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Talking to a scientist: comprehension of physics teachers about the production of scientific knowledge[+*]

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Abstract

The field of Science Education has sought to present science in a less caricatured way. In this context, one of the main criticisms of physics teaching is that the science taught in schools often reproduces misconceptions, especially when dealing with the production of scientific knowledge. In this context, an elementary school teacher, a scientist from the field of Materials Physics and two researchers from the field of Science Education carried out a study focusing on the understanding of high school physics teachers about the production of scientific knowledge. The teachers who took part in this research are all from southern Minas Gerais and work in public schools. The results suggest that having academic degrees such as a master's or doctorate does not always indicate a good understanding of the production of scientific knowledge. Teachers taking part in the research who only have an undergraduate degree performed better in the study regarding their understanding of the production of this knowledge. These results indicate that it is important for undergraduates to experience knowledge production processes during their initial training. We also believe it is necessary for scientists to disseminate their

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research in schools, so that they can talk about the production of scientific knowledge with teachers and students.

Keywords: *Physics Teachers; Open Problems; Production of Scientific Knowledge.*

I. Introduction[2]

Undoubtedly, one of a teacher's responsibilities involves understanding and teaching various aspects of the scientific knowledge production process. In this context, addressing different aspects of scientific knowledge production in the classroom is as fundamental as presenting students with concepts and theories that constitute humanity's organized and historically valued knowledge.

However, there is also no doubt about the inherent complexities of scientific knowledge production. Attempting to understand this process has been the subject of reflection for many thinkers. For example, throughout the 20th century, an interesting debate unfolded among philosophers of science regarding the complexities involved in scientific knowledge production (Bachelard, 1996; Chalmers, 2009; Feyerabend, 1989; Kuhn, 1997; Lakatos, 1979; Popper, 2004). To mention just two philosophers, Kuhn's central idea of a paradigm can be understood, in general terms, as a concept used to name the set of research commitments within a particular scientific community. Popper, on the other hand, argues that scientific theories are always conjectures and, in this sense, there is no way to establish that a theory is true. No matter how well-corroborated it is, it may still become problematic and be replaced by another. Popper also argues that an essential criterion for demarcating science from non-science is empirical tests that put the theory at risk (refutation test).

In this context, the notion of presenting science in a less caricatured way has been a recurring theme in Science Education. In fact, school science is often accused of reproducing misconceptions, either from the perspective of scientific knowledge production or the social, political, and economic conditions that accompany scientific work.

The field's concern with presenting a more authentic Science – contextualized and closer to what scientists actually practice; a problem-oriented science that posits bold hypotheses about reality and adheres to rigorous production criteria – has been considered essential for the kind of civic education required in the 21st century. It is worth noting that, according to Brown, Collins, and Duguid (1989, *apud* Oliveira; Harres, 2017), the term "authentic science" was coined in the 1980s to refer to a teaching approach that seeks to connect students' everyday school life with scientific activities similar to those undertaken by researchers. This perspective proposes using activities conducted by scientists as models for

[2] This work presents original results of a research carried out in the Graduate Program in Science Education of the Federal University of Itajubá.

investigative proposals developed in the classroom. According to Acevedo *et al*. (2005), acquiring scientific knowledge is necessary to form critical citizens, and a better understanding of science contributes to more reflective decision-making. To achieve this, Medeiros (2022) asserts that students need to learn not only concepts but also how science is produced and its relationships with society and technology.

However, according to Hulme and De Wilde (2014), high school students who enter higher education often experience a difficult transition, particularly regarding understanding the scientific field in which they will be trained. The authors suggest that it is only after completing a doctorate that students consistently grasp the meaning of scientific knowledge production.

Kapon, Laherto, and Levrini (2018), in turn, refer to the need to awaken a scientific spirit in basic education students and equip them to gain a clearer understanding of scientific practice by discussing the tension between school education and scientific practice. With this aim in mind, we understand that teachers play a fundamental role in this process, as they are the ones who bring knowledge into the classroom. Cian and Cook (2020) and Strupe, Caballero, and White (2018) suggest that it is the teachers' responsibility to create classroom conditions that help students make connections between their prior knowledge and the issues being discussed.

