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PAPER

Didactic Knowledge of Physics Teacher's in Lesson Study

Conhecimento Didático de Professores de Física num Estudo de Aula

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ABSTRACT

We examined the contributions of lesson study to the development of didactic knowledge among physics teachers about the curricular topic of Ohm's Law. The research involved four physics teachers in public high schools in Rio Grande do Sul state, Brazil. The empirical material consists of transcriptions of audio recordings of lesson study sessions, interviews carried out with teachers, as well as materials produced by students in the research lesson. A qualitative and interpretative analysis showed that the development of teachers' didactic knowledge involves deepening their knowledge of physics for teaching a specific physics topic, as well as strategies for teaching in the classroom. In relation to knowledge of physics for teaching, the evidence is related to the curricular content and the contextualization of the content. In relation to teaching strategies, the importance of using teaching resources, the relevance of investigations in the classroom and collective discussion at the end of the class stand out.

Keywords: Didactic Knowledge. Lesson Study. Physics Teaching. Ohm's Law.

RESUMO

Examinamos os contributos do estudo de aula para o desenvolvimento do conhecimento didático de professores de Física sobre o tópico curricular da Lei de Ohm. A investigação envolveu quatro professoras que ensinam Física no Ensino Médio em escolas públicas do Rio Grande do Sul, Brasil. O material empírico constitui-se das transcrições das gravações em áudio das sessões do estudo de aula, das entrevistas realizadas com as professoras, assim como dos materiais produzidos pelos alunos na aula de investigação. A análise qualitativa e interpretativa evidenciou que o desenvolvimento do conhecimento didático dos professores envolve o aprofundamento dos conhecimentos da Física para o ensino de um determinado tópico da Física, bem como das estratégias para o ensino em sala de aula. Nos conhecimentos da Física para o ensino, as evidências estão

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relacionadas ao conteúdo curricular e a contextualização dos conteúdos. Em relação às estratégias de ensino, destacam-se a importância da utilização de recursos didáticos, da relevância das investigações em sala de aula e da discussão coletiva no fechamento da aula.

Palavras-chave: Conhecimento Didático. Estudo de Aula. Ensino da Física. Lei de Ohm.

Introduction

The development of professional teachers, a process that encompasses the dimensions that influence a teacher's teaching practice and other professional activities, presupposes, among other things, professional knowledge, which includes domains such as *curriculum knowledge* and *didactic knowledge* (Ponte, 1994). In his pioneering work on the knowledge that guides and sustains the work of teachers, Shulman (1986; 1987) categorized three distinct domains: *content* knowledge, *curriculum knowledge* and pedagogical *content* knowledge (PCK). These forms of knowledge are inseparable and complementary to each other, and are not static. Of these categories, Shulman highlights PCK for its potential to bring together specific content knowledge and curricular knowledge.

Understanding about this knowledge and how it affects teacher development has led to this knowledge being broken down into other sub-domains and has revealed basic aspects, such as strategies and resources, knowledge of students' errors and difficulties, and others (Richit, 2020). This category, which is an amalgam of theory and practice, is oriented towards situations of teaching practice, relating various aspects of knowledge of everyday school life with knowledge of the context and of oneself as a teacher (Ponte, 2012).

Research into the professional knowledge of science teachers has led to the proposal of distinct theoretical models that support restructuring teacher training models and approaches (Schneider & Plasman, 2011), and are based on specific issues, such as how to teach difficult and abstract ideas that are common in science (Kind, 2009). One approach valued in research communities is *lesson study*, which characterizes the process of professional development focused on teaching practices and is supported by two fundamental principles: collaboration and reflection (Ponte, Quaresma, Mata-Pereira & Baptista, 2016; Richit, Ponte & Tomkelski, 2020). By focusing on teaching practice, lesson study has strengthened research into aspects intrinsic to didactic knowledge, such as teaching and learning processes in physics (Conceição, Baptista & Ponte, 2020; Tomkelski, Baptista & Richit, 2022; Tomkelski & Baptista, 2023; Tomkelski, Baptista & Richit, 2023; Tomkelski, 2024). The lesson study process inspires changes in physics teaching (Conceição, Baptista & Ponte, 2020; Tomkelski, 2024) and allows deepening teachers' knowledge, especially in relation to PCK (Lucenario, Yangco, Punzalan & Espinosa, 2016; Tomkelski, 2024).

Research on lesson studies reveals contributions to professional development of teachers (e.g., Sims & Walsh, 2009; Rincón & Fiorentini, 2017; Juhler, 2018; Richit & Tomkelski, 2020; Richit, Ponte & Tomasi, 2021). In physics, the research by Conceição, Baptista and Ponte (2020) reports on the development of didactic knowledge about the speed of sound by 8th grade teachers participating in a lesson study. The study highlights that the teachers developed knowledge about the speed of sound from the diagnosis of students' previous knowledge and the planning of the research lesson, as well as about the physical phenomena of the topic and its abstract nature, about the students' learning difficulties, and the need to expand their previous knowledge.

