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Developing Teachers' Professional Knowledge in Measurement Uncertainty: A Praxeological Analysis in STEM Education

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Abstract

Teaching complex concepts in metrology, such as measurement uncertainty, raises significant challenges in higher education, particularly in experimental chemistry where the reliability of results depends on the accuracy of measurements and the interpretation of their associated uncertainty. Although international research highlights the importance of metrological literacy for science education and for promoting rigorous experimental practices, studies examining how chemistry teachers actually integrate this knowledge into their teaching remain limited. This lack is even more pronounced regarding the effects of professional development programmes on teachers' didactic praxeology. Our study addresses this gap by analysing the impact of a specialized metrology training program on the professional development of a university chemistry teacher. Drawing on the concept of praxeology from the Anthropological Theory of the Didactic (Chevallard, 1999) and Professional Didactics (Pastré, 2011), we examine, first the structure and intentions of the training designed by an expert in metrology and, second the teacher's subsequent implementation of a practical chemistry session related to measurement uncertainty. The findings show how the training contributes to the evolution of the teacher's praxeologies, particularly in the diversification of tasks, the mobilization of more explicit measurement techniques, and the strengthening of technological-theoretical justifications. By highlighting the conditions that support the effective integration of metrological knowledge into higher education teaching, this study provides insights that are relevant beyond the local context, contributing to international discussions on teacher professional development in STEM education.

Keywords: *Uncertainty in measurement, Professional didactics, Praxeology, Professional development, university education*

INTRODUCTION

Faced with the complex challenges of a constantly changing world, the professional development of teachers is crucial to ensuring better educational quality and effectively preparing learners for future challenges. In particular, the characteristics of technological innovations are evolving, reflecting new needs and expectations for the socio-economic world. The rapid evolution of digital technologies and instrumentation is transforming not only the tools available to scientists but also the methods of research, analysis and communication of results. Science teachers must therefore constantly update their skills and knowledge to integrate these technologies and information into their teaching. This is in order to prepare students to use them effectively in their future careers and to develop their critical thinking skills when faced with scientific information.

To this end, professional development in university science teaching is both a necessity and a major challenge in order to meet these needs. In this regard, 'the university, as a link between the production and dissemination of knowledge, is called upon to evolve in order to meet the demands of the socio-economic world' (Paquelin, 2020, p. 11). Several researchers have emphasised the importance of research and teacher training

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in overcoming challenges and promoting science education (Buffler et al., 2009; Maisch et al., 2008; Munier et al., 2018). However, for a long time, the analysis of activities in dynamic professions, also known as "service activities" (Ginsbourger, 2010; Pastré, 2011), such as education and health, has not been subject to the same pressure to professionalise as other industrial activities (Pastré, 2011). Thus, technical professions, also referred to by Pastré (2011) as 'procedural or industrial activities', such as those in industry and engineering, have undergone a clear structuring process, making it possible to identify and formalise indicators of competence and development, qualifications and prescribed standards of practice.

On the other hand, the field of education, due to its dynamic nature and the uniqueness of each educational situation (Pastré, 2011), has proven to be characterised by theoretical and conceptual differences (Uwamaria and Mukamurera, 2005). This has led to a distinct approach to describing development and analysing educational activities. For this reason, the study of teachers' professional development, while still essential and of great importance, remains a complex and nuanced undertaking.

Beyond the local context of this study, these issues resonate with broader international concerns regarding STEM education and teacher professional development. Across educational systems worldwide, science educators are increasingly expected to integrate complex scientific practices, digital instrumentation and inquiry-based approaches into their teaching, while supporting students' scientific reasoning and critical thinking skills. Recent contributions published in International Journal of Research in STEM Education emphasize these global challenges and underline the importance of innovating STEM teacher professionalization across diverse contexts (Akhmad, 2025; Sukmayadi, 2023). In this perspective, understanding how teachers appropriate and develop specialised teachers appropriate and develop specialised teaching practices after professional training contributes to ongoing international discussions on the professionalisation of STEM teaching and improvement of science education quality in higher education contexts.

In this contribution, we seek to characterise the knowledge and practices that teachers mobilise and develop in a classroom context after completing training. Our objective is to understand how they develop their expertise in teaching measurement uncertainty in a chemistry tutorial following professional training. We adhere to the perspectives of professionalisation as explained by Uwamariya and Mukamuera (2005) and consider the development of praxeological organisation derived from TAD (Chevallard, 1999) from a PD perspective (Pastré, 2011).

In the rest of this article, we will first present the theoretical framework of our study, then develop the issues and our research questions. We will detail the research methodology used. Finally, we will present and discuss the results obtained before concluding on the implications of this research for teacher training.

