

# Managing uncertainty in the physics classroom: a case study of a preservice teacher's PCK in action (ePCK)

## Summary

The development of Pedagogical Content Knowledge (PCK) is a cornerstone of physics teacher training, although the mechanisms underlying its construction in preservice practice are poorly understood. This article presents a qualitative case study that analyses a preservice teacher's PCK development process when managing their students' persistent "intuitive physics." Using the Refined Consensus Model (RCM), it examines how a critical classroom incident triggers a learning cycle. Findings reveal that professional development was catalysed by the "disruption" of the teaching plan, not its successful implementation. The "surprise" at the deviation between teaching and actual learning prompted deep reflection. This process was mediated by an ecology of practice where institutional "amplifiers," such as structured reflection assignments, were crucial for the teacher to transform the "filters" of practice into learning opportunities. It is concluded that teacher training must equip future teachers with reflective scaffolding tools to learn from the uncertainty inherent in teaching physics.

**Keywords:** Pedagogical Content Knowledge; Initial Teacher Training; Physics Teaching; Teacher Reflection; Refined Consensus Model

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## Introduction

The development of competent science teachers is a fundamental pillar of scientific literacy in society. In this context, Pedagogical Content Knowledge (PCK) has established itself as the most powerful theoretical construct for understanding teachers' distinctive knowledge. This knowledge transforms disciplinary content into subject matter that students can learn and teach. The Refined Consensus Model (RCM) of PCK represents the most current and robust conceptualisation of this knowledge, describing it as a dynamic system situated in practice. However, while the RCM offers a detailed map of the architecture of teachers' knowledge, the research community has highlighted the need for more empirical studies that illuminate the processes and conditions that catalyse the development of this knowledge in authentic contexts, particularly during the critical stage of preservice teacher training.

This article seeks to fill this gap through a qualitative and interpretive case study. It analyses in depth the experience of a preservice physics teacher, "Leandro," during his teaching placement. The study focuses on how managing a persistent teaching problem—the robustness of students' intuitive physics in the face of Newtonian concepts—becomes the driving force of his professional development. We argue that the most meaningful teacher learning emerges not from the successful execution of a plan, but from the reflective management of disruption. We argue that it is in the tension generated by unforeseen classroom "detours" that PCK is most robustly tested, deconstructed, and reconstructed, a process intensely mediated by the ecology of practice; that is, by the interplay of contextual and personal filters and amplifiers.

To guide our analysis, this paper is structured around the following main research question: How is a preservice teacher's PCK development cycle configured when faced with a persistent problem of practice, and what factors of the classroom ecology mediate this process? This question leads to three specific questions that structure

our results: 1) How does a problem of practice manifest itself in the classroom through a recurring cycle of planning, detouring, and reflexive reconstruction? 2) How can the architecture of this cycle be interpreted through the dynamics of exchange between RCM domains? 3) What mediating factors of the ecology of practice explain the conditions that enable the experience to transform into meaningful PCK development?

## Theoretical framework

The study of teachers' professional knowledge underwent a paradigm shift with the introduction of the construct of Pedagogical Content Knowledge (PCK). Initially coined by Shulman, PCK is defined as teachers' distinctive knowledge, an amalgamation of content and pedagogy that allows the transformation of disciplinary material into something comprehensible to students.<sup>1</sup> This transformation is particularly critical in physics education, where many of the fundamental concepts (e.g., fields, forces at a distance, wave-particle duality) are abstract and deeply counterintuitive. Over time, research on PCK expanded, generating multiple models. To unify and strengthen the field, a group of experts developed the Refined Consensus Model (RCM) of PCK.<sup>2</sup> This model represents the most current conceptualisation and describes PCK not as static knowledge, but as a dynamic and situated system, deeply rooted in teaching practice.

## The RCM Architecture: domains and dynamics

The RCM postulates that a teacher's knowledge is organised into distinct, interacting domains. For our analysis, three of these domains are central:

- Collective PCK (cPCK): Refers to the canonical body of knowledge shared by the community of physics teachers, educators, and researchers. It is found in textbooks, curriculum guides, research articles on physics education, and other professional artefacts.<sup>2,3</sup>

- b) Personal Professional Knowledge (pPCK): This refers to the knowledge that an individual teacher possesses. It encompasses their beliefs about teaching (orientations) and their specific knowledge about students' difficulties (e.g., the persistence of Aristotelian conceptions of motion), as well as their understanding of the physics curriculum and relevant teaching strategies (e.g., the use of interactive demonstrations or simulations).<sup>3</sup>
- c) PCK in Action (ePCK): This refers to knowledge as it manifests and is applied during classroom practice. It represents the implementation of pPCK during physics lesson planning, teaching, and subsequent reflection. It is in this domain that the teacher's knowledge is tested and developed.<sup>3,4</sup>

