CONFERENCE PAPER
World Conference on Science, Innovation and Human Progress 2026

Accepted: July 2, 2026 | **Published:** July 20, 2026 | **Language:** English

FUTURITY PUBLISHING

Section of the conference: *Educational sciences*
Sekcja konferencji*: Nauki o edukacji*

The 4E Teacher in Nootechnological Ecologies: Agency, Empowerment, and Professional Reflexivity

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ABSTRACT: The spread of artificial intelligence, digital platforms and datafication systems is transforming educational contexts into nootechnological ecologies – that is, socio-material environments in which the production, mediation and evaluation of knowledge are co-configured by human agents, institutional practices, data and algorithmic infrastructures. In this scenario, the teaching profession risks being interpreted according to a technical-adaptive logic, centered on upskilling and performativity. This paper develops a theoretical model based on 4E cognition – embodied, embedded, enacted and extended – integrated with teacher agency, the capability approach and reflective practice. Through a critical and integrative review of the literature, the construct of the '4E teacher in nootechnological ecologies' is defined as a professional capable of critically shaping, inhabiting and regulating highly technology-dense educational environments. The model highlights that technologies can function both as enabling extensions of professional cognition and as devices that constrain autonomy, depending on the institutional, ethical and pedagogical conditions that guide their design, adoption and use.

KEYWORDS: 4E cognition, teacher agency, capability approach, reflective practice, artificial intelligence, nootechnological ecologies.

How to cite: Tripaldi, M. (2026). The 4E Teacher in Nootechnological Ecologies: Agency, Empowerment, and Professional Reflexivity. *World Conference on Science, Innovation and Human Progress*. Futurity Research Publishing. https://doi.org/10.5281/zenodo.21454561

Introduction

The spread of generative artificial intelligence, educational platforms, learning analytics systems and collaborative digital environments is profoundly altering the conditions under which the teaching profession is practiced. These technologies are no longer merely tools external to teaching, used to make a largely unchanged practice more efficient. They play a part in shaping the times, spaces, relationships, modes of access to knowledge and criteria through which educational processes are observed, documented and assessed.

Studies on datafication have shown that data, metrics and platforms do not merely represent pre-existing educational activities, but help to determine which aspects of teaching are made visible, comparable and assessable. In higher education, datafication alters how teaching activities are recorded and governed, whilst, from a broader perspective, big data infrastructures influence the shaping of educational policies and practices (Macgilchrist, 2020; Williamson, 2017).

The integration of artificial intelligence into school and university systems, therefore, concerns more than just the expansion of available tools. It affects the cognitive, relational, evaluative and decision-making conditions of professional practice. Generative systems can support the design of activities, the development of materials and the provision of feedback and documentation. At the same time, they can introduce opacity, infrastructural dependence, standardization and forms of delegation that are not always clearly controllable.

The risk is that teacher training will be reduced to a logic of technical adaptation, in which changes to tools are expected to be matched by continuous updating of operational skills. From this perspective, professional learning may be reduced to 'upskilling', focused primarily on efficiency and compliance with predefined procedures. The development of professional competence in the age of intelligent machines, however, requires a perspective that takes into account subjectivity, agency and the formative value of educational work (Costa, 2020, 2025).

More generally, the promises of automation, efficiency and rationalization associated with artificial intelligence must be subjected to pedagogical evaluation. The issue is not simply a matter of determining whether machines can replace certain teaching activities, but of understanding how their presence transforms roles, responsibilities, forms of judgment and the aims of education (Selwyn, 2019).

An exclusively technical interpretation overlooks the complex nature of teaching. Educational practice involves interpreting the context, taking responsibility, regulating emotions, planning, responding to the unexpected, and constructing meaning through relationships. Teaching professionalism cannot, therefore, be reduced to an individual repertoire of digital skills.

Various strands of research have provided relevant concepts for addressing this transformation. Studies on teacher agency have analyzed teachers' capacity to act within specific historical, institutional, material and cultural conditions (Priestley et al., 2015). The capability approach distinguishes between

the possession of resources and the actual possibilities for using them to pursue ends considered valuable (Nussbaum, 2011; Sen, 1999). The tradition of reflective practice has clarified the role of reflection during and following professional action (Schön, 1983).