Theoretical framework

This study lies at the intersection of two theoretical frameworks. On the one hand, there is professional didactics (Pastré, 2011), which analyses the activities of professionals in real work situations in order to explain the knowledge and practices mobilised in the exercise of their profession and to support skill development. On the other hand, there is the anthropological theory of didactics (TAD), developed by Chevallard (1999). This theory offers a conceptual framework, the praxeological model, which allows for the analysis of teaching practices and understanding didactic phenomena as manifestations of human activity. Within a praxeology, TAD distinguishes a practical-technical component (the techniques used to accomplish a task) and a technological-theoretical component (the discourse that justifies and legitimizes these techniques).

We hypothesise that teachers' professional development can be understood as an evolution of their praxeologies. By identifying and characterising the praxeologies implemented by teachers in two different contexts for the same subject matter, we seek to account for their professional development. In doing so, this study contributes theoretically by extending the use of the praxeological model to the analysis of STEM teacher professional development, showing how changes in techniques and in the underlying technological-theoretical discourse can serve as indicators of professional growth. It also advances research on STEM teacher learning by proposing a way to articulate professional didactics with TAD to capture how teachers restructure and enrich their practical and conceptual organisation after training.

Within STEM education, this praxeological perspective can be situated within a broader understanding of teachers' professional knowledge. Effective STEM teaching requires teachers to mobilize disciplinary knowledge together with pedagogical knowledge and the capacity to reorganize these forms of knowledge in response to interdisciplinary problems and authentic teaching situations. Chan et al. (2019) emphasize that teachers' practical knowledge for STEM teaching cannot be reduced to mastery of individual subject content; it involves adapting knowledge and teaching practices to the interdisciplinary character of STEM education. From this perspective, praxeological analysis provides a particularly useful lens because it makes professional knowledge observable through the relationship between the tasks teachers construct, the techniques they mobilize, and the discourse through which these techniques are explained and justified. In the present study, this relationship is especially important because teaching measurement uncertainty requires the university chemistry teacher to coordinate experimental chemistry, mathematical reasoning, measurement procedures, and metrological knowledge rather than simply transmit a predetermined chemical procedure. The development of professional knowledge can therefore be examined through changes in how these different knowledge domains are organized and enacted in practice (Chan et al., 2019).

Such professional knowledge is not acquired solely through exposure to theoretical content; it develops through opportunities to connect specialized knowledge with classroom practice, reflection, and the analysis of professional activity. Research on STEM teacher professional development indicates that programs combining learning by design and reflective learning can support teachers in establishing stronger connections between disciplinary content and classroom implementation (Huang et al., 2022). This is particularly significant because the interdisciplinary character of STEM education can itself create difficulties for teachers whose previous professional knowledge and institutional practices have been organized around separate disciplinary traditions. Dong et al. (2020) show that these challenges are related not only to curriculum structures but also to teachers' existing beliefs and knowledge bases, with greater familiarity with STEM pedagogy associated with fewer perceived implementation difficulties. Viewed through Professional Didactics and TAD, professional training can consequently be understood as a potential reorganization of professional activity: teachers may expand the repertoire of tasks they recognize, modify the techniques they use to address those tasks, and develop more explicit technological-theoretical justifications for their actions. This provides the conceptual basis for examining the metrology training in the present study not simply as knowledge transmission, but as a possible source of transformation in the teacher's praxeological organization (Huang et al., 2022; Dong et al., 2020).

The practical enactment of professional knowledge is also central to contemporary conceptions of STEM teacher competence. A comprehensive competence framework requires teachers to coordinate STEM disciplinary knowledge, pedagogical decision-making, and appropriate uses of technology in ways that enable students to participate meaningfully in STEM learning (Le et al., 2025). In particular, authentic STEM education places considerable emphasis on practices such as problem solving, modelling, investigation, evidence-based reasoning, and the interpretation of data. Professional development experiences that explicitly engage teachers with such practices can strengthen both teachers' knowledge and their capacity to create corresponding learning opportunities for students, as demonstrated in professional learning initiatives such as the i-STEM summer institute (Nadelson et al., 2015). Measurement uncertainty provides a particularly relevant context for examining these competencies because estimating uncertainty requires learners and teachers to move between an experimental phenomenon, its chemical representation, mathematical models, sources of measurement variability, and reasoned interpretation of evidence. The praxeological model therefore enables this study to examine whether professional training contributes not merely to procedural competence, but to a richer organization of STEM-related professional knowledge in which techniques are connected to the scientific and technological reasoning that gives them meaning (Le et al., 2025; Nadelson et al., 2015).