Considering the possibility to understand the contributions of lesson studies to the development of physics teachers' didactic knowledge of Ohm's Law, we carried out an investigation involving the voluntary participation of four teachers of physics in the third year of high school. The participants work in public schools linked to the 15th Regional Coordination of Education in Rio Grande do Sul. Considering their experience in teaching physics, they immediately decided that they wanted to study a topic related to electricity. When refining this topic, they chose Ohm's Law because they understood that this topic allows for classes based on differentiated strategies of which they chose to use the potential for developing research tasks and exploring multiple representations (MRs) (Tomkelski, Baptista & Richit, 2022; Tomkelski & Baptista, 2023; Tomkelski, Baptista & Richit, 2023; Tomkelski, 2024).

Ohm's Law states that, for a conductor maintained at a constant temperature and regardless of the nature of the conductor, the intensity of the electric current flowing through an electrical conductor is directly proportional to the difference in electrical voltage applied to its terminals. This establishes the relationship between the Voltage (U) and the electric current (I), resulting in the electrical resistance (R), i.e., $R = \frac{U}{I}$. Ohm's Law is valid for all electrical conductors.

This is a fundamental topic in the physics curriculum in the study of electricity, especially in electrodynamics, and it constitutes an understanding of the other elements present in electrical circuits. This topic is important in teaching, as many daily activities depend on the use of electricity and electrical appliances. We find many examples of its use for lighting purposes (cities, homes, etc.), as a form of heating (electric showers, electric stoves, heaters, microwaves, etc.), and for the operation of various electronic products (TVs, cell phones, computers, etc.) and household appliances (refrigerators, washing machines, coffee makers, blenders, etc.).

Didactic Knowledge

Professional knowledge of teaching has mobilized research, which has culminated in the consolidation of different theoretical models. One model, widely disseminated in various fields of knowledge, is the triad of knowledge proposed by Lee Shulman (1986). According to the author, professionalism is structured around three main categories: *content* knowledge, *curriculum* knowledge and *pedagogical content* knowledge *(PCK*), known as didactic knowledge (Ponte, 1994).

Didactic knowledge has been highlighted as a basic dimension of teaching, as it characterizes the set of knowledge, skills and practices specific to each disciplinary field, which shape a teacher's practice (Van Driel, Verloop & De Vos, 1998; Shulman, 2004). From this perspective, teaching is configured as a process in which specific content, complemented by resources and strategies, is transformed in the teacher’s practice (Richit & Tomkelski, 2022), considering students’ difficulties, the context, assessment methods, the curriculum, etc. (Fernandez, 2015).

Shulman (1986) describes PCK as “a particular form of content knowledge that embodies the aspects of content most germane to its teachability” (Shulman, 1986, p. 09) and which comprises “the ways of representing and formulating the subject that make it comprehensible to others” (Shulman, 1986, p. 09). This category constitutes the knowledge base for teaching, because it can help resolve “blind spots” resulting from a relative lack of research into the content being taught (Shulman, 1986). PCK also involves understanding students’ difficulties and facilities in learning specific topics, considering their conceptions and preconceptions, without considering differences in age and origin (Shulman, 1986). In other words, if a student has formulated concepts incorrectly, it is up to teachers to use knowledge of the various teaching strategies to help students in their learning process and to have alternative forms of representation and formulation (ideas, analogies, illustrations, examples, explanations and demonstrations), some derived from research and others from the wisdom of practice.

Shulman (2004) adds that although the other types of knowledge have equivalents in different professional fields, didactic knowledge remains exclusive to teachers, because content and pedagogy are combined as teachers organize their understanding of a topic, and the strategies and additional knowledge needed to promote student learning. Didactic knowledge has been assumed to be a fruitful concept because it has the potential to promote changes in teaching practice and is a central objective in teacher training.

Van Driel, Verloop and De Vos (1998) conceive of didactic knowledge as a specific form of professional knowledge for science teachers, as it involves a transformation of content knowledge so that it can be developed in the process of communication between teachers and students in classrooms. Thus, it is presented as a concept of interpretation and transformation of teachers’ knowledge that aims to help students learn, by offering the opportunity to link research into teaching and research into learning. The authors add that because it refers to specific topics, it should be differentiated from knowledge of pedagogy, educational purposes and student characteristics in a general sense, as distinguished from knowledge of the subject itself.

Another central aspect of didactic knowledge, particularly in the sciences, refers to the use of different representations in the study of concepts and phenomena. Assuming that “two representations are better than one”, i.e. that the use of multiple representations (MRs) is fundamental in teaching, Ainsworth (2006, p. 183) emphasizes that teachers need to develop MRs to broaden their knowledge and improve their practice (Tomkelski, 2024).

According to Grossman (1990), didactic knowledge is at the heart of teaching and is surrounded by three related categories: content knowledge, general pedagogical knowledge and contextual knowledge. He points to four potential sources from which it can be developed: (a) lesson observation, from the perspective of both students and teachers; (b) disciplinary education, which can lead to personal preferences for specific educational purposes or topics; (c) specific teacher training workshops or courses; and (d) classroom teaching experience.