Recent research on ePCK has deepened our understanding of it as a dynamic and situational construct. Alonzo et al.<sup>3</sup> distinguish between macro and micro ePCK, where macro ePCK encompasses the entire planning-teaching-reflection cycle of a lesson, while micro ePCK is manifested in the multiple momentary pedagogical decisions made during classroom interactions. This conceptualisation captures both deliberate pedagogical decisions and teachers' in situ responses. Empirical research has shown that the development of ePCK is uneven across its components. Can<sup>5</sup> found that chemistry teachers exhibit greater ePCK in reflecting on conceptual teaching strategies but lower performance in teaching related to curricular relevance. Similarly, longitudinal studies reveal that while knowledge of instructional strategies consistently improves, knowledge of assessments shows more limited progress.<sup>6</sup> Peer coaching enriched with content representations (CoRe) has emerged as a key factor in the development of ePCK. Research shows that observing peer instruction, combined with structured reflection, enhances the development of personal PCK and its subsequent enactment in the classroom.<sup>6</sup> This finding reinforces the importance of the social and collaborative component in the development of pedagogical content knowledge.

### RCM in empirical research: recent focus

Since its formulation, the RCM has served as a powerful heuristic for empirical research on teacher knowledge. Recent studies have used it to analyse the development of PCK in various areas of science and at different stages of teachers' careers, from preservice to expert teacher training.<sup>7</sup> A prominent line of research has focused on the domain of ePCK, seeking to understand how teachers' personal knowledge translates (or not) into concrete actions in the classroom and what factors modulate this process.<sup>4</sup> The literature agrees that the development of PCK is a complex, non-linear, and highly context-dependent process, where experience alone does not guarantee learning.<sup>8</sup> This underscores the need to investigate the specific mechanisms that catalyse meaningful professional development, especially at the critical stage of preservice training.

### Reflective practice: the PCK development mechanism

RCM posits a feedback loop in which practical experience (ePCK) modifies personal knowledge (pPCK). However, the cognitive mechanism that drives this transformation is reflective practice. Inspired by the foundational work of Schön,<sup>9</sup> reflection is understood as the process by which professionals reflect on their actions to extract learning from them. It is not an automatic process; it requires teachers to distance themselves from the immediacy of practice in order to analyze it critically.<sup>10</sup> In the context of RCM, reflection is the engine that transforms the "detours" and "surprises" of ePCK into structured and consolidated knowledge in pPCK. Without reflection, a challenging classroom experience can remain merely an anecdote or

a source of frustration. With it, it becomes a case study for the teachers themselves. For this reason, fostering reflective capacity is one of the central objectives of initial teacher training, achieved through specific tools that serve as scaffolding for this process.<sup>11</sup> Reflective practice in relation to ePCK has been the subject of recent intensive research. Studies reveal that adequate reflection on ePCK requires specific tools and scaffolding. Research has identified three distinct forms of ePCK: ePCKP (planning), ePCKT (teaching), and ePCKR (reflection), each requiring distinct reflective strategies.<sup>12</sup>

Beginning teachers exhibit inconsistent ePCK profiles across the planning, teaching, and reflection phases, indicating the need for targeted scaffolding for each phase of the pedagogical cycle.<sup>5</sup> Research indicates that teachers tend to reflect more effectively on teaching strategies than on curricular or assessment aspects, highlighting specific areas that require attention in teacher training. Recent studies on reflective practice in the natural sciences show that, although teachers consistently engage in reflection, they often do so individually without involving peers, managers, or supervisors.<sup>13</sup> This suggests that the transformative potential of reflection could be maximized through more collaborative and institutionally supported approaches.

### The ecology of practice: filters and amplifiers

The translation of pPCK into practice (ePCK) is not straightforward. The RCM recognises that this process is mediated by the ecology of practice, a set of contextual factors that can limit or enhance teacher action. To analyse this ecology, the model proposes two key concepts:

- a) Filters: These are factors that constrain or inhibit teachers' ability to put their knowledge into practice. Research has categorised these filters according to their origin, and they may be related to the teacher themselves (e.g., their beliefs or orientations), the students, or the institutional context.<sup>4</sup> In physics teaching, a recurring and powerful filter is students' alternative conceptual paradigms, which are highly structured and resistant to change, representing a constant challenge for teaching practice.
- b) Amplifiers: These are factors that facilitate, enhance, or catalyse the application and development of teacher knowledge. These can include teachers' attitudes and beliefs that promote learning, as well as contextual support structures.<sup>2</sup> A favourable classroom climate or the scaffolding provided by a training program, as analysed in this study, are examples of amplifiers that can help teachers overcome filters and transform the experience into meaningful learning.