The development of such professional knowledge must also be considered in relation to the digital transformation of contemporary STEM practices. Traditional formulations of technological, pedagogical, and content knowledge have increasingly been extended to recognize that digitalization changes not only the tools available for teaching but also the cultural and epistemic conditions under which scientific knowledge is produced, represented, communicated, and evaluated. The extension from TPACK toward DPACK therefore emphasizes the importance of knowledge concerning digital transformation and its sociocultural consequences for teaching and learning ("From TPACK to DPACK: The 'Digitality-Rel...'," 2023; Thyssen et al., 2023). STEM teachers are increasingly required to interpret digitally generated data, work with sophisticated instrumentation, and enable students to reflect critically on the role of digital technologies in scientific and societal practices ("From TPACK to DPACK: The 'Digitality-Rel...'," 2023; Thyssen et al., 2023). This perspective is directly relevant to metrology, where measurement, calibration, uncertainty estimation, data processing, and the communication of experimental results are increasingly mediated by digital instruments and analytical systems. Accordingly, the praxeological perspective adopted in this study can be understood within a wider conception of STEM professional knowledge: professional development involves not only acquiring new procedures, but learning how to select, justify, adapt, and critically mobilize disciplinary, pedagogical, technological, and increasing digital knowledge within authentic teaching situations. Continuous professional development is therefore essential for enabling teachers to respond to interdisciplinary and technological change while maintaining the conceptual and epistemological coherence required for high-quality STEM education ("From TPACK to DPACK: The 'Digitality-Rel...'," 2023; Thyssen et al., 2023).

Research problem and objectives:

The analysis of professional development in the teaching profession has been the subject of several research studies focusing on development in the field of education (Frenay, Jorro and Poumay, 2011; Guskey, 2000; Lefeuvre et al., 2009; Pastré, 2011).

These studies show that the concept of "professional development" is fundamental to research in the field of education, but that it remains complex and does not yet have a consensus or a stable meaning. This complexity can be explained by the difficulty of determining indicators of professional development in dynamic or relational professions. The meaning of the concept of 'professional development' is indeed polysemic and unstable, which has given rise to numerous debates and differences of opinion within the research community.

According to Uwamaria and Mukamurera (2005), researchers disagree on the name, content and limits of the stages of professional development. Some authors, such as Brodeur, Deaudelin & Bru (2005), consider the terms "professional development" and "continuing education" to be synonymous. In studying teachers' activities, Pastré states that "It was seen primarily as an art form, which was difficult to subject to rigorous work analysis. But their analysis shows that certain character traits can be found in it. (Pastré, 2011, p. 71).

Similarly, views on how to promote this development also vary. Some studies emphasise external interventions such as continuing or professional training programs aimed at stimulating teachers' reflection on their practices (Boucher and L'Hostie, 1997; Clément and Vanderberghe, 1999; Lafourtune and Deaudelin, 2001). Other authors postulate that professional development is a profound transformation of the teacher, influenced by their experiences, social environment, and educational contexts (Raymond, But and Townsed, 1992; Limoges and Hébert, 1988).

This lack of consensus on the meaning and modalities of professional development leads to difficulties on two levels. First, it is difficult to determine clear and usable criteria for evaluating the effects and mechanisms of development. Second, it complicates the development of prescriptive recommendations to effectively guide the educational process. In other words, the absence of a shared definition of professional development makes it difficult to identify reliable indicators for measuring its impact and understanding the processes involved (Lefeuve et al., 2009).

Professional training is a highly recommended way of ensuring teacher development. Seeing the impact of training on teachers' professional development remains a major concern for those interested in educational issues.

With the aim of promoting her teaching metrology skills, an experienced university lecturer specialising in chemistry voluntarily took part in a professional training package organised by a private training firm. She then put the knowledge she acquired during this training into practice in a real classroom setting. In our research, we aim to study the effect of this training on the development of this lecturer's professional practices. To do this, we first examined the teaching practices implemented by the expert trainer during a continuing education session dedicated to estimating measurement uncertainty in the context of acid-base titration. Next, we analysed the practices of a university lecturer who had previously taken the same training course. A comparison was then made between the professional actions of the teacher in a teaching situation and those of the trainer, the latter being considered a reference for teaching measurement uncertainty. Although this approach does not allow us to directly trace the evolution of the teacher's practices, it provides a relevant framework for identifying deviations from expected practices and, thereby, revealing the adjustments that are still necessary.

Analysis of the praxeologies developed on these occasions makes it possible to model the practices implemented, focusing on the concrete actions of the teacher and the trainer in teaching situations, and to understand the logic behind and justifying these practices. This study also allows us to understand how knowledge relating to the teaching of measurement uncertainty is constructed, transmitted and appropriated in the context of teaching and learning. On another level, comparative analysis of these praxeologies allows us to identify the effect of professional training on teaching practices. This effect is measured in terms of differences and similarities.

The research attempts to answer the following question:

1. what types of tasks, techniques, technologies and theories relating to measurement uncertainty and acid-base dosages are implemented by the trainer and then by the teacher?
2. What types of difficulties were identified in this teacher?
3. By comparing the praxeologies used by the two actors, what are the points of convergence and divergence? Why?