Against this challenging background, a group formed by a high school biology teacher from a public school on the outskirts of London, a biomedical science researcher, and other science education researchers, all from University College London (UCL), gathered to develop an investigative project that could shed light on how 16- and 17-year-old students from public and private schools understand and discuss contemporary open scientific issues. The work with the students was centered on various conversations between biomedical scientists and public school students. The scientist presented and discussed an open problem he was researching, namely, the mechanisms behind post-mitotic cellular movements in the developing spinal cord of chick embryos. Throughout the discussion, the science education researchers gathered data that provided valuable insights into how students use their school knowledge to think about open research questions in biomedical science (Levinson *et al*., 2023).

In this UCL study, the researchers found that the students who offered the most creative and potentially consistent arguments for solving the open research problem were not necessarily those with the highest grades. The authors also noted that exposing students to open scientific problems – that is, questions or challenges in science that have not yet been fully resolved or understood – alerts them to the fact that there is no set recipe for solving scientific issues and that many uncertainties are involved in producing this knowledge (Levinson *et al*., 2023).

This project expanded through collaboration with research groups from different countries, including Brazil. In Brazil, faculty from the Science Education Graduate Program at the Federal University of Itajubá (Unifei) accepted the invitation to participate in the research in Southern Minas Gerais. Due to the COVID-19 pandemic, the investigative approach was modified to focus on basic education teachers and their understanding of scientific knowledge production, particularly in the context of a conversation with an experimental physicist.

Thus, the research question guiding this study is: what understandings are developed by high school physics teachers about scientific knowledge production when they converse with a scientist about an open problem in experimental physics?

It is worth noting that we understand scientific knowledge production as the process by which scientists conduct research, develop theories, test hypotheses, and generate new knowledge within their fields of study. This process involves the systematic investigation of problems, critical review of existing literature, formulation of testable hypotheses, collaborative teamwork, and the pursuit of innovative solutions to relevant scientific issues. In this view, the goal of scientific knowledge production is to expand human understanding of the natural and social world through rigorous methods of data collection and analysis, as well as logical and critical reasoning. This process is fundamental to scientific advancement, allowing researchers to identify gaps in knowledge, propose new theories and explanatory models, and empirically test their ideas. Additionally, scientific knowledge production is driven by curiosity, intellectual challenge, and the quest for solutions to problems relevant to society. Thus, the work of scientists not only generates new knowledge but also contributes to innovation, technological development, and the improvement of people's quality of life. In summary, scientific knowledge production is a dynamic and collaborative process in which researchers use systematic and rigorous methods to investigate phenomena, test hypotheses, and generate new insights about the natural and social world, to expand the limits of human knowledge and promote scientific and technological progress.

To address this question, we invited physics teachers working in basic education schools under the jurisdiction of the Regional Education Superintendency (SRE) of Itajubá. We also invited a physicist, a researcher at a public university in Southern Minas Gerais, whose investigative work focuses on improving dye-sensitized solar cells (DSSCs).

II. Methodological Procedures

This is a qualitative research study. Following Godoy's (1995) guidelines, the qualitative/interpretative approach seeks to understand the subjectivity of human experience and focuses on the participants' actions and intentions.

The context of this investigation involved the proposal and implementation of a collaborative project including physics education researchers, a scientist specialized in materials physics, and physics teachers working in public schools.

Nine physics teachers participated in the study, ranging in age from 25 to 50 years, all working in state public basic education schools under the jurisdiction of the Regional Education Superintendency (SRE) of Itajubá. These teachers had varying levels of professional experience, from 2 to 22 years, and were allowed to learn about and discuss a scientist's research on dye-sensitized solar cells (DSSC).

The physicist involved is based at the Institute of Physics and Chemistry at Unifei. He identifies himself as an experimental physicist in the field of materials physics and researches materials intended for use in dye-sensitized solar cells. Additionally, the team included two physics education professors and a graduate student from the Graduate Program in Science Education at Unifei.