### Methodology

This paper adopts a qualitative research approach from an interpretive perspective,<sup>14</sup> aiming to gain a deep and contextualised understanding of a complex phenomenon: the development of Pedagogical Content Knowledge (PCK) in a preservice teacher. To this end, an instrumental case study design was chosen, analysing "Leandro's" experience not only for its intrinsic value but also as a vehicle for illuminating the processes and conditions that underlie professional learning in practice. The participant developed his internship in a second-year secondary school Physics course with 35 students aged 13 and 14, at a school in the province of Buenos Aires, Argentina, addressing the topic of "Newton's Laws." The corpus for analysis consisted of a rich, naturalistic dataset generated by the resident himself. Sources included his final analysis project, a research paper on his internship, his class journals, which provide a longitudinal view of his reflections, and transcripts of classroom

discussions, along with other artefacts such as photographs of the blackboard and student productions. All ethical precautions were taken in the processing of this information: a pseudonym was used to protect the participant's identity, and his informed consent was obtained for the use of the data for research and publication purposes, ensuring confidentiality throughout.

The analysis procedure was based on the resident's inquiry process. The central themes of our study—"intuitive physics" as a problem and "deviations" as critical incidents—emerged from the analysis Leandro conducted in his final project, guided by the "Dimensions" of the assignment he had been assigned. Our work, therefore, deepens and theoretically reinterprets the categories that the participant himself identified as significant. Based on these themes, the analysis was conducted in three progressive phases: a narrative reconstruction phase to describe the practice cycle, a theoretical-interpretative analysis phase to examine this narrative through the RCM, and an explanatory phase to account for the conditions that mediated the process through the concepts of filters and amplifiers. This approach aligns with recent research that highlights the significance of ePCK analysis in authentic teaching contexts, where pedagogical decisions arise from the dynamic interplay between personal knowledge and the situational demands of the classroom.

To ensure scientific rigour, data sources were triangulated, contrasting information from the final project, diaries, and transcripts to construct a robust interpretation.<sup>15</sup> The credibility of the findings is reinforced by the intensive use of the participants' voices, anchoring our interpretations in their own words and reflections. Finally, this study aims for transferability, offering a "thick description" of the case that allows other researchers and teacher educators to make connections and resonances with their contexts, rather than seeking statistical generalisation.

## Results

### Scenario of an inquiry: the emergence of "intuitive physics" as a problem of practice

The development of Leandro's pedagogical knowledge is embodied in a recurring cycle of planning, action, and reflection. For our analysis, we reconstructed this cycle based on evidence from his practice (journals, transcripts) and, crucially, from his final analytical work. This work was a summative instance in which, following a specific prompt, the resident investigated his practice through three analytical "Dimensions": the use of modelling and experimentation (Dimension 1), addressing students' alternative conceptions (Dimension 2), and managing the goals and deviations from the original plan (Dimension 3). The narrative of his cycle, therefore, is built on the same critical incidents he was guided to investigate.

**Initial planning (ePCK-Plan):** The starting point was a structured and collaborative planning. The action plan, agreed upon with his instructors, consisted of introducing Newton's Second Law through a demonstration using a low-friction cart and a weight system to apply a constant force. The central strategy, which Leandro would later analyse in his "Dimension 1" as an instance of modelling, was to perform the demonstration himself to control the variables and focus the students' attention on the nature of the resulting motion. This decision was made consciously, as his instructors knew that intuitive ideas about force and motion are one of the most persistent obstacles in teaching physics.

The Staging and the "Detour" as a Critical Event (ePCK-in-Action): The execution of the plan in class quickly encountered the

unpredictable reality of the classroom. Barely had the demonstration been completed when a student's intervention: "Teacher, it is obvious. If you apply a greater force, the cart moves faster," fractured the planned sequence. This moment is identified by Leandro himself in his "Dimension 3" as a "detour," an event that forces him to deviate from the script to confront an idea that associates force with velocity, rather than acceleration, a confusion he had not expected to arise so explicitly and so soon. The class, therefore, becomes from the beginning a scenario of tension between the Newtonian model and the students' intuitive physics.