METHODOLOGY

Participants and Research Context

The study sample consists of an expert trainer in metrology who leads the training course in question and an experienced university lecturer specialising in chemistry, who is part of a group of participants from different fields. The training took place at a private training center in the Tunis region. The teacher observed was chosen based on our research question, her initial training in chemistry and her professional background. Her involvement in a metrology training program, combined with her university teaching experience, made her a particularly relevant candidate for analysing the evolution of teaching practices related to measurement uncertainty.

The filmed tutorial session took place at a state university in the capital, Tunis. This session, intended for students at the professional master's level specialising in Environment and Industrial Physico-Chemical Analysis, lasted 1 hour and 30 minutes. The entire professional training package took place over a period of almost four months (84 hours in total). In this proposal, we examine an analysis of one session from this package, a 3-hour recording excerpt on the topic of estimating measurement uncertainty for acid-base titration. This excerpt was chosen because of its relevance to our research objective, which is to model the trainer's practices when teaching knowledge related to measurement uncertainty.

Data Collection Procedures

Data was collected from two interconnected professional situations: the metrology training situation and the subsequent university teaching situation. This design made it possible to document professional knowledge first as it was introduced and organized by the expert trainer and then as it was mobilized by the university chemistry teacher in an authentic teaching context. Participant observation and video recording were used to preserve the chronological organization of professional activity, including the tasks proposed, techniques demonstrated or employed, explanations provided, and interactions occurring between the trainer and participants and between the teacher and students. The training and teaching materials used during these situations were also considered as complementary sources for interpreting the observed activity.

Self-confrontation interviews complemented the observational data by providing access to the reasoning associated with selected professional actions. Rather than relying exclusively on what could be observed in the recorded sessions, these interviews enabled the participants to revisit particular moments of their activity and explain the considerations underlying their choices. This was especially relevant for identifying elements of professional knowledge that might not have been explicitly verbalized during the training or tutorial sessions. The combination of observation, video recordings, instructional materials, and self-confrontation interviews therefore provided multiple sources through which the professional activity could be reconstructed and interpreted within the praxeological framework.

For data collection, we used participant observation, video recording and self-confrontation interviews. The sample was selected based on the training subject, the trainer's training and expertise, and their experience. The praxeological elements come from the training session materials and the interactions between the trainer and participants, as well as between the teacher and students, the tutorial materials and the course materials. These interactions were transcribed and divided into sequences according to the praxeological model expressing tasks, techniques and technologies.

Praxeological Coding and Data Analysis

The analysis was conducted by treating the recorded professional activity as a sequence of situations in which particular tasks were addressed through identifiable techniques and supported by forms of technological discourse or *logos*. The transcripts were first segmented according to changes in the object of professional activity, such as defining the measurand, constructing a measurement model, identifying sources of uncertainty, estimating standard uncertainties, or expressing the measurement result. Each segment was then examined to determine what task was being addressed, how the trainer or teacher attempted to accomplish it, and what knowledge or reasoning was mobilized to justify the selected technique. This procedure enabled the empirical data to be reorganized according to the task–technique–logos structure adopted in the study.

The analysis was conducted separately for the trainer and the teacher before the two praxeological organizations were compared. This separation was necessary because the trainer and teacher operated within different professional and institutional situations. The trainer organized specialized knowledge within a metrology training environment, whereas the teacher mobilized and adapted that knowledge within university chemistry instruction. The comparison therefore focused on identifying which praxeological elements introduced during training subsequently appeared in the teacher's practice, how they were reorganized in response to the chemistry teaching context, and which elements were absent or less explicitly developed. Convergence and divergence between the two praxeologies were consequently interpreted as evidence for examining the nature and extent of professional knowledge development rather than as a direct measure of teaching effectiveness. To identify tasks, techniques and technologies, we opted for the following table:

Table 1 Identification of elements of disciplinary praxeology

Tasks	**Techniques**	**Logos**
What actions should the trainer (or teacher) take to deal with the situation described?	What tools and resources are being used?	What reasons justify accomplishing the task in this manner?

Since we did not identify a theory category, we used a three-column praxeology approach.

Analytical Alignment with the Research Questions

The analytical procedure was directly aligned with the three research questions guiding the study. The first level of analysis identified the tasks, techniques, and *logos* mobilized by the expert trainer and subsequently by the university chemistry teacher. This provided a descriptive and analytical reconstruction of the two praxeological organizations. The second level examined the difficulties that became visible when specialized knowledge of measurement uncertainty was transferred from the professional training environment to university chemistry teaching. Particular attention was given to situations in which techniques were mobilized without the same degree of technological-theoretical justification observed in the trainer's activity.

The third level involved a comparative analysis of the trainer's and teacher's praxeologies. Convergences were examined as possible indicators that elements encountered during professional training had been appropriated and subsequently mobilized by the teacher, whereas divergences were analyzed in relation to the disciplinary and institutional conditions of university chemistry teaching. Importantly, similarity between the two praxeologies was not interpreted automatically as professional development, nor was divergence considered evidence of failure. The analysis instead examined how professional knowledge was selected, reorganized, and adapted when moving between the two professional situations.