In the sciences, there is a growing movement of research into the development of didactic knowledge in teacher education, highlighting the importance of providing teachers with contexts for professional learning about teaching at different points in their career (Nilsson, 2008; Tomkelski & Baptista, 2023). For example, Shamsudin, Abdullah and Yaamat (2013) state that teachers must undertake professional learning about the objectives of each curriculum content and how to prepare students to deal with life's changes and challenges.

Magnusson, Krajcik and Borko (1999) proposed a model of didactic knowledge (PCK) for science teaching, in which the knowledge for teaching – knowledge of the science curriculum, students' understanding of science, teaching strategies and assessment – were conceptualized as constituent elements of orientations for teaching, which impact the development of teachers' didactic knowledge. The development of didactic knowledge is determined by the content to be taught, the context in which the content is taught, and the way in which teachers reflect on their teaching experiences, so that reflection emerges as an important element in teachers' professional development (Magnusson, Krajcik and Borko, 1999). The authors add assessment as an important aspect of didactic knowledge, considering that when teachers plan lessons, by knowing the science that will be examined, they can adjust their teaching strategies according to the eminent needs, adjusting the assessment methods to discover what the students have learned.

In addition to these, there are other elements that compose the didactic knowledge of physics teachers, which highlights the importance of this research. It is worth noting, however, that current models have sought to include aspects not highlighted in Shulman's (1986) categorization, such as metacognition, affectivity, and others.

Lesson Study

Lesson study, in Japanese *jugyou kenkyuu*, is an approach to teacher professional development widely practiced in Japan[1], and is considered to be the main factor responsible for improving teaching in that country (Yoshida, 1999; Richit & Tomkelski, 2020). This approach[2] has established itself as a process for preparing teachers to undertake their practice (Lewis, 2002) and became widespread in that country (Yoshida, 1999), and since the late 1990s began to be promoted in the West (Stigler & Hiebert, 1999; Richit & Tomkelski, 2020).

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[1] It emerged in Japan in the early twentieth century, under the Meiji government, when changes to the education system were urgently needed. The Meiji Era was the first period of the Japanese Empire**,** from 1868 to 1912. It was extremely important for Japan's development, as during this time the country became one of the world's great capitalist powers. It was marked by a period of political, economic and social change, including the enactment of the Education Code (1872), which established normal schools (Richit, Ponte & Tomasi, 2021).

[2] Lesson study has been disseminated in Western countries since the late 1990s, mainly through the book "*The Teaching Gap*", which credited the problem-solving structure of Japanese lesson study, and especially the professional development process that all Japanese teachers are involved in, for the success of the country's mathematics students in the TIMSS - *Trends in International Mathematics and Science Study* (Stigler & Hiebert, 1999).

One of the characteristics of lesson study is that it is a collaborative effort by a small group of teachers (Lewis & Tsuchida, 1998; Yoshida, 1999), consisting of a reflective and collaborative process of professional development focused on teaching practice (Yoshida, 1999; Lewis, 2002; Richit, Ponte & Tomkelski, 2024). The characteristics of this model help teachers develop knowledge about curriculum topics and how to teach them (Stigler & Hiebert, 1999), and about student learning and teacher learning (Richit & Tomkelski, 2020).

The lesson study developed in Japan has a common core structure, which consists of four stages: *goal setting*; *collaborative planning*; *lesson investigation* and *post-class reflection* (Lewis, 2002; Richit, Ponte & Tomkelski, 2019).

The *definition of objectives* for the research lesson considers the students' learning needs and difficulties in the curriculum topic chosen by the teachers in the lesson study. This includes *planning*, which involves designing the research lesson based on the previously defined objectives, involves careful collaborative and reflective work that tries to foresee students' ways of thinking, their strategies for solving the proposed tasks, their difficulties, what they are going to say during the lesson activities, etc. During the *research lesson*, one of the team members voluntarily teaches the planned lesson to a class of students and the others, including the team coordinating the process, observe and record the students' actions in solving the proposed tasks. In the *post-lesson reflection*, the group meets to discuss and reflect on what was observed in relation to the lesson, encouraging professional self-criticism (Richit, 2020; Richit, Ponte & Tomkelski, 2019). If desirable, the cycle can be repeated a few more times to deepen the understanding of a particular piece of content or to start a new one (Fujii, 2016). Thus, lesson study systematically incorporates teacher professional development in the classroom, anchored in the idea that a single lesson contains many (if not all) critical components that teachers need to consider to improve their training (Sims & Walsh, 2009).

The literature in the field of physics teaching (e.g., Juhler, 2018; Rodrigues, 2019; Conceição, Baptista & Ponte, 2020; Melo, Cañada-Cañada, González-Gómez & Jeong, 2020; Tomkelski, 2024) reports on research which shows that lesson study promotes professional learning related to the development of tasks on certain topics in the physics curriculum (Conceição, Baptista & Ponte, 2020; Tomkelski, Baptista & Richit, 2022) and enables teachers to discuss the teaching of the topic based on student results, and provides classroom approaches that favor student learning.

