic approaches prevailing in pedagogical discourse—within which AI is primarily viewed as a means of optimizing or automating educational processes—our work proceeds from a fundamentally different premise. Specifically, artificial intelligence is conceptualized not as an external add-on to pedagogical activity but as a factor that reshapes the very structure of educators' professional thinking.

The study demonstrates that educators' functional literacy in AI-mediated contexts cannot be reduced to expanded digital competence or to a set of technological skills. In contrast, it constitutes a complex, dynamic, and value-laden system in which the cognitive, methodological, reflective, and ethical dimensions of pedagogical activity are inextricably intertwined. Such an understanding enables us to move beyond reductionist models of professional development and to restore pedagogical subjectivity to the center of analysis—that is, the educator's capacity to make meaningful, responsible, and contextually grounded decisions within an algorithmically mediated reality.

The scientific and methodological model of educators' functional literacy development proposed in this study, which is based on the integration of level-based and functional-block logics, makes it possible to conceptually delineate qualitative differences between stages of professional development under conditions of AI integration. The identification of adaptive, integrative-operational, and reflective-projective levels demonstrates that genuine professional maturity in a digitally hybrid educational environment is associated not with the intensity of technology use but with the ability to critically interpret the pedagogical meaning, limitations, and consequences of AI. In this context, AI does not replace pedagogical judgment; rather, it tests its depth, resilience, and value orientation.

A significant contribution of the present study is the affirmation of the methodological priority of pedagogical responsibility under conditions of algorithmic mediation. In an era in which educational decisions increasingly rely on data, predictions, and recommendations generated by intelligent systems, the educator remains the bearer of ultimate responsibility for educational outcomes, learners' personal development, and the preservation of the humanistic foundations of education. As contemporary research indicates, neglecting this dimension leads to the formalization of pedagogical activity and undermines trust in educational institutions. In contrast, the proposed model emphasizes the necessity of consciously managing the boundaries of technological intervention and preserving pedagogical authorship.

Within a broader theoretical context, the results of this study contribute to the development of pedagogical theory by expanding the understanding of functional literacy as a form of professional rationality suited to conditions of high uncertainty and technological complexity. Our work demonstrates that AI integration in education is not a neutral process and cannot be successfully implemented without a robust scientific and methodological framework capable of aligning technological innovation with the value-based and humanistic aims of education. In this sense, the proposed model may be viewed as part of a broader scholarly discussion on the future of the teaching profession and the role of the educator in the age of intelligent technologies.

In conclusion, the development of educators' functional literacy under conditions of artificial intelligence use is not a narrowly defined methodological task but rather a fundamental problem in contemporary education. Addressing this problem requires a shift from fragmented technological initiatives toward a systemic, scientifically grounded, and value-oriented approach to educators' professional development.

Naturally, the scientific and methodological model proposed in this study does not claim finality. Nevertheless, we contend that it delineates a conceptual space within which further theoretical and empirical reflection on pedagogical activity in the age of artificial intelligence becomes possible—an age in which human professional judgment, rather than algorithmic efficiency, emerges as the key condition for the sustainability and quality of education.

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