At the same time, 4E cognition has challenged a conception of the mind as an exclusively internal, individual and computational entity. The term encompasses perspectives that interpret cognition as embodied, embedded, enacted and extended (Carney, 2020). The embodied and enactive roots can be traced back to the conception of the mind developed by Varela et al. (1991), whilst the 'extended' component is specifically articulated in Clark and Chalmers' (1998) theory of the extended mind.

4E cognition does not, however, constitute a perfectly unified theory. The four components stem from partly different traditions and should not be treated as synonyms. Rather, their combination offers a heuristic framework for analyzing cognition as a bodily, contextual, relational and distributed process. In the field of education, this perspective has been applied primarily to learning processes and teaching practices, highlighting the importance of the body, action and the environment in the construction of knowledge (Schilhab & Groth, 2024; Videla & Veloz, 2023).

However, a systematic integration of 4E cognition, teaching professionalism, agency, capabilities and reflexivity in environments governed by platforms, data and algorithms remains underdeveloped. The literature on teacher agency explores the relationship between the individual and the context, but does not always address algorithmic infrastructures as components of the cognitive environment. The capability approach highlights the role of substantive freedoms and conversion factors, but is rarely integrated with a distributed conception of professional cognition. Finally, reflective practice is often analyzed separately from processes of datafication and automation.

This paper addresses this fragmentation by proposing the construct of the '4E teacher in nootechnological ecologies'. The 4E teacher is understood as a professional whose cognition is distributed across body, environment, action, relationships and artifacts, and who exercises their pedagogical responsibility by shaping and critically questioning the socio-technical environments of learning.

Objective and research questions

This paper aims to develop a theoretical model of teaching professionalism in nootechnological ecologies, integrating 4E cognition with the constructs of teacher agency, empowerment and reflective practice.

The following research questions guide the analysis:

Q1: How does 4E cognition enable us to rethink teaching professionalism in digital and algorithmic educational environments?

Q2: What theoretical relationships exist between teacher agency, capabilities and reflective

practice?

Q3: Under what conditions can educational technologies function as enabling extensions of professional cognition?

Q4: Under what conditions can algorithmic infrastructures constrain teachers' autonomy, professional judgment and educational freedom?

This contribution consists of constructing an integrated framework capable of interpreting technologies simultaneously as cognitive artifacts, environmental conditions, resources to be converted into capabilities, and objects of critical reflection.

Method of theoretical analysis

This study adopts a theoretical-conceptual methodology based on a critical-integrative review of the literature. This approach was chosen to bring together traditions that have developed in different fields: philosophy of mind, cognitive sciences, pedagogy of professionalism, studies on teacher agency, the capability approach, reflective practice and critical analyses of educational datafication.

The critical-integrative review is not intended to provide an exhaustive reconstruction of the entire body of scientific literature relating to each strand. It aims to identify concepts, relationships, overlaps, divergences and possibilities for synthesis that are useful for constructing a new interpretative model.

The analysis was structured in four stages. The first involved defining the main constructs: 4E cognition, nootechnological ecology, teacher agency, capability and reflective practice. The second identified the respective units of analysis: body, environment, action, artifacts, institutional constraints, resources, substantive freedoms and processes of professional reflection. The third stage examined the convergences and tensions between the constructs. The fourth stage produced a synthesis aimed at formulating the model and theoretical propositions suitable for future empirical investigation.

This paper does not assess the effectiveness of specific artificial intelligence systems and does not seek to make empirical generalizations. It aims to propose an interpretative framework through which to analyze how technologies contribute to shaping cognition, agency and the conditions of professional freedom.

Results of the theoretical analysis

Nootechnological ecologies

In this paper, the term 'nootechnological ecology' refers to a socio-material educational system in which the production, preservation, circulation and evaluation of knowledge are co-configured by the interaction between human agents, professional practices, institutions, data, cognitive artifacts and algorithmic infrastructures.

This definition critically draws on the transformations described in studies on datafication,

platformisation and knowledge technologies, without attributing to those studies the specific use of the expression 'nootechnological ecology'. The term is employed here as an analytical category to highlight the transformation of the cognitive and epistemic conditions of education.