On this basis, the methodological analysis addressed the following research questions: (1) What types of tasks, techniques, technologies, and theoretical knowledge related to measurement uncertainty and acid-base titration are mobilised by the expert trainer and subsequently by the university chemistry teacher? (2) What difficulties become visible when the university chemistry teacher mobilises this professional knowledge in an authentic teaching situation? (3) What points of convergence and divergence emerge between the praxeologies of the expert trainer and the university chemistry teacher, and what do these differences reveal about the development of professional knowledge following training?

RESULTS AND ANALYSIS

In this section, we will present the elements of praxeology employed by the trainer and then by the teacher, respectively, and we will present a comparative table of these praxeologies.

Praxeologies developed by the trainer in a training situation

The table below summarises, in chronological order, the Praxeologies used by the trainer to resolve the purposed situation.

Table 2 Disciplinary Praxeologies used by the trainer to teach measurement uncertainty in a training center

Tasks	Techniques	Logos
Presentation of the process and definition of the measurand	Determine the object of measurement using the formula provided. Analyse the experimental process using a graphical representation of cause-effect relationships. Develop a mathematical model to express the measurand.	5M diagram Law of propagation of uncertainties
Determination of standard uncertainties	Select, from the data collected, the law that best represents the phenomenon under study. Identify the components of uncertainty and estimate their values.	Law of probability Law of propagation of uncertainties
Determining the standard uncertainty	Express the result of the measurement, whose value corresponds to the sum of the individual standard uncertainties associated with the input quantities of the measurement model	Law of propagation of uncertainties
Determine the expanded uncertainty U.	Present the result together with its uncertainty, obtained by applying the combined standard uncertainty multiplied by the coverage factor K to the result.	Law of probability

Analysis of the trainer's activity reveals a logical and rigorous structure to the training sequence on the assessment of measurement uncertainty. This structure is evident in the logical progression of four main tasks that the trainer implements sequentially.

The trainer begins by explaining the basics of the analysis, clearly defining the object of measurement (the measurand) and explaining the measurement process (definition of the measurand and description of the measurement process). This step is fundamental to the exercise because it provides context for the uncertainty assessment and ensures that participants understand the quantity to be measured and how to measure it. The trainer then moves on to the second step of the assessment process, which is to estimate the standard uncertainties. This step involves quantifying the uncertainty associated with each identified source of error. Once the standard uncertainties have been estimated, the trainer guides participants in combining these uncertainties to obtain an overall measure of the combined standard uncertainty (the overall uncertainty). Finally, they explain how to expand the combined standard uncertainty to obtain a 95% confidence interval. In other words, a range of values within which the true value of the measurand is likely to lie with a certain level of probability.

To carry out these tasks, the trainer uses a set of techniques that rely mainly on mathematical measurement models and judgements based on available data on the variability of input quantities, such as calibration certificate data, data provided by manufacturers, etc.

With regard to the theories used by the trainer, the results of our analysis showed that he relies on international standards such as the JCGM 100:2008 guide. These standards define statistical terms and justify the approaches used to assess uncertainties.

Beyond the chronological progression of the four tasks, the trainer's praxeology reveals an important relationship between procedural action and the knowledge used to justify that action. The techniques are not presented as isolated computational procedures; rather, they are organized around a measurement model that progressively connects the definition of the measurand, identification of uncertainty sources, estimation of standard uncertainties, combination of these uncertainties, and expression of expanded uncertainty. This organization reflects a professional logic in which each technique responds to a specific measurement problem and is supported by explicit logos. In particular, the use of the 5M diagram, probability laws, and the law of propagation of uncertainties provides the technological basis for explaining why particular procedures are selected. From a praxeological perspective, this articulation between tasks, techniques, and logos is significant because professional knowledge becomes visible not simply through the trainer's ability to perform calculations, but through the capacity to justify and organize those calculations within a coherent measurement process. This finding is consistent with the JCGM (2008) framework, in which uncertainty evaluation is treated as a structured process linking the specification of the measurand, modelling, identification of uncertainty components, and expression of the measurement result.

The trainer's activity also illustrates how measurement uncertainty can function as an authentic interdisciplinary STEM practice rather than as an exclusively metrological procedure. Determining a measurand requires the interpretation of a scientific phenomenon; constructing the measurement model requires mathematical representation; identifying sources of uncertainty requires systematic analysis of instruments, methods, materials, and experimental conditions; and evaluating the resulting uncertainty requires statistical and probabilistic reasoning. Such coordination of scientific, mathematical, and technological reasoning is consistent with the broader conception of STEM practices as involving modelling, evidence-based reasoning, investigation, and interpretation of data (Lehrer & Schauble, 2006; Nadelson et al., 2012). In this sense, the trainer's praxeology provides more than a sequence for calculating uncertainty. It demonstrates how different forms of disciplinary and professional knowledge can be mobilized around a common experimental problem. This feature is particularly relevant to STEM teacher professional development because effective STEM teaching requires teachers to connect disciplinary knowledge with practical and interdisciplinary forms of reasoning rather than treating knowledge domains as separate components of instruction (Chan et al., 2019).