The reflection that transforms the plan (ePCK-Reflect): It is in the reflective space where the cycle is completed and restarts with greater force. Leandro's "surprise" upon correcting the activities and realising that the students "were drawing force and velocity vectors as if they were proportional" validates the importance of the deviation that occurred in class. His analysis of the student work, which forms the basis of his "Dimension 2," confirms that the  $F \propto v$  conception is a profound pedagogical problem, not an isolated comment. This diagnostic reflection becomes the driving force for concrete and deliberate action. As he notes, "For all of this, I decided that next class we cannot move forward. We have to go back and attack this idea head-on." This decision, which involved devoting half of the following class to a "predict-observe-explain" activity to contrast both models, is the most unmistakable evidence of how reflection on a problem (intuitive physics) and a critical event (the deviation) materialises in an explicit redesign of future planning.

This plan-act-reflect cycle was not a single event. It was repeated throughout the teaching sequence, demonstrating a dynamic e-PCK that is tested, evaluated, and reconstructed. The narrative of his practice is, in essence, the story of how she managed a central problem (his Dimension 2: the robustness of Aristotelian thinking) manifested through unforeseen events (his Dimension 3: deviations from the plan), using specific strategies (his Dimension 1: demonstrations as an instance of modelling).

Figure 1 visually reconstructs the cycle that catalysed Leandro's learning. The process begins with initial planning (ePCK-Plan), which focuses on modelling Newton's Second Law. When implemented (ePCK-in-Action), it is disrupted by a critical incident: the "detour" generated by a student's intuitive physics. This event triggers a transformative reflection (ePCK-Reflect), where the "surprise" and the diagnosis of the problem's robustness lead to evidence-based replanning, closing the cycle and demonstrating tangible professional development.

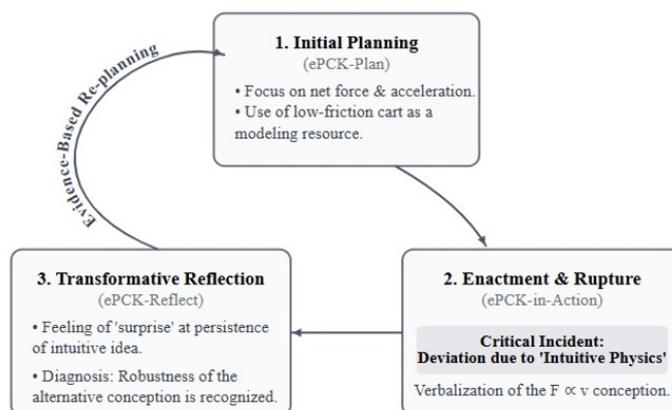


Figure 1 Reconstruction of the practical learning cycle of the future teacher.

## An analysis of cross-domain exchange in RCM

The narrative of Leandro's practical cycle, as described previously, assumes a more profound pedagogical significance when analysed through the lens of RCM. This model allows us to uncover the dialectical tension of teacher knowledge: a constant exchange between the community's expert knowledge, the teacher's personal belief system, and the acid test of classroom practice. We will analyse two crucial avenues of exchange that reveal how Leandro's knowledge was forged in a process of negotiation, rupture, and reconstruction.

### Negotiated influence: from collective knowledge to practice (cPCK → pPCK → ePCK)

The community's professional knowledge—the collective PCK (cPCK)—is not an instruction manual to be passively applied; it is a force that challenges and dialogues with the teacher's emerging knowledge. Leandro's pPCK is constituted in this negotiation. On the one hand, he assimilates the guidelines of his trainers, who, based on their experience, warn him that *"the idea that 'force causes movement' is compelling and a single demonstration is not enough to dismantle it."* This cPCK (the didactic theory and experience of the trainers) is processed and filtered by his pPCK, resulting in a classroom action (ePCK) that is a unique and personal synthesis. His decision to use a real cart instead of a simulation, for example, arises from this deliberation: *"We concluded that it was better to use the cart so that the real movement would be more impactful and less abstract."* It is practice, therefore, that is not the mere execution of external knowledge, but the staging of knowledge that has already undergone a first process of deliberation and appropriation.