The concept differs from the more general notion of a digital environment. The latter may refer to a technologically mediated space in which educational activities take place. A nootechnological ecology, by contrast, concerns how technologies affect the organization of attention, memory, access to information, the visibility of behaviors and decision-making possibilities.

Platforms are not neutral containers. They incorporate classification criteria, access logics, tracking capabilities and forms of representation. They make certain activities visible whilst leaving others in the shadows. They transform complex phenomena, such as participation, engagement or learning progression, into data that can be recorded and compared (Macgilchrist, 2020; Williamson, 2017).

Generative AI systems can support design, the production of materials and the processing of feedback. However, they can also implicitly influence linguistic, content-related, epistemological and evaluative choices. The issue concerns not only the automation of individual tasks, but the redefinition of the conditions under which the teacher exercises their judgment.

Teaching professionalism, therefore, operates within an environment in which pedagogical knowledge must engage with the capacity of infrastructure to mediate, select and organize experience. The teacher is not merely a user, but an agent who helps to shape a cognitive, relational and value-based ecology.

4E cognition applied to teaching professionalism

4E cognition regards knowing as a process emerging from the relationships between body, environment, action and tools, as opposed to an exclusively intracranial localization of cognition (Carney, 2020).

When applied to the teaching profession, this framework allows teaching to be interpreted as a distributed cognitive activity. Instructional design, situational understanding, evaluative judgment and the regulation of relationships do not depend solely on internal mental representations. They emerge from the dynamic interplay between teachers, students, spaces, objects, norms and technologies.

Educational applications of the 4E perspective have highlighted the importance of embodiment, situationality and action in the construction of knowledge, whilst operating within theoretical frameworks that are not always consistent (Schilhab & Groth, 2024; Videla & Veloz, 2023).

Embodied cognition

The embodied dimension highlights the body's constitutive role. Gestures, posture, voice, rhythm, gaze orientation, perception and emotional regulation are all components of teaching practice. The teacher continually interprets bodily signals: hesitations, silences, movements, levels of attention,

tensions and forms of participation.

Bodily presence is not merely an external support for professional cognition. It plays a part in understanding the situation and regulating interaction. The embodied and enactive conception of the mind demonstrates how perception and knowledge are rooted in the coupling between organism and environment (Varela et al., 1991).

In digital and hybrid environments, physicality does not disappear, but is reconfigured. Webcams, microphones, chat functions and interfaces select the available signals. Some are amplified, others attenuated or lost. The teacher must therefore develop different ways of paying attention and regulating the relationship.

Embedded cognition

The embedded dimension emphasizes that action is always situated within material, cultural, institutional and regulatory conditions. The teacher does not operate in a neutral space, but within curricula, organizational timetables, assessment systems, professional cultures, the availability of resources, data policies and specific infrastructure.

In nootechnological ecologies, the environment also encompasses the architecture of platforms and the criteria embedded in algorithmic systems. Professional possibilities depend on levels of access, the ability to modify settings, the transparency of procedures, privacy regulations and the scope for challenging automated decisions.

Professionalism is therefore situated within a field of resources and constraints that can either support or constrain the teacher's initiative.

Enacted cognition

The 'enacted' dimension interprets meaning as emerging through action. Teaching does not mean transferring pre-formatted content, but rather constructing situations in which teachers, students, tasks and tools produce meaning through interaction.

The educational value of a technology does not lie in the tool itself. It emerges from the way in which the tool is integrated into a practice, linked to a purpose and reinterpreted by those involved. The same application can foster collaboration, exploration and reflection, or fuel repetition, standardization, and dependence.

The enactive perspective, therefore, allows us to shift our focus from tool adoption to the pedagogical design of the activity (Varela et al., 1991; Videla & Veloz, 2023).

Extended cognition and distributed cognition

The 'extended' dimension asserts that artifacts and tools can become components of cognitive

processes when they are firmly integrated into the individual's activity. In teaching practice, digital logs, archives, rubrics, platforms, dashboards and generative systems can participate in processes of memory, planning, documentation and decision-making.

This possibility can be interpreted through the theory of the extended mind, according to which certain external artifacts can constitute functional parts of the cognitive system (Clark & Chalmers, 1998). A complementary perspective is offered by distributed cognition, which analyses how complex cognitive activities are distributed amongst people, tools, representations and socio-material environments (Hutchins, 1995).