II.1 Data collection procedures

The project was submitted to and approved by the Research Ethics Committee. Data collection was conducted remotely during the Covid-19 pandemic, using information and communication technologies. Nine high school physics teachers from state schools in the Itajubá region agreed to participate in the study voluntarily, after being invited and informed of the study's objective. The participants were labeled P1 to P9 and taught in various cities and schools.

The first stage of the study involved a video provided to the teachers. In this video, the scientist explains the development and partial results of his ongoing research at the university. The scientist's presentation in the video covered the following topics: an introduction to the research; the motivation behind the research; an explanation of semiconductor structures; the structure of silicon solar cells; an introduction to the concept of Fermi energy; an explanation of what a PN junction is; the behavior of the junction in a silicon solar cell; characteristics of a DSSC; the basic operation of a DSSC and the problems encountered. It is important to note that each teacher had complete freedom to watch the video at a time and place of their choice.

One week later, in the second stage of the study, each physics teacher was invited to meet with the scientist via an online meeting using a videoconferencing app (the same app used in public schools and recommended by the government of Minas Gerais during the pandemic) at a time convenient for them. In this setting, the scientist engaged in one-on-one conversations with each teacher. We note that the first author of this article participated as an observer in the conversations that took place between the scientist and each physics teacher. These conversations were consistently focused on discussing the research conducted by the scientist. The discussions centered on issues related to creating more efficient photovoltaic cells for converting light energy into electrical energy. Part of the data was gathered from these meetings between the scientist and each physics teacher, with field notes taken for documentation. Additionally, the researchers had access to all conversations, as these were recorded.

The scientist used pre-set questions aimed at assessing the teachers' understanding of scientific knowledge production. For the scientist, the questions were intended to foster a dialogue about the teachers' understanding of the research problems he encounters and to encourage them to propose creative solutions to address the problems. For the researcher, the questionnaire aimed to obtain data that could identify various aspects that teachers associate with scientific knowledge production.

Table 1 – Questions posed by the scientist to the physics teachers.

Questions	
1	After watching the video, did you understand how a solar cell works?
2	Did you understand anything about the problems we are researching?
3	Suppose you were involved in such research. Would you have a proposal to tackle these problems?
4	Among your students, do you think some might volunteer to participate in research of this nature?

Source: Authors, 2024.

After the conversation with the scientist, in the third stage of the study, the first author of this article began a semi-structured interview with each physics teacher to gain a more detailed understanding of their views on scientific knowledge production. An interview guide (Appendix 1) was used for this purpose.

II.2 Participants

Chart 1 presents some information about the physics teachers who participated in the study.

Chart 1 – Some information about the teachers who were the subjects of the investigation.

Identification	Age	Years of teaching experience
P1	36	14
P2	37	14
P3	29	7
P4	42	14
P5	45	10
P6	31	7
P7	34	8
P8	38	2
P9	48	22

Fonte: Autores, 2024.

Table 2 presents the academic qualifications of the physics teachers who took part in the study. The data shown in Table 2 indicates that some teachers hold a master's degree or specialization and some are also pursuing or have completed a doctorate, which may suggest a stronger engagement with scientific knowledge production.

Table 2 – Academic qualifications of Physics teachers who participated in the investigation.

Identification	Degree	Specialitazion	Master's Degree	Doctorate
P1	Physics and Mathematics Teacher Training			
P2	Physics Teacher Training		Materials Science	Materials Science
P3	Physics and Mathematics Teacher Training		Science Education	PhD candidate in Physics Education
P4	Physics Teacher Training		Materials Engineering	PhD candidate in Materials Science
P5	Physics, Chemistry and Mathematics Teacher Training			
P6	Physics and Mathematics Teacher Training Pedagogy	Supervision, Guidance, and Teacher Training	Management, Planning, and Teaching	
P7	Physics Teacher Training			
P8	Agricultural Engineering Undergraduate in Physics Teacher Training			
P9	Mathematics Teacher Training	Educational Psychology		

Source: Authors, 2024.