### The crucible of practice: from ePCK rupture to pPCK reconstruction

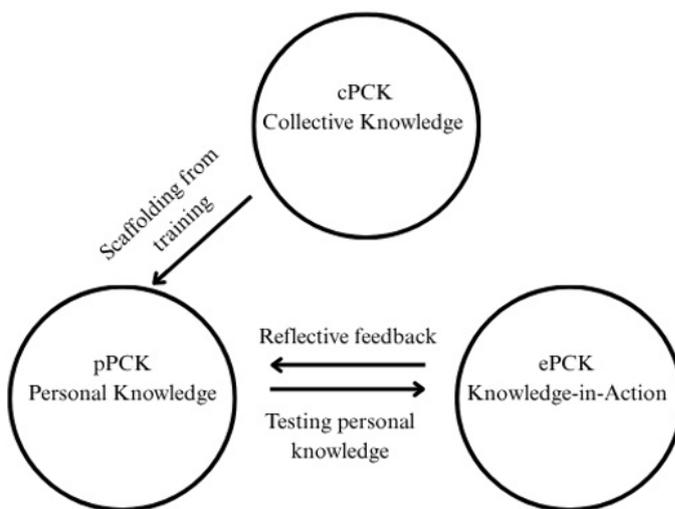
If the previous path explains how practice is prepared, this feedback loop explains how we learn from conflict. This is where tension is at its highest and learning is at its deepest. The classroom experience (ePCK) becomes a crucible that exposes and, at times, fractures the teacher's personal knowledge (pPCK) when it collides with reality. The most unmistakable evidence of this rupture is the "surprise" Leandro expresses in his diary while marking class work: *"To my surprise, the demonstration had not worked. Almost everyone associated force directly with final velocity, not with the change in velocity. I thought they would realise it once they saw it, but the intuitive idea is powerful."* This is not a simple emotion; it is the realisation that his PCK—his belief about the effectiveness of his teaching and how students learn—has been refuted by the evidence. This moment of imbalance, where he also recognises his own "uncertainty about how to dismantle such a deeply rooted idea," is what compels him to do intense intellectual work.

It is through reflection that this rupture becomes productive. Instead of becoming paralysed, Leandro transforms the crisis into an act of professional agency: he takes the "conceptual errors in the guides" as research data. He redesigns his next class to address them explicitly. The decision to "conduct a predict-observe-explain activity" is evidence of how the fracture of experience (ePCK) is repaired and overcome through a conscious shift in his know-how (pPCK).

This cycle culminates in the modification of his deepest beliefs about teaching. His conclusion, that *"it is not enough to simply demonstrate the Newtonian phenomenon; we must make the student's intuitive idea explicit and put it in direct conflict with the evidence,"* represents the reconstruction of his pPCK. The knowledge forged in

the crucible of practice is now more resilient, flexible, and responsive to the classroom's uncertainty.

Figure 2 adapts the Refined Consensus Model (RCM) to illustrate the learning architecture in the case study. The "training scaffolding" provided by the expert community's cPCK feeds into Leandro's pPCK (Personal Knowledge). This knowledge is then "tested" in classroom practice (ePCK). The crucial mechanism, highlighted in the diagram, is the "reflective feedback" loop: the arrow returning from ePCK to pPCK, representing how reflection on action—and especially on the breakdown of action—becomes the main driver for the reconstruction and development of his professional knowledge.



**Figure 2** The dynamics of exchange between RCM domains as a driver of teacher learning.

### Mediators of PCK development: an anatomy of the ecology of practice

Leandro's learning cycle, while powerful in its mechanism, did not occur in a vacuum. Its development can only be explained by analysing the complex ecology of the practice in which he was immersed. Why did a challenge that could have led to frustration become an engine of growth? The answer lies in the dialectical tension between two types of mediating forces: the "filters," which created the necessary conditions for change, and the "amplifiers," which provided the resources to make that change possible. Analysing this interaction allows us to explain the conditions that made the transformation of his knowledge possible.

#### Filters: the anatomy of a productive tension

The filters that mediated Leandro's practice should not be understood as isolated obstacles, but rather as a system of constraints that operated synergistically. Their confluence generated a scenario of high cognitive and pedagogical demand that exposed the limitations of his initial Pedagogical Content Knowledge (PCK), thus catalysing the need for its reconstruction. Below, these filters are broken down into two levels of analysis: structural and contingent.

- **The Epistemological Filter as a Structural Constraint:** The primary and most persistent constraining factor was the robustness of the students' alternative conceptual paradigm, commonly referred to as "intuitive physics." Far from being a sporadic error, this constitutes an internally coherent mental model that is highly resistant to change. In his journal, Leandro reflects on this resistance:

"I thought they would realise their mistake once they saw the demonstration, but it is as if the idea that 'force pushes and moves' is a wall that the explanation runs up against. It is not that they do not understand; it is that they already have another explanation that seems more logical."