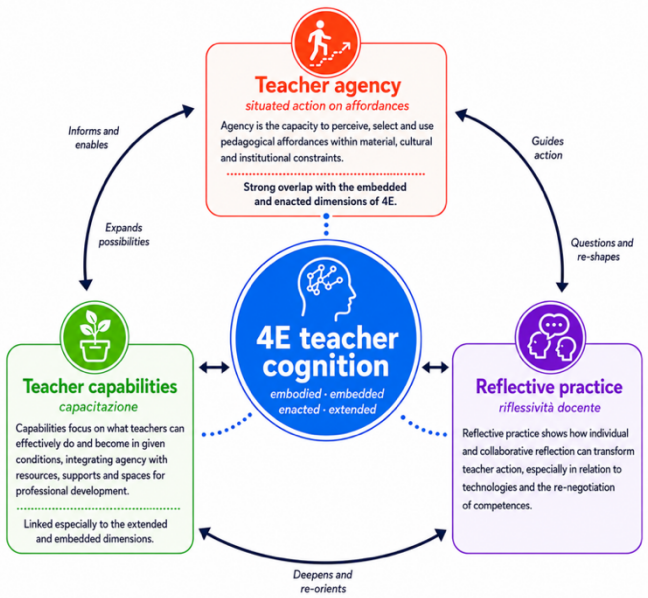
However, not every use of a technology constitutes a case of extended cognition. An artifact can be considered part of the professional cognitive system when it is stably integrated into practice, is sufficiently reliable in terms of accessibility, is used repeatedly, and plays a significant role in memory, planning, or decision-making.

A system used episodically to generate an exercise does not necessarily become a component of the teacher's cognition. Infrastructure that is firmly embedded in design, documentation and assessment, on the other hand, can take on a deeper cognitive function.

Cognitive extension does not automatically coincide with an expansion of autonomy. A technology may enhance certain functions whilst, at the same time, reducing understanding of processes, increasing dependence or transferring decision-making power to the infrastructure.

Figure 1

The 4E teacher model in nootechnological ecologies: relationships between 4E cognition, teacher agency, capabilities and reflective practice.



Teacher agency: action situated within affordances

Teacher agency can be defined as a teacher's ability to intentionally direct their actions within specific historical, institutional, material and relational conditions. From an ecological perspective, agency is not a stable, isolated property of the individual, but an emergent result of the interaction between professional experience, future-oriented perspectives, practical judgment, resources and contextual conditions (Priestley et al., 2015).

The concept of affordance helps us understand how possibilities for action are neither simply objective properties of the environment nor exclusively the intentions of the individual. They emerge from the relationship between environmental characteristics and the organism's perceptual and operational capacities (Gibson, 1979).

Applied to teaching, the concept shows that the teacher acts by perceiving and selecting pedagogical possibilities in their relationship with students, spaces, materials and tools. From an ecological-enactive perspective, the perception of affordances can be understood as a relational process through which the teacher recognizes possibilities for pedagogical action within the dynamic relationship with the environment (He & Levrini, 2024).

In nootechnological ecologies, teachers must interpret not only physical and relational affordances, but also digital and algorithmic ones. They must understand what a platform enables, what it prevents, what it makes visible and what it tends to exclude from its field of representation.

The interaction between digital affordances and agency has also been observed in specific contexts of online language teaching, where the utilization of technological opportunities depended on teachers' professional interpretation and contextual conditions (Yue et al., 2022). This finding cannot be automatically generalized to all educational systems, but it shows that affordances do not produce uniform, context-independent effects.

An AI system can suggest activities, produce rubrics or generate feedback. Professional agency is exercised through the ability to evaluate such proposals, modify them, reject them or adapt them to the educational situation. The presence of an algorithmic recommendation does not remove the teacher's responsibility.

When the system's criteria are not comprehensible, and the procedures cannot be challenged, the agency may be curtailed. When the teacher possesses understanding, control and decision-making autonomy, technology can instead support broader and more informed action.

Agency does not, therefore, equate to independence from technology. It concerns the possibility of participating in the shaping of the socio-technical relationship without relinquishing professional judgment and educational responsibility.