From the perspective of professional development, the trainer's praxeology can therefore be considered a reference organization against which the teacher's subsequent classroom activity can be examined. This does not imply that the teacher is expected to reproduce the trainer's practices identically, since the two actors operate within different institutional and didactic contexts. The trainer works within professional metrology training, whereas the teacher must transform the knowledge acquired during training into tasks that are meaningful within university chemistry instruction. The analytical value of the trainer's praxeology lies instead in identifying the professional knowledge made available through the training: the range of tasks introduced, the techniques associated with them, and the technological-theoretical reasoning that legitimizes their use. Professional development can then be examined through the extent to which these elements are selected, reorganized, adapted, or omitted when the teacher constructs her own teaching praxeology. This interpretation is consistent with Professional Didactics, which considers professional learning through transformations in activity and the knowledge mobilized in real work situations (Pastré, 2011), and with the TAD perspective in which praxeological organizations are shaped by the institutional conditions in which practices take place (Chevallard, 1999).

Praxeologies developed by the teacher to teach measurement uncertainty in university classrooms

The Praxeologies used by the teacher to teach measurement uncertainty are presented in the table below, in chronological order of the lesson.

Table 3 Disciplinary Praxeologies used by the teacher to teach measurement uncertainty at university

Tasks: The student will be required to	Techniques	Logos
Writing the equation for the titration Reaction	Put the molecules representing the reaction between the titrant solution and the titrated solution into a chemical model. Or represent the reaction between a basic solution and an acidic solution in a chemical model CH3CHOOH and a basic solution NaOH	Bronsted-Lowry acid-base theory.
Expression of the concentration of the solution "S"	Determine a quantity (the Cs concentration) of solution 'S' based on the parameters involved (volume Vs of the test sample of S, the CNaOH concentration	Bronsted-Lowry acid-base theory Proportions theory Chemical equivalence.
Deduce the Cs concentration of solution "S"	Express the value of a concentration. Its value is equal to the sum of the terms [1]: CS=(CNaOH*Ve)/Vs Establish a mathematical model for expressing the measurand, the variables in this model being: the volume Vs of the test sample of solution S, the concentration CNaOH and Ve the volume of NaOH at equivalence.	Theory of proportions Chemical equivalence.
Description of sources of uncertainty on Vs	Establish a mathematical model for expressing each measurand (Vs then Ve).	Law of propagation of uncertainties 5M diagram.

Tasks: The student will be required to	Techniques	Logos
and Ve	Based on the data provided, determine the sources of error in the input quantities for each model expressing the measurand (Ve then Vs). Establish a mathematical model for the expression of each measurand based on the input quantities for each model Determine, based on the data provided, the sources of error for each input quantity in the system expressing the measurand (Ve then Vs)	
Determine the standard uncertainties for Vs and Ve	Based on the data collected, select the law that appears to be representative of the measurand in question. Select the components of uncertainty and estimate their values	Rectangular distribution law Law of propagation of uncertainties
Determine the standard uncertainty on Cs, the concentration of solution S	Based on the data collected, select the law that appears to be representative of the measurand in question ([Cs]). Select the components of uncertainty and estimate its value	Law of propagation of uncertainties
Deduce the standard uncertainty for the concentration Ccom of the commercial solution $Cs= \frac{\mathbf{Ccomm}}{\mathbf{10}}$ C_{com}	Based on the data provided, select the law that appears to be representative of the measurand in question [Ccom]. Selection of sources of uncertainty in question and estimation of its value	Law of propagation of uncertainties 5 M diagram

Analysis of the praxeologies used by the teacher during the tutorial session reveals a structured progression of tasks set for the students. Initially, the teacher focuses on establishing the chemical context of the titration, asking students to write the reaction equation and model the acid-base reaction using Bronsted-Lowry theory (Task 1). She then guides the students in determining the concentration of the titrated solution (Tasks 2 and 3), using the concepts of chemical equivalence and proportionality. Finally, the teacher addresses the central issue of measurement uncertainty (Tasks 4 to 7). She guides the students in identifying sources of uncertainty, determining standard uncertainties and estimating the standard uncertainty for the commercial solution. To do this, she uses the law of propagation of uncertainties and the 5M diagram.