The recurrence of this model throughout classroom interactions acted as a persistent force of resistance to the Newtonian model Leandro sought to teach. This situation systematically challenged the effectiveness of his PCK in action (ePCK), imposing a substantial pedagogical and cognitive demand on its management.

- **Contextual and Personal Filters as Contingent Disturbance Factors:** In addition to the epistemological structural constraint, contingent disturbance factors were also present. On the one hand, contextual constraints, such as the time constraints of the curriculum and the limitations of the teaching materials, led to a sharp increase in cognitive load in real-time. These pressures are recorded in his final work: *"The schedule called for 40 minutes for the activity, but between the cart getting stuck on the rail and the bell about to ring, I had to skip the group discussion section, which was the most important."*

On the other hand, these factors exacerbated the personal filter of his vulnerability as a preservice teacher, manifested in feelings of frustration and doubt in the face of the apparent ineffectiveness of his teaching strategies: *"After that class, I felt frustrated. You start to doubt whether what you planned is useful, or if the problem is you because you cannot explain it well."*

It was the convergence of these contingent shocks with the underlying structural constraint that created a high-pressure scenario, revealing the inadequacy of its initial PCK and generating the imperative need for a strategic reconfiguration.

### **Amplifiers: the scaffolding that transforms tension into agency**

If the filters created the need to learn, the amplifiers provided the ability to do so. These factors did not eliminate the problems, but instead gave Leandro the tools and confidence to confront them and transform them into opportunities.

- a) **Classroom climate as a safety net:** The first amplifier was the participatory culture of the classroom. Students' comfort in expressing their "misguided" ideas without fear of punishment created a fundamental safety net. This allowed the primary filter—intuitive physics—to become audible and visible. The "deviation" could be treated as a fascinating fact rather than an act of indiscipline, turning a potential conflict into a shared work object.
- b) **Institutional scaffolding as a navigation tool:** The most decisive amplifier, however, was the very structure of its training program, which functioned as a sophisticated scaffolding system for reflection.
  - Feedback meetings with his physics instructor provided him with an "expert map" (cPCK), helping him name the problem ("what you are seeing is a classic manifestation of Aristotelian thought") and not feel alone in it.
  - Even more powerful, the "Analytic Assignment" served as a cognitive tool that compelled him to become an investigator of his practice. The assignment did not simply ask him to "reflect," but instead required him to use the "three dimensions" as analytical lenses. Thus, the "deviation" (Dimension 3) ceased to be an anecdote and became evidence of an underlying conceptual problem (Dimension

2), which in turn led him to question the adequacy of his modelling strategy (Dimension 1). This scaffolding did not provide him with the answer, but it did offer him a method for constructing it, transforming the chaotic classroom experience into a structured analysis.

Leandro's professional development cannot be attributed solely to his effort, but to the virtuoso interaction within his ecology of practice. It was possible because powerful institutional amplifiers did not protect him from the filters, but rather equipped him to process them. Reflexive scaffolding allowed him to transform the tensions generated by the filters—confusion, frustration, and surprise—from paralysing obstacles into valuable research data. His professional agency flourished, not despite the problems, but because he had the support and tools to learn from them.

## **Discussion of Results**

### **The ePCK cycle as a learning engine for a preservice teacher**

Our analysis reveals that Leandro's professional development revolves around a dynamic and recursive cycle of planning, action, and reflection. This finding provides a high-resolution, empirical illustration of the domain of Pedagogical Content Knowledge in Action (ePCK), as conceptualised in the Refined Consensus Model (RCM). ePCK is defined in the foundational literature as "PCK-in-action," the core of which is a cycle of "planning for, teaching, and reflecting on science teaching for a specific topic, with specific students, for a specific purpose". Leandro's practice fits precisely into this theoretical model. The analysed experience demonstrates the power of this cyclical mechanism. Leandro's initial planning (ePCK-Plan) is put to the test in the classroom (the "teaching" phase), and the results of that action—particularly the deviation caused by the student's intuitive physics—are processed through intense reflection (ePCK-Reflect). It is in this final phase that our case illuminates the central mechanism of teacher learning. The RCM model postulates that "reflection can result in modifications to pPCK". Leandro's experience not only supports this assertion but also demonstrates its catalytic power. His "surprise" at realising the robustness of the alternative conception is not a mere anecdote but the input that fuels a reflection that generates an observable change in his knowledge (PCK) and his subsequent practice. The explicit decision to dedicate a significant part of the following class to confronting the detected error is tangible proof of this virtuous circle: the ePCK experience, processed by reflection, reconstructs the pPCK, which in turn informs a new and more sophisticated planning (ePCK-Plan), thus closing the learning loop.