Teacher empowerment: substantive freedoms and enabling factors

The second dimension is teacher empowerment. Through the capability approach, professionalism is assessed not only based on what the teacher actually achieves, but also based on what they are genuinely free to do and become under certain conditions.

In the terminology of the capability approach, resources are not the same as capabilities. The former refer to goods, tools and opportunities that are formally available. The latter concern the combinations of ways of functioning that a person actually has the opportunity to choose and realize (Nussbaum, 2011; Sen, 1999).

Access to a platform, an artificial intelligence system or a training course, therefore, constitutes a resource. This resource becomes a real professional opportunity only when the teacher has the necessary enabling factors: time, support, autonomy, adequate infrastructure, critical expertise, institutional recognition, data protection and the ability to adapt the tools to educational purposes.

Two teachers may have access to the same technology without possessing the same capabilities. The first may work in an institution that promotes experimentation, collaboration and participatory governance. The second may be working in a context where the use of the tool is imposed through standardized procedures and control objectives. The resource is formally similar, but the actual professional freedoms differ.

The development of professional capabilities, therefore, does not depend exclusively on individual training, but also on the quality of professional learning environments, collegial relationships and the organizational support available (Nolan et al., 2020).

From a broader pedagogical perspective, lifelong learning can be interpreted as a condition that fosters professional subjectivity and as a fundamental right in contexts transformed by artificial intelligence and robotics (Costa, 2016, 2022).

Empowerment thus enables us to move beyond an individualistic conception of competence. It is not enough to simply ask teachers to keep their skills up to date. We need to establish institutional conditions in which they can transform technological resources into opportunities of pedagogical value.

The development of agency in the age of artificial intelligence, therefore, requires us to go beyond upskilling by adopting an empowering and transformative perspective on educational work (Costa, 2025).

Reflective practice in algorithmic ecologies

The third dimension is reflective practice. This refers to the teacher's ability to critically examine their own experience both during and after an action.

Schön (1983) distinguishes between 'reflection-in-action' – which takes place whilst the professional

is dealing with an uncertain situation – and 'reflection-on-action', which involves reconsidering the experience after it has taken place. In both cases, reflection is not merely self-analysis, but a re-examination of the relationship between knowledge, decision-making and the situation.

In nootechnological ecologies, reflexivity takes on particular significance, as professional experience is mediated by data, indicators, dashboards, automated feedback and algorithmic recommendations.

Reflection can help strengthen agency by enabling the reinterpretation of experience, the recognition of contextual constraints, and the identification of alternative courses of action. The relationship between different forms of reflection and teacher agency has been explicitly explored within the ecological model of agency (Toom et al., 2020).

Reflectivity in algorithmic ecologies must develop on at least two levels. The first concerns reflection on technologies: the teacher analyses the pedagogical, epistemic, ethical and political implications of the tools. The second concerns reflection through technologies: data, digital traces and feedback can be used as materials for understanding practice, without regarding them as exhaustive representations of educational reality.

It is also possible to distinguish four forms of reflexivity. Technical reflexivity concerns the effectiveness of tools and procedures. Practical reflexivity considers the appropriateness of decisions in relation to contexts and learners. Critical reflexivity questions the values and power relations embedded in the infrastructure. Collaborative reflexivity develops through dialogue with colleagues, learners and professional communities.

A significant risk lies in the transformation of reflectivity into performative self-monitoring. When teachers orient their practice exclusively towards measurable indicators, reflection can be reduced to mere adaptation to metrics. In this case, the data do not support professional judgment but tend to replace it.

Pedagogically meaningful reflection must also examine what systems do not record: relationships, emotions, vulnerability, creativity, conflicts, emerging meanings and non-quantifiable dimensions of the educational experience.

Relationships between the dimensions of the model

Teacher agency, empowerment and reflective practice constitute a dynamic and recursive system. Agency enables the teacher to select, interpret and transform the available affordances. Empowerment defines the space of real possibilities within which agency can be exercised. The reflectivity allows one to interrogate experience, reorient decisions and transform, at least in part, the conditions of action.