Methodology

Nature and objectives. This qualitative study[3] examines how research problems are approached, leading researchers to look for appropriate methods and procedures to study the problems (Bogdan & Biklen, 1994). This study is characterized as qualitative because it sought to understand the contributions of lesson study to the development of physics teachers' didactic

[3] Approved by the Ethics Committee of the Institute of Education of the University of Lisbon, Lisbon - Portugal. Opinion number: 4328 of 22/10/2018.

knowledge on the curriculum topic of Ohm's Law. The data was collected in a lesson study involving four physics teachers in the 3rd year of high school in public schools linked to the 15th CRE (Regional Education Coordination Office of the State of Rio Grande do Sul, Brazil), who participated voluntarily in this process. Participants were selected by invitation or convenience, i.e. proximity to the researcher.

Participants. The participants (Jô, Mel, Roberta and Sol[4]), from 38 to 52 years old, are public school teachers with between 8 and 25 years' professional experience in basic education[5], specifically in primary education (final years) and secondary education. The teachers have initial teacher certification in mathematics, with accreditation in physics, two teachers also have a specialization (*lato sensu*) in the field and one teacher has a master's degree (stricto sensu) in mathematics and physics education.

The Lesson Study. The study consisted of eighteen, two and a half hour sessions, and was organized into five stages: (1) theoretical constitution of the lesson study approach and analysis of legal documents from current Brazilian educational legislation; (2) analysis of investigation tasks for the classroom; (3) planning the work plan for the first research class, reflections and refinement of the activity; (4) carrying out the first research class in the classroom, post-class reflections and revision of the work plan and; (5) carrying out the second research class, post-class reflection and finalization of the work plan. Fifteen sessions took place on the premises of the 15th CRE and the rest in the schools where the teachers worked. The two research classes, each lasting 100 minutes, focused on the same physics topic, the first was taught by Jô and the second by Sol.

Empirical material and data analysis. The research, due to its nature and its focus on teachers' didactic knowledge, used a triangulation of data collection instruments to capture different aspects of this category of knowledge. The empirical material consists of the researcher's field notes (NC) and the teachers' logbooks (DB); audio recordings (AD) and transcripts; a collection of documents (AD) of the teachers' written productions and notes made by students' during the lesson; and interviews (E) with the teachers. The sessions were observed by the researcher, the first author of the article, who adopted a participant-observer role (Cohen, Manion & Morrison, 2011).

The interviews, carried out after the end of the lesson study, were transcribed, textualized and incorporated into the empirical material of the research.

The categories emerged from content analysis (Bardin, 2011), delineated by subcategories, as shown in *Chart* 1.

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[4] The names of the teachers used in this article are fictitious, to respect the confidentiality of the participants.

[5] In Brazil, basic education, which is compulsory and free of charge, takes place from the age of 4 (four) to 17 (seventeen), and includes the following levels: early childhood education, primary education and secondary education. Early childhood education (pre-school) lasts two (2) years; primary education lasts nine (9) years and secondary education lasts three (3) years. Primary education is organized into the "early elementary years" (1st to 4th grade) and "late elementary years" (5th to 9th grade) (Brasil, 1996).

Chart 1: Categories and subcategories of analysis of the physics teachers' PCK

Category	**Subcategory**
Knowledge of Physics for Teaching	Curriculum content; Difficulties with curriculum content.
Strategies for Classroom Teaching	Use of materials; Carrying out research; Collective discussion.

Source: Authors.

After analyzing the material, the aspects highlighted were grouped into the corresponding categories and subcategories, and the data that was difficult to categorize was discussed among the authors with the aim of reaching a consensus. Data about which no consensus was reached was not used.

Results

Each category is made up of agglutinating sets of aspects of didactic knowledge developed in the lesson study, which are called subcategories. This inductive process brought out elements of the teachers' didactic knowledge about teaching the topic of Ohm's Law. We also emphasize that the development of aspects of didactic knowledge in lesson studies is a dynamic, complex and plural process. Therefore, the analysis cannot be disconnected from the movement of the lesson study itself, or it would become sterile. That is, aspects of didactic knowledge cannot be removed from the dynamics of lesson study for the purposes of the analysis presented.

Knowledge of Physics for Teaching

In the lesson study, the participants engaged in moments of discussion and reflection on physical concepts, especially Ohm's Law, which promoted the mobilization and deepening of aspects of didactic knowledge related to the teaching of the topic.

The teachers developed **knowledge about teaching physics**, mainly involving the *curricular content* covered in the classroom and the possibilities for promoting *the contextualization of curricular topics*.

With regard to *curriculum content*, the teachers mentioned some weaknesses in their initial training relating to the development of didactic knowledge and also highlighted the importance of practical activities, such as laboratory activities, for understanding physics concepts and for teacher education.

> When we were at university, the professor had the experiments [...] and would show us: "Look, you do it like this, like this", because we were being prepared to be teachers; "Look, you're going to do it like this, like this and like this", a ready-made cake recipe. (Jô, E)

> and now here, when you're teaching them [students], you first learn the physical concept, what's really happening there in the physics experiment. (Roberta, RA)

Jô and Roberta reflected on the role of initial training in the development of didactic knowledge, especially for learning about the curricular contents of physics, which are essential for teaching. When referring to the development of practical classes, Jô considered that her initial training was geared towards sequential learning of content, supported by steps of demonstration/proof. Roberta added that teachers' professional education becomes different when they take up teaching.