II.3 Data Analysis Procedures

We used Bardin's (2010) Content Analysis procedures to analyze the data, specifically thematic analysis. To begin the analysis, the interviews and field notes taken during the conversations with the scientist were transcribed. After transcription, we conducted multiple readings of the texts to familiarize ourselves with the context and identify potential meaning units, which can be understood as the key elements or units of meaning within the communication. The presence or frequency of these units may signify something relevant to the analytical objective.

The transcriptions were entered into a computer with NVivo[3] software, a qualitative data analysis tool that helped us organize the data according to the identified meaning units. Reading sheets were created to organize these meaning units and record passages and excerpts from the transcribed texts that highlighted the most important elements in the research. We then carefully re-read the material to group the recording units (segments of content categorized for frequency and meaning) for further analysis. Bardin (2010) explains that frequently recurring themes should be isolated for analysis:

> *Themes that frequently recur are isolated from the text in comparable categorization units for thematic analysis and coding modalities to record the data* (Bardin, 2010, p. 100).

We understand that analyzing the material should not follow a sequential and linear approach but rather a cyclical and circular process to extract meaning from the data. At this stage, we categorized the collected data using expressive criteria – i.e., aspects of the data that are meaningful or representative of the intended analysis.

Finally, we present the data in this article using charts and tables where the meaning units are organized into groupings, allowing us to construct interpretations regarding the different understandings teachers have about scientific knowledge production.

III. Findings

In this section, we present the data gathered in our investigation, which allows us to discuss the high school physics teachers' understanding of scientific knowledge production. Table 3 provides examples of elements that characterize scientific production, according to the teachers' responses during the semi-structured interviews.

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[3] Nvivo is a software that supports various qualitative research methods. It is designed for the analysis of qualitative dada (QDA), and is produced by QSR International. Available in: http://www.qrsinternational.com/nvivo.

Table 3 – Elements that physics teachers consider to comprise scientific knowledge production.

Grouping	Representative excerpts from the grouping
Characterization of scientific knowledge production	[...] it doesn't always have a theoretical basis or anything like that, sometimes you're starting from scratch […]. (P2)
	Science is a human construction that has its errors, its successes. (P3)
	[...] It's hands-on, trial and error, sometimes it's almost empirical. (P2)
	It's hard research. (P2)
	They have practical problems that require practical solutions, so they'll look for that solution, which would be the case with applied research. […] In pure research, I develop certain knowledge. In applied research, I make that knowledge useful for something. (P5)
	[...] It requires extensive theoretical knowledge. (P1)
	[...] scientists work with curiosity, with an investigative mentality. (P4)
	[...] science isn't linked to science itself, but to society and the social context. (P6)

Source: Authors, 2024.

Examining the excerpts presented in Table 3, we note P1's mention of the theoretical perspective on knowledge. This comment suggests that this teacher does not share the traditional view that scientific knowledge production begins with neutral observation of facts. This traditional view tends to oversimplify the process of scientific knowledge construction.

However, P2 mentioned that scientific knowledge production sometimes starts from scratch. This statement may have been influenced by the scientist's emphasis on studying an open problem in materials physics, which sometimes involves encountering unexpected situations. In such cases, it may be necessary to go back to the starting point and choose new theoretical frameworks to approach the problem. Additionally, it's worth noting that P2 experienced scientific knowledge production in a highly engaged manner during their academic training (holding a master's and a doctorate). We emphasize that this type of statement also highlights a certain complexity in discussing scientific knowledge production. On one hand, some considerations indicate that theory precedes practice in scientific knowledge construction (Chalmers, 2009; Feyerabend, 1989; Kuhn, 1997). On the other hand, it is also necessary to recognize that there is an intertwining of theory and practice, making it difficult to delineate which comes first in the process of scientific knowledge production.

We also obtained research data from monitoring the conversations between the scientist and each physics teacher. Below, we highlight some excerpts from the teachers' arguments during their conversation with the scientist, particularly those in which the scientist questioned the teachers about their understanding of his research on solar cells. Table 4 summarizes the data obtained.

Table 4 –Different understandings by teachers regarding the research presented by the scientist.