4E cognition forms the integrative core of the model. The embodied dimension links professional action to bodily perception and affective regulation. The embedded dimension highlights the role of

institutional constraints and resources. The enacted dimension interprets teaching as the production of meaning through action. The extended dimension clarifies the role of artifacts in processes of memory, planning and decision-making.

Table 1

Dimensions and mechanisms of the 4E teacher model

Dimension	***Main focus***	***Mechanism***	***Risk***	***Enabling condition***
Embodied	Body, perception, affects	Presence and regulation	Compression of corporeality	Relationally sensitive environments
Embedded	Institutional context	Constraints and affordances	Dependence on infrastructure	Participatory governance
Enacted	Situated action	Co-construction of meaning	Standardisation	Design autonomy
Extended	Cognitive artefacts	Distributed functions	Opaque delegation	Control and intelligibility
Agency	Professional action	Selection and transformation	Heterodirection	Contestability
Capabilities	Substantive freedoms	Conversion of resources	Inequality	Real support and opportunities
Reflectivity	Professional experience	Critical inquiry	Self-monitoring	Collaborative spaces

Six theoretical propositions arise from the integration of these constructs.

P1. Educational technologies enhance professional capabilities only when accompanied by institutional, cultural, training and ethical enabling factors.

P2. The technological extension of teachers' cognition strengthens agency when the professional retains understanding, control, the ability to challenge and decision-making responsibility.

P3. Algorithmic opacity tends to curtail agency by transforming technical recommendations into prescriptions that are difficult to challenge.

P4. Collaborative reflexivity can reduce the risk that learning analytics and monitoring systems will produce performative compliance.

P5. The educational quality of nootechnological ecologies depends on the configuration of relationships between technologies, individuals, norms and pedagogical aims, rather than on the quantity of tools available.

P6. The greater the dependence of teachers' judgment on unintelligible infrastructure, the greater the risk of a reduction in professional epistemic autonomy.

Implications for teacher training

This model implies a review of initial and continuing professional development programs. Training teachers in nootechnological ecologies does not merely mean developing operational skills for using artificial intelligence platforms and systems. It means fostering a professional ethos capable of understanding, evaluating and transforming complex educational environments.

In initial training, it is necessary to integrate instructional design, analysis of affordances, ethical reflection and a critical understanding of artificial intelligence. Future teachers should be trained to question not only how a tool works, but also the forms of knowledge, interaction and assessment that it enables.

Every educational technology should be analyzed through pedagogical questions: what activities does it facilitate? What aspects of learning does it make visible? What behaviors does it tend to favor? What data does it collect? What dimensions of experience does it leave out of its representation?

Reflective professional communities play a key role in continuing professional development. Teachers must be able to analyze real-world cases, compare human decisions with algorithmic suggestions, discuss the effects of platforms and share strategies for the pedagogical reappropriation of tools. Professional development is not merely technical updating, but the building of capabilities through collaborative and reflective environments (Nolan et al., 2020).

Training consistent with 4E cognition should itself be embodied, situated, acted upon and distributed. It should not be limited to the transmission of procedures, but should create conditions in which teachers can experiment, discuss, make mistakes, rethink their decisions and develop professional judgment.

Implications for the governance of artificial intelligence

The model has implications for the governance of artificial intelligence within education systems. The adoption of technologies cannot be assessed solely based on criteria such as efficiency, personalization or cost reduction. It must also be analyzed in relation to its capacity to expand or restrict professional freedoms.

Governance geared towards empowerment should ensure transparency, contestability, participation, data protection and ultimate human accountability.

Transparency requires that teachers be able to understand the purposes, limitations and general criteria of the systems used. Challengeability implies that algorithmic recommendations and classifications can be discussed, corrected or rejected. Participation involves teachers in the selection, adaptation and evaluation of the tools.

Data protection concerns not only legal compliance but also consistency between data collection practices and pedagogical aims. Ultimate human accountability stipulates that educational decisions

cannot be delegated entirely to automated systems.

In the absence of these conditions, technologies may foster an externally directed form of professionalism. When participatory governance is in place, it can become an empowering extension of educational planning.

This perspective aligns with the need to interpret continuing professional development as a fundamental right rather than merely an individual obligation to adapt to contexts transformed by artificial intelligence and robotics (Costa, 2022).