Furthermore, the fact that this dynamic was mediated by a laboratory demonstration is significant. At the same time, other research has highlighted the role of simulations in facilitating the activation of pPCK and its transformation into ePCK.<sup>12,16</sup> Our case suggests that physical demonstrations play a crucial and analogous role in physics teaching. The trolley demonstration not only served to model the Newtonian phenomenon but also acted as a powerful diagnostic catalyst. By making the canonical phenomenon visible, it simultaneously provoked the verbalization of the student's alternative conception, a manifestation of the robust mental models that research in educational physics has extensively documented.<sup>17,18</sup> In this way, the demonstration intensified the reflective cycle by creating the conditions for making explicit the tension between planned teaching and actual learning, a key strategy in approaches such as "Interactive Lecture Demonstrations".<sup>19</sup> Our study therefore validates the ePCK cycle structure proposed by the RCM and, in turn, illustrates how

physics-specific pedagogical tools can serve as catalysts for such a cycle.

### The breakdown of the plan as a catalyst for deep reflection

While RCM describes the architecture of teacher knowledge, analysing Leandro's case allows us to delve deeper into its catalysts, arguing that it is the unpredictable disruption of practice that significantly activates the learning cycle. The literature on PCK in action highlights the complexity and disorder inherent in classroom practice,<sup>20</sup> in contrast to the structured nature of theoretical models. Our case suggests that it is precisely in managing this unpredictability that the most significant formative potential for a preservice teacher lies.

The “detours” that occur in real time in the classroom are the events that make the tension between planning and reality visible. When a student of Leandro introduces Aristotelian logic (“*more force, faster*”), this “critical incident”<sup>21</sup> creates a cognitive demand that forces the teacher to act. The detour, therefore, is not a mere interruption, but a diagnostic opportunity. It manifests the activation of an alternative conceptual framework by the student, whose structure, persistence, and strategies for its conceptual restructuring continue to be a central area of research and a current challenge in contemporary physics teaching.<sup>22,23</sup> Without this detour, the students' alternative conception might have remained latent or invisible. In this context, “surprise” emerges as a key concept. Leandro's experience allows us to postulate that surprise is more than a simple emotion; it is the verbalisation of an epistemological rupture on the part of the teacher. His note, “*To my surprise, the demonstration had not worked,*” is not a passing comment. It is the precise moment in which his knowledge (pPCK)—his belief in the effectiveness of a teaching strategy—is revealed to be insufficient in the face of evidence from practice (ePCK), generating a dissonance that demands to be resolved through reflection. It is in these authentic and “messy” data of practice—an unexpected comment, a recurring error—where the most powerful reflection is catalysed.

The development of robust PCK appears to depend less on a preservice teacher's ability to execute perfect plans and more on their skill in interpreting and learning from the moments when those plans fracture. The sequence that emerges from our analysis—a plan breakdown that generates a reflective “surprise,” manifesting in the management of a “detour”—allows us to propose a model of how the development of PCK is catalysed. This allows us to engage with other RCM constructs. For example, Behling et al.<sup>4</sup> analyse the “filters” that hinder the expression of knowledge. In our case, surprise can be understood as the teacher's awareness that a filter (the student's intuitive physics) has operated successfully, and it is this awareness that transforms an obstacle into a learning opportunity by triggering reflective action. Our analysis highlights the “zero moment” of this development: the critical incident, fraught with surprise, that compels the preservice teacher to transition from a mere executor of plans to a researcher of their practice.

### Mediators of development in the tension between agency and structure

The development of Leandro's PCK, as we have argued, is an ecological process. Our analysis of mediators aims to address the research community's call for further empirical exploration of the filters and amplifiers that shape teaching practice.<sup>24</sup> In doing so, we not only identify these factors but also interpret their interaction in light of current debates in physics teaching. The epistemological filter

imposed by the robustness of students' “intuitive physics” can be interpreted through the lens of research on teacher noticing. Leandro's “detour” and “surprise” are more than a simple reaction to an obstacle; they represent a key moment in the development of his capacity to notice significant classroom events and make pedagogical sense of them.<sup>25</sup> Rather than dismissing the student's comment as a mistake, Leandro transforms it into a piece of information, a “critical incident” that reveals an underlying thought. This shift from perceiving the error to interpreting the conception is a milestone in teacher learning, especially in physics, where student thinking is often counterintuitive and complex.<sup>26</sup>