Grouping	Teachers	Representative excerpt from the grouping
Showed evidence of understanding the research	P7	Yes. What stood out the most was exactly that idea of the electrons returning. And that's unwanted, because how can you create a filter? That's interesting to solve because then you could ensure efficiency by making the electrons flow in only one direction. Another thing, I also think that wasn't there, but I'm seeing it now: the durability of this material, because a typical solar cell material lasts about 20 years. Something like that. This material has to be durable. (P7)
No evidence of understanding the research	P1, P2, P3, P4, P6 and P9	Yes, I found it interesting, because we know that in the energy field, there needs to be a greater effort, and the point is that we increasingly need energy, and this is a way to have a smaller impact on the environment. (P1)
Showed partial understanding of the research	P5 and P8	Ah, as always, we have more questions than answers. I found it fascinating, especially the part where you can have a dye that captures solar energy and transforms it into electricity. I thought it was very fascinating how you talked about having photosensitive clothing so that we can walk around in our daily lives and capture solar energy. I thought it was fantastic, very cool. Overall, it was fascinating. (P5)

Source: Authors, 2024.

In the conversation between the teacher and scientist, we observed that the teachers remained interested and curious about the development and applications of the research on solar cells. However, we noticed that only P7 demonstrated a clearer understanding of the challenges associated with the scientist's research. We also noted that P7 is one of the three teachers who do not have academic training beyond an undergraduate degree. This teacher mentioned key aspects of the main research problem and inquired about how similar commercial devices function. P7 maintained an active dialogue with the scientist throughout the conversation, displaying significant curiosity about the topic.

It was not possible to determine that six of the teachers who participated in the conversation understood the research presented. Two of them demonstrated an understanding of the research's justification and context (P1 and P2) but not of the knowledge production process itself, which includes the research challenges. Two other teachers focused their dialogue on students and how to connect the presented research with the content they teach in the classroom (P2 and P9).

From the dialogues, we noted that teachers with more classroom experience tend to emphasize various aspects of teaching in the conversation (P1, P2, P4, and P9). They discussed elements related to their background knowledge and teaching experience. Teacher P9, for instance, made connections between the research and topics covered in basic education:

[...] I work a lot on this topic of renewable and non-renewable energy with the third-year students. I was just discussing with them why energy costs are high during the dry season. I also talk with them about renewable energy, but as for the depth that you mentioned, unfortunately, I don't have that knowledge myself, I know more about high school-level knowledge. I cover the concepts of potential difference, resistance in series and parallel, these concepts we need in high school for renewable energy, solar energy, that's what I teach the kids. (P9)

It is worth noting that P9 did not graduate in Physics. Additionally, it seemed to us that greater classroom experience (more teaching experience) helps teachers make various contextual connections between scientific knowledge and everyday aspects, which is undoubtedly highly relevant for the basic education context (Ricardo; Zylbersztajn, 2002; 2007; 2008). However, these teachers did not sufficiently explore the scientific problem being researched by the scientists.

It is interesting to present data from the point in the conversation where the scientist asks the teachers about their understanding of the research problem he is investigating

According to Wong and Hodson (2009), research problems are identified by scientists as one of the factors guiding the design of the investigations they carry out. In the video sent to the teachers, the scientist presents his research problem. The data obtained from this part of the conversation are summarized in Table 5.

As shown in Table 5, two teachers correctly identified the problem behind the research question and discussed topics that are relevant to the proposed discussion. Once again, P7 stands out among these teachers, discussing the solar cell's efficiency as presented in the video and other aspects related to its durability.

However, five teachers claimed to have understood the research, but, during the conversation with the scientist, we could not identify evidence of this understanding. Observations in the field notes indicated that some of these five teachers expressed uncertainty in identifying the scientist's research problem and were unsure if they were correct. They did not provide consistent evidence that they had identified the problem, as we can see in the statement by teacher P5:

"Yes. The efficiency is 10%, which is much lower than what is needed, is that right?" (P5)

Table 5 – Different understandings of the scientific problem presented by the scientist in a conversation with Physics teachers.