In terms of techniques, the teacher used chemical modelling to represent acid-base reactions and mathematical modelling to express concentrations and uncertainties. She also emphasised the analysis of the data provided to identify sources of error. The concepts used by the teacher are mainly derived from Bronsted-Lowry acid-base theory, the theory of proportions, the concept of chemical equivalence and the law of propagation of uncertainties. She also refers to methodological tools such as the 5M diagram.

The teacher's praxeology therefore shows an important transformation of the metrological knowledge encountered during professional training into a disciplinary teaching context. Unlike the trainer, whose sequence begins directly with the definition of the measurand and the measurement process, the teacher first reconstructs the problem through the conceptual structure of chemistry. The acid-base reaction, chemical equivalence, proportional reasoning, and determination of concentration become necessary intermediate steps before measurement uncertainty is introduced. This reorganization indicates that professional knowledge is not simply transferred unchanged from a training situation to a classroom situation. Rather, the teacher adapts and recontextualizes it according to the disciplinary objectives of the university chemistry course. From the perspective of TAD, this finding is significant because praxeologies are shaped by the institutional conditions in which tasks acquire their meaning (Chevallard, 1999). The teacher's activity can thus be interpreted as a process of didactic reconstruction in which specialized metrological knowledge is incorporated into an existing chemistry praxeology.

This reconstruction also reveals a distinctly interdisciplinary dimension of the teacher's professional knowledge. Students are required to move from a chemical representation of the titration reaction to proportional reasoning, mathematical modelling of concentration, identification of experimental sources of uncertainty, selection of probability distributions, and propagation of uncertainties. The resulting learning sequence therefore connects scientific content, mathematical reasoning, experimental measurement, and methodological decision-making within a single problem. Such coordination is particularly relevant to STEM education, where professional knowledge involves the capacity to mobilize and reorganize disciplinary knowledge around authentic problems rather than treating science and mathematics as isolated domains (Chan et al., 2019). It also reflects the importance of modelling, investigation, data interpretation, and evidence-based reasoning as central STEM practices (Lehrer & Schauble, 2006; Nadelson et al., 2012). Measurement uncertainty consequently becomes not only an additional technical topic within analytical chemistry, but also a context through which students can encounter the interconnected character of scientific and mathematical reasoning.

At the same time, Table 3 suggests that the teacher's appropriation of the training remains selective. Several elements characteristic of the trainer's praxeology are identifiable in the teacher's practice, particularly mathematical modelling, identification of uncertainty sources, the 5M diagram, and the law of propagation of uncertainties. However, these elements are reorganized around the immediate requirements of the acid-base titration task, and the technological-theoretical discourse supporting some techniques remains less explicit than the procedural sequence itself. This distinction is important when interpreting professional development. From the perspective of Professional Didactics, development cannot be reduced to reproducing procedures acquired during training; it involves the capacity to reorganize knowledge and schemes of action when confronting the constraints of a new professional situation (Pastré, 2011). The teacher's praxeology therefore provides evidence of appropriation and adaptation of the training content, while simultaneously revealing areas in which the relationship between technique and its technological-theoretical justification could be further developed. These observations provide the basis for the comparative analysis of the trainer's and teacher's praxeologies and for identifying the specific forms of convergence and divergence between the two professional situations.

DISCUSSION

Praxeological analysis enabled us to identify the tasks performed by the trainer during a vocational training session and those implemented by by the university lecturer during the tutorial session. In both cases, teaching revolved around estimating the measurement uncertainty in acid-base titration, and both practitioners structured the activity progressively, breaking down a complex task into simpler sub-tasks. the emphasis placed on mathematical modelling and the identification of sources of uncertainty aligns with findings in international research, which highlight the central role of modelling and uncertainty reasoning in STEM learning (Bismack et al., 2014; Lehrer & Schauble, 2006). These similarities suggest that both the trainer and the lecturer engage with core STEM practices, even though their contexts and aims differ.

However, important differences emerged. The trainer operates within a vocational context with a strong, orientation toward professional accreditation and metrology standards. This explains the use of more advanced, transferable techniques, and the mobilisation of Praxeologies that draw on a broader ecosystem of laboratory practices. This capacity to delocalise tasks placing them within a family of professional situations is consistent with TAD's emphasis on articulating local techniques with wider technological-theoritical organisations. It also corresponds to findings in STEM education that stress the importance of connecting classroom tasks to authentic or engineering practices (Krajcik & Shin, 2014).

By contrast, the university teacher works in an academic context in which uncertainty estimation is tightly tied to a specific chemistry task. The teacher attempts a form of generalization, referring to inter-laboratory comparisons or professional quality systems, but these remain beyond the students' experience.

Verbatim extract:

Teacher said: "…and identifying sources of error is still (she gestures with her hand to indicate that it is probabilistic work), we will mainly rely on previous experiences, on the work of other laboratories, on inter-laboratory comparisons, etc. OK?"