> what we didn't learn in undergrad [studies], we now learn [in practice]. So, actually, you [the teacher] really learn what's going on when you go to teach the student. (Roberta, RA)
>
> In other words, even though I'd done my degree [initial training], even though I'd been a student teacher of Physics [a compulsory stage of education]; I taught Physics to the first year [...] but I learned Physics, I learned about these concepts; and then, I listened to the explanations, and I also remembered what voltage is, what current is, all these things were taking shape again in my head as a teacher; but yes, the fact of stopping, discussing and listening to you talking, for me it was a Physics course - on a specific topic - I learned Physics here. (Mel, DB)

Reflecting on the teaching of curricular topics of physics in the classroom, with a view to promoting student learning, Roberta and Sol pointed out that teachers need to mobilize knowledge of the topic and the importance of lesson planning to cover it.

> First you have to know the content you're going to teach. Pedagogical practices, you have to know which approach you're going to take to develop the lesson. (Roberta, RA)
>
> Planning! [In the lesson study] as we were building the planning we were building the knowledge. (Roberta, E)
>
> [planning] is fundamental because for everything [we do] we need an objective! If we do anything without an objective, we have no one to teach and they have no one to learn from. (Sol, E)

The teachers emphasize the importance of planning for the development of didactic knowledge because it challenges them to learn new things, review theories, deepen concepts and, consequently, propose actions for the classroom. The lesson study favored the development of didactic knowledge regarding Ohm's Law through the sharing of classroom experiences. Sol reported on the importance of planning together in the lesson study for understanding the physics concepts of the topic studied, which were essential for developing the task on Ohm's Law.

> I think I was able to relate everything - electric current and voltage difference - within the circuit, [understand] why the LEDs turned on or didn't turn on, double

> the current. I think [the task] related a lot of things [concepts] and that you can follow up later. I think it opens up a very wide range. (Sol, E)

Reflecting on the contributions of the lesson study to deepening aspects of the curriculum topic of Ohm's Law, Mel says:

> I knew that household appliances, light bulbs in general, have a maximum current limit that they can withstand, but I never realized that there was a minimum limit. When the teacher said "we have this problem: these LEDs here only turn on at "*x*" volts, one point eight (1.8) or two (2.0) volts", I realized. So, for me, this was a learning experience in the field of electricity itself; in addition to many others that I had from this experience! (Mel, E)

Planning the task in the context of a practical activity with LEDs[6] gave the teachers the opportunity to develop aspects of didactic knowledge relating to Ohm's Law, the fundamental laws of electricity and the functioning of electrical appliances.

The teachers reported other aspects of didactic knowledge they developed as a result of the research lesson and post-class reflection, namely on electrical circuits, practical classroom activities, student errors and difficulties, the use of multiple representations, and the organization of the lesson from an investigative perspective.

> The simple circuits, I confess, I learned to assemble there. For me, that was the main part, the practical part! Getting the students to work, to learn together. (Sol, E)
>
> I learned how to work with the circuitry of a light fixture and test LED bulbs. (Roberta, E)
>
> I didn't give much importance to representations, but now I'm certainly going to focus more on this in my classes. (Roberta, RA)

The research class began with the construction of a simple circuit (wires, light bulbs and batteries), followed by the analysis and interpretation of the physical concept, anchored in planned tasks, articulating forms of representation (multiple representations). In relation to *the students' difficulties with the curriculum topic*, the teachers highlight the learning of concepts and problem-solving.

> [Students] have difficulty understanding the concepts of electric charge and electric current intensity. They don't understand what the intensity of an electric current is. [...] alternating currents, direct currents. (Sol, RA)
>
> They [students] have great difficulty understanding electricity, electric current and voltage. So [this lesson explored] these definitions so that they could understand the relationships of Ohm's Law. (Sol, E)

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[6] LED (*light emitting diode*) is an electronic semiconductor component that has the property of transforming electrical energy into light.

Jô adds that the lesson study provided insights into the students' mistakes.

> in relation to student error, they often tried to give us information about the task. What we could see was that each group had a slightly different answer from the group next to them, or the group in front of them, because the way each group [thought was different]. We could see that there isn't just one way of solving [...] in that they try and try to come up with the answer [...] and that it's by making mistakes that they get it right. (Jô, E)

This highlights the importance of the teacher dedicating some class time to analyzing the students' errors, whether conceptual or operative, considering this an important aspect in the development of knowledge for teaching physics.

> I learned a lot in the sense of looking at the student's mistake, which we often don't do. Looking at the student's mistake leads you to ask: "Why did he come to that answer? This way?" [...] we understand their difficulties group by group, so I think that yes, it brings a lot of knowledge to us teachers, we improve a lot as teachers [...]. (Jô, E)

The planning needs to include moments during the execution of the lesson so that the teacher can observe the students, understand their reasoning and doubts, and look for strategies to resolve them. Jô highlighted how the lesson study helped them to observe and understand the students' mistakes.