Grouping	Teachers	Representative excerpt from the grouping
Showed evidence of correct identification of the research problem	P4 and P7	[…] That's interesting to solve. You could ensure efficiency by making the electrons flow in only one direction. Another thing, is the durability of this material, because a typical solar cell material lasts about 20 years, and this material has to be durable. (P7)
No evidence that teachers understood the problem	P1 and P9	Hmm, hm! (P1)
Claimed to understand, but evidence confirming this was not found	P2, P3, P5, P6 and P8	[...] I confess that when I watched it [referring to the research video] with a less in-depth view than I should, I saw the proposal of the cells. I made an association, I believe I'm not mistaken, with photovoltaics, right? The proposal was different from traditional silicon, but I couldn't fully grasp it. What was the final goal of this proposal? (P6)

Source: Authors, 2024.

In general, the teachers identified that the scientist's research was directly related to improving the efficiency of the solar cell. We also observed that some teachers attempted to propose solutions to address this problem. Overall, we can say that the teachers showed varying levels of understanding of the research described by the scientist. However, only a few of them provided more bold and consistent considerations about the problem posed by the scientist.

In this context, we emphasize that the data do not allow us to say that most teachers fully understood the essence of the problem. Nevertheless, as suggested by Levinson *et al*. (2023), we raise the following questions: what knowledge of scientific knowledge production do teachers need to develop classroom activities that more closely align with how scientific knowledge is truly produced? Or, what training is necessary for teachers to gain a more realistic view of contemporary scientific knowledge production?

We also highlight that one of the physics teachers, who had no academic training beyond an undergraduate degree, was the one who most actively engaged with various aspects of the research problem presented by the scientist. The teacher's observations about the organic nature of the material used in the solar cell – which could limit its durability – stood out in our research data. This teacher also suggested using a filter to limit electron recombination, thus increasing the efficiency of the device. In other words, the teacher demonstrated an understanding of some of the problem's challenges and offered a tentative solution through a filter, though without venturing to guess what type of filter or mechanism could be used to create it.

In this sense, having a master's or doctoral degree is very beneficial for teachers working in basic education, but it does not automatically guarantee that they will have a broad and creative view of scientific knowledge production. It seems pertinent to assert that a solid academic foundation in an undergraduate program may be sufficient for teachers to build a more comprehensive understanding of the scientific knowledge production process.

Cotta, Munford, and França (2023) argue that doing and understanding scientific research means combining processes such as observation, inference, and experimentation with scientific concepts and theories. They further note that a perspective imbued with scientific theories is an essential part of scientific work, which often does not receive adequate emphasis in teaching. Demo (2014) warns of the need for teachers to broadly understand scientific knowledge production, to prevent science education in schools from becoming simply a series of events, campaigns, and occasional initiatives, rather than part of students' foundational education.

According to Chinn and Malhotra (2002), authentic scientific research methods are complex and uncertain, and scientists invest significant time and effort in addressing potential methodological errors, both in their own work and in that of other scientists.

We also highlight that during the conversation with the scientist, the teachers were invited to imagine they were involved in the presented research. They were encouraged to propose a possible solution to the research problem. The data allowed us to identify some ideas that teachers developed in response to this question, reflecting attempts to engage with the scientist's research. These responses are organized and presented in Table 6.

We observed that the participating teachers drew on knowledge gained in their training and teaching experience to propose solutions to the research problem presented. Thus, teachers' participations were classified into three distinct ways in which they engaged with the scientist in trying to find a mechanism that could improve solar cell efficiency:

1. A negative response that resulted from a non-constructive dialogue and another response from a teacher who did not address the issue.
2. Four responses referring to concepts commonly covered in physics, such as graphene, but which did not relate to solving the research problem.
3. Three coherent proposals attempting to make progress toward a solution, such as P5's suggestion involving quantum dots or P2's idea of searching for a theoretical framework to inspire new ideas.

Table 6 – Proposed paths for investigative development of the research problem presented by the scientist.