This gap echoes international literature noting the difficulty of supporting authentic scientific reasoning when students lack access to the epistemic contexts that give meaning to such practices (Dushl & Grandy, 2013). The teacher compensates by using chemical modelling absent from the trainer's approach to anchor the task within the conceptual field of chemistry. This reflects an academic logic rather than a professional one, reinforcing the idea that Praxeologies are shaped by institutional expectations.

The analysis also reveals an imbalance between technical component in both practitioners' Praxeologies. The limited presence of fully articulated technological-theoretical discourse mirrors findings in science education research showing that students and sometimes teachers often engage with uncertainty procedures without understanding their epistemological foundations (Allie et al., 1998 ; Lippmann Kung & Linder, 2007). This imbalance, observed in trainer's and the teacher's approaches, may hinder learners' ability to construct deeper conceptual meaning around uncertainty, a difficulty also noted by Chesnais and Munier (2015).

Furthermore, although the teacher attempts to adopt a more participatory and inquiry orientated approach, her discourse remains shaped by a transmissive epistemology what Astolfi (2005) describes as a "traditional image of knowledge as a set of truths to be transmitted." This tension is well documented in international studies on teacher professional development, which show that shifting epistemological stances requires long-term support, opportunities for reflection, and sustained engagement with authentic scientific practices (Loucks-Horsley et al., 2010; Capps & Crawford, 2013).

Finally, the comparison of Praxeologies suggests that the teacher's development, although real, remains partial. While training positively influenced techniques and task organisation, it did not fully transform the technological-theoretical dimension of her praxeology. This echoes broader findings showing that professional development programmes focusing primarily on procedural or practical elements often produce limited epistemological change (Desimone, 2009). The limitations observed can be explained by the underlying logic of professional didactics, which prioritises starting from real work analysis but may not sufficiently support teachers in restructuring the theoretical dimension of their Praxeologies an aspect central to sustained teacher learning in STEM.

CONCLUSION AND PERSPECTIVE

In summary, the professional training analyzed in this study appears to have contributed positively to the teacher's professional development by expanding the repertoire of tasks, techniques, and resources that she was able to mobilize when teaching measurement uncertainty. The comparison of the two praxeologies shows that several elements introduced by the trainer were subsequently appropriated and reorganized by the teacher within the university chemistry context, including mathematical measurement modelling, identification of sources of uncertainty, the 5M diagram, and the law of propagation of uncertainties. Rather than simply reproducing the trainer's practices, the teacher integrated these elements with the disciplinary requirements of acid-base titration, including chemical modelling, Bronsted-Lowry acid-base theory, chemical equivalence, and proportional reasoning. This suggests that professional development involves not only acquiring new knowledge and techniques but also recontextualizing them within authentic teaching situations. The diversity of tasks proposed during the training and the integration of new methodological resources therefore appear to strengthen the teacher's capacity for action and support more autonomous teaching practices oriented towards student learning.

At the same time, the analysis reveals that this professional development remains uneven across the different components of praxeology. The transformation is more visible at the level of tasks and techniques than at the level of the technological-theoretical discourse used to explain and justify those techniques. While the teacher was able to mobilize several procedures introduced during training, the deeper theoretical and epistemological meanings underlying measurement uncertainty were less explicitly developed in her teaching practice. This finding indicates that professional training may successfully strengthen practical professional know-how without necessarily producing an equivalent transformation in the conceptual foundations that support professional action. For STEM teacher education, this distinction is important because effective interdisciplinary teaching requires teachers not only to perform procedures but also to connect scientific concepts, mathematical models, experimental measurements, technological resources, and evidence-based reasoning. Professional development should therefore provide opportunities for teachers to strengthen both their capacity to act and their ability to explain and justify the knowledge underlying those actions.

Beyond the local context of this study, the convergence and divergence identified between the trainer's and teacher's praxeologies offer a broader perspective for understanding professional growth in STEM education. Praxeological evolution—understood as the transformation, selection, and reorganization of teachers' tasks, techniques, technologies, and didactic logics—can provide an analytical lens for examining how professional knowledge moves from specialized training into authentic disciplinary teaching. This perspective may be relevant internationally, particularly in STEM contexts where teachers are increasingly expected to integrate disciplinary knowledge with modelling, experimentation, measurement, data interpretation, and technologically mediated scientific practices. Looking ahead, longitudinal research would be particularly valuable for examining whether the praxeological transformations identified in this study become stable components of professional practice or continue to evolve as teachers encounter new content, students, technologies, and institutional constraints. Extending this approach to a larger and more diverse group of STEM teachers could further determine which patterns of professional development are context-specific and which may be transferable across disciplines and educational systems, thereby contributing to international discussions on how the impact of STEM teacher professional development can be characterized, monitored, and sustained over time.

LIMITATION

The study is limited to the analysis of two specific teaching and training situations, which reduces the scope of the results. Furthermore, the absence of longitudinal follow-up does not allow for observation of the long-term evolution of the teacher's professional development.

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