> [In the lesson study we had] a different view of planning a lesson, of the importance of looking at the student's mistake [...]. And I'd never thought about it. I'd say: [...] Oh, he's made a mistake! And that was it. Today, I look at the mistake and ask myself: If he got the concept, what was missing for him to get it right? Is it a mistaken sign, a multiplication mistake, interpretation? (Jô, RA)

When planning the lesson, the teacher must consider the organization of the contents foreseen in the curriculum, as a way to promote a more integrative approach and prepare the students for the following topics.

> This lesson study has enabled us to analyze this and see what I should work on before and what I should work on afterwards, whether I should follow it or not. (Sol, E)

Another aspect of didactic knowledge revealed is related to *the contextualization of the task for the lesson*. Defining an instigating context for the task is a way to stimulate interaction among students, encouraging them to explore physical concepts and establish connections between content and everyday situations.

> I see today that, without a doubt, contextualized tasks increase students' understanding. Students understand better when the question is contextualized

> and when they work in pairs, trios, groups in which they can interact. This type of activity leads students to understand the physical phenomenon, the theoretical part of physics, which is abstract. (Roberta, E)

Sol emphasizes the importance of promoting a context that encourages students to work autonomously on the task.

> It is up to the teacher to create favorable environments for carrying out investigations and to encourage students in the face of difficulties, because difficulties will arise since the task is a challenge, because it pushes the student. (Sol, DB)

Other aspects involving the *contextualization of content* were highlighted: teaching strategies, defining clear objectives, and generalization by the students. Jô highlights the importance of relating curriculum content to the students' context, facilitating learning.

> Whenever a teacher manages to relate the content to everyday issues, she notices that the students are stimulated to take part in the lesson. She also sees better results in the understanding of physics concepts, as students are able to learn more easily and explain the world around them. (Jô, DB)

The analysis points out that the objectives set for the lesson must be aligned with the context of the task and with the students' learning objectives.

> So the idea is to make the [planning] focused on the student, on their interests. [...]. In other words, we need a well-planned lesson with clear objectives to fulfill the curriculum. (Mel, RA)

Mel adds aspects relating to teaching strategies, the development of curricular knowledge based on classroom experiences

> It's different because we're mobilizing what we learned at university and combining it with our classroom experience. So, this knowledge, this learning that we have developed in practice, I think that here [lesson study] we learn in a different way, with aspects that make this experience different. (Mel, RA)

The teachers deepened their didactic knowledge of physics teaching in terms of curriculum content and how to approach it in the classroom. They developed knowledge about curricular content that had weaknesses, emphasizing the importance of collaborative planning in a context of sharing and professional growth. With regard to the approach to physics topics in the classroom, the teachers deepened their understanding of students' conceptual and operational errors based on their observation when carrying out the tasks; on teaching strategies, as well as classroom resources and ways of involving students in investigative activities; on ways of organizing the content, promoting an integrative approach and preparing students for later topics; and finally, on the potential of contextualized tasks to promote students' autonomous work.

Strategies for Classroom Teaching

With regard to *teaching strategies*, the teachers argued that it is necessary to *use materials* as an alternative to teach a certain curriculum topic, and to promote the development of their didactic knowledge.

Mel recalled that in her initial training, experimental activities were carried out, but they were only demonstrative. She said that because they were only observed, they didn't prepare them to carry them out in the classroom.

> When I was at university [...], we would go to the laboratories, but it was forbidden to touch things there, the professor did. [...] Because we didn't touch, the professor did it there, I don't even know a socket, because I never learned there. [...] if I had the resources and knew how to do it, I could take it to the classroom! (Mel, RA)

In addition, Mel argues in favor of a differentiated school curriculum that addresses up-to-date topics that allow students to understand and intervene in society, carrying out critical analyses, presenting solutions and innovating.

> [It's essential] to adjust the curriculum to the students' needs [...], to make connections with reality, because in physics we have a traditional curriculum [...]. Not to mention the fact that it totally ignores modern physics and quantum physics. (Mel, RA)

Another aspect of the didactic knowledge developed in the lesson study, as Jô mentioned, refers to the use of materials in physics teaching.

> Appropriate materials make it easier for the students to understand [...] and are beneficial for me as a teacher to explain the subject [...]. It brought new ideas for preparing activities to be undertaken with the students in investigative lessons. (Jô, E)

The teachers suggested other materials for physics lessons, which can help teachers develop aspects of their didactic knowledge and improve their practice.

> [I use the] textbook, because [students] need to have a guide, something concrete, but I look for [materials on the internet], I study video lessons [...], I look for mock tests [objective tests from selection processes], I work [with] a lot of mock tests. So I select a lot. To the degree possible I take exercises from various books! (Sol, RA)
>
> You can do simulation [...] there are a lot of websites that have those physics simulators [applets and virtual learning objects]. (Roberta, RA)

Roberta emphasizes the importance of the teacher covering topics from the physics curriculum that encourage the process of generalization.