Grouping	Teachers	Representative excerpt from grouping
Presented a coherent proposal for advancing the research	P4, P5 e P7	[...] well, I think there are several points to resolve there, right, because I think the research is still in the initial phase. I think the main point, though others will need addressing later, is this polarimeter issue. It's very important, but I think the main point is this collection. Even if there's electron return, it seems to me that if you have an effective collection, you'll already have energy generation. Then, after that, you'd need to address this one, by finding a filter or a way to direct the electron. I think focusing on energy collection would be a good first step to get a result. (P7)
Presented a proposal unrelated to the research presented	P2, P3, P6 and P8	[...] if I had to choose a direction based on what you presented to me—look, it's not a topic I'm well-versed in—but thinking about the abundance of graphene, maybe that could be a path to follow, I don't know. (P6)
Did not propose a solution for the research problem presented	P1 and P9	At the moment, I haven't thought of anything. (P1)

Source: Authors, 2024.

Among the coherent proposals, it is notable that P5 and P7 do not have experience with a master's or doctoral degree. P2, however, holds a master's degree in Materials Science.

We emphasize that in part of P2's dialogue with the scientist, the teacher suggested reviewing the literature to see if any similar research offered direction. They also mentioned the idea of looking into other theoretical frameworks:

Good question! I don't know, but maybe I'd start by checking if there's any similar research in the literature, something to compare [...]. Maybe a theoretical framework could give me an insight, a hint, or spark another idea. (P2)

In this response, P2 demonstrated an understanding that scientific work often begins with a literature review and a consistent theoretical foundation.

Teacher P5, in turn, showed a sound understanding of the research problem. Although P5 did not present a consistent hypothesis to advance the investigation, they pointed to a possible path, engaging constructively with the scientist:

[…] I'd start by identifying what's preventing me from maximizing cell efficiency. I have a 10% return! Great! Where's the energy loss happening? What's causing that loss? That's where I'd start. (P5)

The researcher asked the participants if they had a proposed solution to the research problem. The difference in this sequence lay not in the quality of the initial suggestion but in the fact that both the researcher and the teacher tried to build a constructive dialogue around it. During the discussion, the researcher did not provide knowledge but structured a line of reasoning, occasionally asking questions to identify gaps. Three out of the nine teachers appeared uncertain when suggesting possible solutions or formulating hypotheses related to the research problem, as seen in the following excerpt:

Well, […] review the process in practice and do several trials until finding a way to organize the electron reaction situation there. I don't know if it will result in a new dye or if another material could be added besides the dye, maybe inserting it there […] along with the dye to prevent electron recombination or loss… I don't know, maybe it'll need a practical trial. I think it's essential to experiment several times, try several times, try several things, different dyes, other approaches, and test ideas beyond just the dye […]. (P8)

Additionally, we considered it relevant to present more data obtained in the interviews, especially when we asked the physics teachers to describe how a scientist works in producing scientific knowledge. Some teachers presented vague ideas on this topic, while others gave relatively simple descriptions of how science is produced, as shown in P4's response:

[…] I think that to develop science, you first need to generate that spark of curiosity, of challenge, of novelty. […] I think scientists work with curiosity, like investigators. (P4)

When P4 shared their view on how scientific work occurs, they noted the curiosity needed for scientific work development but did not elaborate further or introduce other ideas that would clarify their understanding of the topic.

We highlight that P5 suggested that scientists are individuals committed to creating a better world. This response seems simple compared to the question, which requires a deeper answer:

Today we have people dedicated to creating a better world. They face practical problems that require practical solutions, so they go look for that solution, which is the case with applied research. (P5)

Teacher P5 considered the social benefits and how this might motivate scientists in scientific knowledge production, without going into further detail. Other teachers, such as P7 and P8, noted relevant aspects of scientific knowledge production:

[…] it's very difficult for scientists to work alone. (P7)

[…] a scientist, over the years of experience they have, will try to find answers within what they see as gaps in a certain area, to address and fill that gap. (P8)

Teacher P7 observed that in producing knowledge, scientists work in teams, indicating that scientific knowledge production is a collaborative endeavor often involving many people. Teacher P8, meanwhile, emphasized the need to build answers to open questions in a given field of knowledge.

IV. Final thoughts

In this section, we revisit some points from the literature that underpin our investigation and the main results of this research, before presenting some recommendations for the initial training of physics teachers.