On the other hand, institutional amplifiers can be understood as scaffolding tools for evidence-based reflection. The “Analytic Work Instructions” that guided Leandro are an example of an instrument designed to structure inquiry into one's practice, a topic of growing interest in physics teacher training.<sup>27</sup> These types of cognitive tools are crucial because they help preservice teachers move beyond the merely descriptive level of reflection, providing them with a framework for connecting classroom evidence (deviations) with theoretical frameworks (alternative conceptions) and with their repertoire of actions (class redesign). This scaffolding is what enables PCK to develop in an informed rather than purely intuitive manner.<sup>28</sup>

Ultimately, the contribution of our analysis lies in illustrating the dialectical interaction between these phenomena. Leandro's development was possible because the amplifiers (reflective tools and expert scaffolding) allowed him not only to confront the filters (the challenge of alternative conceptions) but also to develop the professional competencies (pedagogical attention) to interpret them as learning opportunities. Our case, therefore, suggests that physics teacher training should focus less on shielding future teachers from the real problems of practice and more on equipping them with powerful scaffolding tools that allow them to investigate and learn from the inherent complexity of their classrooms.

### Conclusion

This case study has analyzed the development of a preservice physics teacher's Pedagogical Content Knowledge (PCK), concluding that the most significant professional learning arises not from the successful execution of a plan, but from the reflective management of disruption. We argue that it is in the tension generated by authentic problems of practice—in this case, the persistent robustness of students' intuitive physics—that teacher knowledge is most robustly tested, deconstructed, and reconstructed. Leandro's experience demonstrates that unforeseen “detours,” far from being mere obstacles, function as catalysts that activate a cycle of inquiry, transforming the classroom into a laboratory for the teacher's learning. This process, however, is not purely individual but is intensely mediated by the ecology of practice, where the presence of “amplifiers”—mainly institutional and reflective scaffolding—is what determines the possibility of turning challenges into meaningful professional growth.

To reach this conclusion, our study followed an analytical trajectory of increasing depth. First, the narrative of the practice was reconstructed, identifying the students' intuitive physics as the persistent problem that, manifesting in “deviations,” fractured the teaching plan and activated a recurring cycle of action and reflection. This cycle was then interpreted through the lens of the Refined Consensus Model (RCM), demonstrating how the management of these critical incidents activated the feedback loop where classroom experience (ePCK) was transformed, through reflection, into consolidated personal knowledge (pPCK). Finally, the analysis of

the ecology of practice revealed that this learning process was made possible by the dialectical interaction between filters and amplifiers.

The main contribution of this study lies in its fine-grained analysis of the catalyst for the development of PCK in preservice teachers. While the RCM describes the architecture and cycle of teacher knowledge, our work illuminates the “zero moment” of that cycle: the critical incident, laden with “surprise,” that forces the preservice teacher to transition from a mere executor of plans to a researcher of their practice. By theorising “surprise” as an epistemological rupture, we offer insight into how the deep reflection presupposed by the model is activated. Likewise, this work directly responds to the research community’s call to delve deeper into the ecology of practice. By analysing the dialectical interaction between filters and amplifiers, we not only identify these factors in a physics teaching context -validating models such as that of Behling et al. but also argue that significant professional growth depends on the strength of institutional amplifiers. Our case demonstrates that it is these reflective scaffolds that equip novice teachers with the necessary tools to transform the challenges of practice into consolidated learning.

The findings of this study have significant implications for the design of physics teacher training programs. If deeper learning is catalysed by uncertainty management, then preparation must go beyond a focus on planning. First, it suggests the need to design practice experiences that value students’ conceptual “detours” (e.g., those related to force, energy, or circuits) as professional learning opportunities, rather than as teaching failures. Second, our case demonstrates that experience alone is insufficient. Programs must provide robust and explicit reflective scaffolding, equipping preservice teachers with theoretical tools (such as the RCM) that allow them to interpret the complexity of their practice. Finally, a pedagogy of uncertainty must be cultivated, developing practitioners with an inquiry-based stance, capable of viewing their classrooms as a laboratory for the ongoing development of their PCK.

Ultimately, the learning of the future teacher, from a teacher seeking to execute a demonstration to a practitioner exploring the complexities of student thinking, exemplifies the transformative potential of authentic practice when mediated by reflective scaffolding. Future research should continue to explore these “ecologies of practice” in diverse physics teaching contexts to understand better how to design programs that cultivate the reflective wisdom essential for navigating and growing within the complexity of teaching.

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