> We realized how the process of constructing the tasks should be and that we should start with simpler examples and from there, shape the concepts, and not go directly to the concepts [...] and then create a task that the student can carry out based on a concept that they had previously about the content, and this way they will be able to carry out the tasks, without even having had contact with that content. (Roberta, E)

This dynamic is propitious to differentiated physics lessons, favoring student learning and the generalization of properties. The analysis pointed to other aspects of didactic knowledge for teaching physics curriculum topics, mobilized in the lesson study, with special emphasis on *the language used in the task and on the communication* between teacher and students. The teachers emphasize that learning depends on the language used to establish relationships between concepts and that the scientific terms used are often not understood by students, which compromises understanding and the communication of ideas and conclusions.

> [the students] need to understand the language. So we have to make sure [...] that our language is accessible to them. Because if they make [mistakes] in their interpretation, it's because [maybe we weren't clear and objective enough]. (Sol, RA)

Later, in an interview, the teacher added that understanding the importance of training processes, such as lesson study, contributes to reflection on the development of professional practice and communication with students.

> I realized that lesson study opens up a range of information for preparing an attractive and dynamic lesson. All of this has allowed me to be closer to the students, to see each one's performance, to observe the difficulties encountered by the students, and thus be able to help them resolve these doubts. (Jô, E)

Sol adds the importance of teachers deepening their professional knowledge.

> And our entire discussion, in this time reading and reflecting; and what's most interesting is that we're here because we want to be, nobody forced us to come. We're here because we want to be, so that's what's lacking in us as education professionals (Sol, RA)

Sol emphasizes the importance of training (*"getting out of our comfort zone"*) as a way of improving teachers' didactic knowledge.

> I think this training, this class study, makes us get out of our comfort zone, makes us feel more professional and search for other things. Little by little, coming together, even if it's by subject in the schools, [...] it changes a lot, planning is different. We need teachers to believe in it and go after it. (Sol, E)

Finally, the teachers value *collective discussion* as an important element of didactic knowledge associated with physics teaching. Jô and Roberta explain that from the collective discussion, they were able to evaluate the students' learning in relation to the objectives set, as well as evaluating their own practice.

> This experience has provided us with the tools to develop productive and investigative lessons, especially valuing collective discussions in the classroom through collaborative work. (Jô, DB)
>
> The interesting thing about this activity is that when you work on questions together, not only is it more productive, but it also becomes a professional learning moment because your colleague mentions facts about the content that you might not have seen. (Roberta, DB)

Promoting collective discussion emerged as an important dimension of didactic knowledge for teaching physics, because it favored the students' participation in class and, in particular, provided the teachers with information to identify and understand their learning on the topic. In addition, the students showed a change of attitude in their actions in class.

The lesson study allowed the teachers to develop knowledge about how to promote research classes, highlighting the process of investigation and the autonomous work of the students; about how to approach curriculum topics combining a practical context and the investigation of the factors involved in Ohm's Law, favoring the process of generalization. They grasped the importance of collective discussion to promote the communication of students' ideas and improve the process of assessing their learning, as well as creating an environment that involves students in the activities.

Discussion

The analysis revealed the contributions of lesson studies to the deepening of physics teachers' didactic knowledge (Shulman, 1986, 1987; Ponte, 1994) on the topic of Ohm's Law, anchored in Magnusson, Krajcik and Borko (1999) model of didactic knowledge for science teaching. The lesson study enabled them to plan and implement a lesson, from which they were able to deepen their didactic knowledge.

The results show that the development of teachers' didactic knowledge depends on their *knowledge of physics for teaching* a given topic, as well as their *strategies for teaching this topic in the classroom*. With regard to the knowledge of physics for teaching, the research points to evidence of the relationship between *curriculum content* and the *contextualization of content*. As for the strategies for teaching physics in the classroom, the results point to the importance of *using materials* suitable for addressing specific curriculum topics, the need to *conduct research,* and the process of *collective discussion* at the end of the lesson.

With regard to the knowledge of physics for teaching, steered toward *curricular content,* the need for continual training was noted as a way to develop and deepen some of the weaknesses of initial teacher education, i.e. the need for training throughout one's career to broaden and deepen the knowledge needed for teaching (Schneider & Plasman, 2011). In this sense, the lesson study allowed the group to develop specific aspects of didactic knowledge about Ohm's Law, by assisting teachers to broaden their skills in the disciplinary field (Van Driel, Verloop & De Vos, 1998; Shulman, 2004) and reflect on the importance of planning; on the type of activities carried out in the classroom, which often focus on memorization, minimizing the importance of theory. The participants also benefitted from observing how students carry out the activities, and from classroom experiences that encourage the development of teachers' professional knowledge. These reflections, involving the curriculum content and the associated materials, enable teachers to relate this content to subjects seen by the students in previous years and to anticipate essential aspects that will be taught later in school (Shulman, 1986). Teachers need to mobilize alternative forms of representation, some derived from research and others from the wisdom gained from practice (Shulman, 1986; Grossman, 1990), to make content considered difficult or abstract accessible to the student (Kind, 2009) and thus make the content comprehensible to others (Ponte, 2012).