Discussion

The proposed model takes neither a technophile nor a technophobic stance. Educational technologies are ambivalent: they can either expand agency, capabilities and reflexivity, or constrain them.

A first tension concerns the relationship between cognitive extension and deskilling. A tool can support memory, planning and feedback without replacing professional judgment. However, when it progressively automates complex decisions, it can weaken essential skills.

A second tension concerns the relationship between personalization and surveillance. Data can contribute to an understanding of students' needs, but it can also transform the educational experience into an object of continuous monitoring (Macgilchrist, 2020; Williamson, 2017).

A third tension concerns the distinction between data-informed teaching and data-driven teaching. In the former, data is one of many sources and informs the teacher's judgment. In the latter, it assumes a dominant role and tends to directly guide decision-making.

A fourth tension concerns the relationship between individual agency and infrastructural power. Even a competent and reflective teacher may have little room for maneuver if they operate within closed platforms, non-modifiable procedures and unchallengeable assessment systems.

The model helps us understand that the pedagogical quality of technology does not depend solely on the intentions of the individual teacher. It also depends on the design of the tools, the distribution of decision-making power, data governance and organizational conditions.

Limitations of the model

The model has certain limitations. It is a theoretical proposal and has not yet been empirically validated. The relationships between the dimensions are formulated as conceptual hypotheses rather than as proven causal links.

Furthermore, the model does not aim to represent all aspects of teaching professionalism. Constructs such as care, identity, tacit knowledge, educational justice, moral responsibility and the political dimension of the profession require further exploration.

The integration of 4E cognition, agency and the capability approach is not without its tensions either. 4E cognition primarily describes the organization of cognitive processes; the capability approach introduces a normative perspective on freedoms and real opportunities; teacher agency focuses on the subject's temporally situated action. The model does not eliminate these differences but utilizes them as complementary levels of analysis.

Finally, the term 'nootechnological ecology' requires further discussion and comparison with related categories, such as digital ecology, cognitive ecology, sociomateriality, platformisation and post-digital education.

Research Prospects

A first line of research concerns qualitative studies of teachers' practices in using generative artificial intelligence systems in planning, assessment and professional reflection. Interviews, observations and case studies could reveal how these tools are actually integrated into professional cognitive systems.

A second line of research involves comparing institutions with different governance models. Such a comparison could examine how transparency, participation and contestability affect capabilities and agency.

A third direction involves developing indicators to empirically observe agency, empowerment and reflexivity within nootechnological ecologies. Such indicators could support the development of both qualitative and quantitative tools.

Further studies could investigate the relationship between algorithmic explainability and professional trust, the differences between experienced and novice teachers, and the longitudinal effects of automation on skills.

It would be particularly relevant to test the model's propositions in different school and university contexts, analyzing how the same technologies produce different effects in relation to institutional and cultural conversion factors.

Conclusions

This paper has proposed a theoretical model of teaching professionalism in nootechnological ecologies, based on the integration of 4E cognition, teacher agency, the capability approach and reflective practice.

The argument put forward is that teaching in the age of artificial intelligence cannot be adequately understood through technical or adaptive categories alone. Teaching professionalism is an embodied, situated, acted-upon and extended phenomenon that takes shape in the interaction between body, environment, action, relationships and artifacts.

The 4E teacher construct allows us to interpret technologies not as neutral tools, but as components of cognitive and institutional ecologies capable of expanding or restricting professional freedoms. Artificial intelligence can support memory, planning, documentation and reflection; however, it can also lead to dependence, opacity, standardization and a reduction in epistemic autonomy.

The crucial point, therefore, is not whether to adopt or reject technologies, but to establish pedagogical, institutional and ethical conditions that enable teachers to exercise agency, develop capabilities and maintain critical reflexivity.

The significance of the model lies in linking the ecological organization of cognition to the normative and institutional conditions of professionalism. From this perspective, a technology can be considered pedagogically empowering not because it abstractly increases the number of available functions, but because it expands the teacher's actual possibilities to design, choose, understand, challenge and responsibly make educational decisions.

The future of the teaching profession will therefore depend not only on the evolution of tools, but on the ability of education systems to construct intelligible, democratic and human-development-oriented nootechnological ecologies.

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