We start from the premise that teachers are daily challenged to present science as it "truly is," rather than merely promoting what can be found in textbooks only (Martin; Kass; Brouwer, 1990). We also agree with Chinn and Malhotra (2002) that there are significant differences between what constitutes scientific knowledge production and what is typically taught in schools about how science is produced. According to Lee and Butler (2003), it is important to create a learning environment where elements of authentic scientific knowledge production are present.

Our results indicate that high school teachers with more specialized academic training, including master's and doctoral degrees, are not always those who offer the most thought-provoking insights into scientific knowledge production. In this context, while not dismissing the importance of teachers having contact with investigative processes through master's and doctoral programs, we understand that undergraduate training may be sufficient to provide teachers with the tools to engage in creative and consistent dialogues about scientific knowledge production. That is, an initial training process in which teachers have the opportunity to experience scientific knowledge production. In this regard, we emphasize the importance of offering undergraduate students opportunities to participate in scientific initiation projects. In this sense, our research seems to differ from some of the considerations of Hulme and De Wilde (2014), particularly regarding their claim that students only consistently understand the meaning of producing scientific knowledge after completing a doctorate.

Moreover, we consider it essential to advocate for and maintain undergraduate teaching programs that are exclusively disciplinary (Physics, Chemistry, Biology, Mathematics, etc.). Our findings indicate that teachers without an initial training background in physics had greater difficulty understanding fundamental conceptual aspects that could aid in comprehending the research problem presented by the scientist, who in this case was an experimental physicist in materials physics. Based on our results, we argue that a consistent disciplinary foundation in initial teacher training is important, enabling teachers to better understand scientific knowledge production within their respective fields.

The results also show that some of the teachers in this study appear not to have mastered important aspects of scientific knowledge production, particularly those with more years of classroom experience. This hinders the development of appropriate teaching practices on this topic. Thus, we emphasize the need to provide in-service teachers with various opportunities to discuss contemporary scientific knowledge production with scientists. We believe the ideal situation would involve scientists from diverse fields regularly visiting basic education schools, particularly to share their work and engage in conversations with teachers about modern scientific knowledge production.

Finally, our investigation allows us to formulate other questions that could be explored in future studies, such as: what aspects are essential in a physics undergraduate teaching program to enable future teachers to conduct lessons that address authentic aspects of current scientific knowledge production?

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Appendix 1

Script of the semi-structured interviews carried out with Physics teachers working in state schools within the jurisdiction of the Regional Education Superintendency of Itajubá.

Stage	Aims	Questions
1 Participants' profiles	To build the physics teachers' profile	1- What made you choose your academic training?
		2- What was your initial undergraduate course that allowed you to teach high school Physics?
		3- Where did you graduate? Tell us a little about your initial training.
		4- Have you undergone any scientific initiation? Have you got a Master's degree? A Doctorate?
		5- What was the topic of your course completion work? Tell us a little about it.

2 Data on physics teaching understandings	To obtain data about the physics teachers' understandings on physics teaching in public schools	6- In your opinion, what is the purpose of teaching physics in high school?
		7- What is it like to be a teacher in state schools?
		8- Which methodologies do you seek to employ when teaching high school Physics?
		9- What concepts do you typically cover with your students?
		10- In your opinion, in which situations do high school students learn something about the production of scientific knowledge?
3 Data on understanding how the scientific knowledge is produced	To obtain information about the Physics teachers' understanding of how scientific knoledge is produced	11- How do scientists work in the production of knowledge?
		12- What distinguishes a research problem from a Physics problem in a textbook?
		13- What did you understand about the research carried out by the scientist who works with solar cells?
		14- What research problems is that scientist involved in?
		15- Are the research problems presented by the scientist open problems? Or are they problems with a solution in sight?
		16- Do there remain any doubts and questions about the scientist's work? Which?
		17- Would you like to know any further information about that scientist's work?
4 Other information	To obtain information about the effects the conversation with the scientist could have on the teachers' future teaching practices	18- Is there anything about your classes that you believe can be modified because of the conversation with the scientist?