In the *contextualization of the contents,* a transformation of the pedagogical dimension of teaching was observed, considering as primary factors the students' difficulties (Fernandez, 2015) with the subject of electricity or on the topic of investigation, as well as the promotion of a favorable working context with activities developed in pairs or groups. The lesson study provides moments for deepening didactic knowledge and for reflective training and planning involving teaching strategies (Grossman, 1990; Richit & Tomkelski, 2022) including assimilation, understanding and evaluation, as well as the definition of clear objectives, the use of correct and appropriate language and a coherent sequence of activities (concrete to abstract) whose main purpose is to obtain generalizations (Shamsudin, Abdullah & Yaamat, 2013; Fernandez, 2015), supported by a teacher's theoretical, social and experiential knowledge (Ponte, 2012).

Therefore, to address specific curriculum topics, teachers need to develop knowledge of the school curriculum, considering the changes and challenges experienced by students (Shamsudin, Abdullah & Yaamat, 2013) and social, economic and environmental issues. In addition to cognitive difficulties, other behavioral factors - resistance to learning - and emotional factors - fear, anxiety and dread - that can be linked to frustrating classroom experiences (Grossman, 1990) should be explored in greater depth. Through these processes, the development of teachers' didactic knowledge is promoted.

In relation to classroom teaching strategies, especially the *use of materials,* the analysis indicates the need to work with a differentiated curriculum that favors connections with other subjects, curricular components and areas of knowledge (Shamsudin, Abdullah & Yaamat, 2013; Richit & Tomkelski, 2022). From this perspective, teachers have the opportunity to combine content and pedagogy on the topic being studied, using strategies and resources that promote student learning (Shulman, 1987; Grossman, 1990).

Finally, the analysis shows the importance of using differentiated strategies and materials (Grossman, 1990; Richit & Tomkelski, 2022) when teaching physics topics, such as illustrations, analogies, explanations and demonstrations to make the subject understandable to students (Shulman, 1987). To this end, teachers must broaden their knowledge, especially when attention is directed towards learning involving multiple representations in the approach to physical concepts and phenomena (Ainsworth, 2006).

Carrying out research in the classroom stood out as a central element of the teacher's didactic knowledge for teaching physics. This requires collaborative and interdisciplinary planning, which allows preparing activities that are coherent with the curriculum and the needs of the students. This planning needs to (i) begin from a context that is close to the students' reality, (ii) promote student interaction with activities that promote understanding of the concepts and (iii) foster generalization processes (Shulman, 1987; Grossman, 1990; Magnusson, Krajcik & Borko 1999; Ponte, 2012; Richit, Ponte & Tomkelski, 2019).

The analysis also points to the need to present the contents in a language that is accessible to the students' level of understanding and maturity and the language used in the classroom (Grossman, 1990). The language used in class can approximate teachers and students and also allow evaluating student learning. Collaborative planning promotes predisposition and changes in professional practice (Magnusson, Krajcik & Borko 1999; Richit & Tomkelski, 2022), based on an integrative classroom process oriented towards actions necessary for the development of practice (Van Driel, Verloop & De Vos, 1998).

The *collective discussion* at the end of the research lesson stands out as one of the main contributions of the lesson study in terms of didactic knowledge. The analysis highlights that collective discussion is fundamental to deepening teachers' knowledge of student learning, as it enables them to understand their conclusions and their reasoning processes (Richit, Ponte & Tomkelski, 2019; Richit, 2020). It also provides the team with information needed to review lesson planning and propose improvements, and contributes to a deeper understanding of the topic under study, deepening didactic knowledge (Nilsson, 2008) related to the curriculum. Finally, collective discussion promotes greater student involvement and engagement in interpreting the resolving of tasks and systematizing the learning that has taken place.

Conclusion

In physics teaching, teachers' didactic knowledge depends on their *knowledge of physics*, as well as their *strategies for teaching in the classroom*. Among the knowledge of physics for teaching, teachers need to explore relationships between *curriculum content* and the *contextualization of content*. With regard to strategies, the following aspects emerged as being central to didactic knowledge: the *use of teaching materials* suitable to the need to carry *out investigative processes*, as well as *collective discussion* at the end of the lesson and after the lesson by the teachers, taking the opportunity, if necessary, to make the needed adjustments and additions to the planning, leaving it organized for future interventions.

The lesson study gave the group the opportunity to change how they approach physics concepts in the classroom insofar as they expanded aspects of their didactic knowledge. The research revealed advances in the development of teachers' knowledge in different educational contexts, as well as the potential of this approach for the professional training of physics teachers, and the development of classroom strategies to help students with their difficulties. However, it is important to emphasize that the aspects of didactic knowledge developed in classroom studies, because they are complementary and dynamic, are manifested in an integrated way throughout the cycle. For the purposes of this analysis, we have chosen to address them separately.

We would like to highlight some of the limitations of the research. The small number of teachers participating in the classroom study may have compromised the data collection process, making it difficult to generalize the results. We believe that with a larger number of teachers, the discussions would be broader and other aspects may be revealed. Another factor is related to the development of the lesson study considering the teachers' working conditions. This made it necessary to adjust the planning and the meetings during the process to prioritize everyone's participation. With regard to time management, it was found that the time to carry out the research lesson was not enough, as it took longer than expected to resolve the tasks. These factors did not harm the development of the research class or the proposed objectives.

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