Utilizing Physics Teachers' Epistemological and Pedagogical Conceptions to Develop a Research Instrument for Training Programs

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Abstract In this research, we used a theoretical framework for physics teachers' training as a starting point to develop a new research instrument (online questionnaire) for exploring teachers' conceptions on the epistemology and pedagogy of physics, using thermodynamics as the field of reference. Our goal was to validate the theoretical framework and also use it as a methodological framework to make informed decisions on the design and evaluation of future training programs based on teachers' ideas. Our analysis ($N = 42$ in-service physics teachers in Athens, Greece) indicated four factors that can facilitate a practical use of the theoretical framework. These factors addressed the teachers' prior knowledge, alternative instructional design, traditional framework perception, and intention to change their current instruction. We suggest that further research should address larger populations and make adaptations for additional physics fields to validate and generalize these results.

1 Introduction

Physics teachers' training programs is a common practice for in-service teacher professional development. In this research we support that such programs should consider teachers' prior ideas about the epistemological and pedagogical dimensions of physics as a subject to be taught (Porlán et al. 2004). For the design and evaluation of a webinar series for physics teachers in Greece, we utilized a theoretical framework for physics teachers' training (Gil-Pérez and Pessoa de Carvalho 1997). In this respect, we developed a new research instrument (questionnaire) to identify in-service physics teachers' epistemological and pedagogical conceptions, using thermodynamics as the field of reference. Based on our results, we suggest the utilization of the theoretical framework as a methodological framework as well that can guide the design and evaluation of physics teachers' training programs.

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2 Theoretical Framework

Gil-Pérez and Pessoa de Carvalho (1997) suggested a theoretical framework for physics teachers' training that was an appropriate foundation for the development of both research instruments and instructional materials (Gil-Pérez and Pessoa de Carvalho 1997). This framework included four components (or *fundament points*): (a) knowing physics as the subject matter to be taught, (b) knowing teachers' spontaneous ideas on physics and on teaching and learning physics, (c) acquiring theoretical knowledge about the physics teaching and learning process, and (d) teachers' involvement in physics education research and innovation.

2.1 Component 1: Knowing Physics as the Subject Matter to Be Taught

Regarding the first component, the training program should be concerned with teachers' knowledge of physics as a subject matter to be taught. Teachers give prominence to the conceptual aspect of scientific knowledge rather than its methodological and cultural aspects (Fadaei 2012). We consider that teachers' scientific knowledge is bound, in contrast to their epistemological knowledge of physics, since the latter is more "optional" to delve into during physics studies. The main epistemological dimension of physics concerns the history of science, which is usually disconnected from the subject matter to be taught (Apostolou and Koulaidis 2010; Kanderakis et al. 2011). Epistemological knowledge of physics includes conceptual issues, methodological choices, and interactions between science, technology, and society that have driven the construction of physics knowledge (Gil-Pérez et al. 2005). In addition, it is related to the enrichment of scientific knowledge with modern discoveries, to support the dynamic development of physics. Based on the above, teachers are expected to adjust and choose the content they present to students to strengthen an epistemologically correct image of science, but also to be eager to enrich their personal knowledge in this direction.

Fadaei (2012) conducted a survey to 25 physics teachers regarding this first component of the theoretical training framework, asking them to rate its elements in terms of importance. Teachers considered quite important to know how the scientific knowledge has emerged, as well as the interactions between science, technology, and society. For this aspect, more detailed conclusions were added from Irez's (2006) research on the Nature of Science (NOS) in 15 pre-service science teachers. While 86% recognized that society influences science, at the same time only 53% considered science as a cultural product and just 20% believed that scientific knowledge was depended on the social context. Regarding the knowledge of the methodological developments that supported the scientific knowledge, the teachers in Fadaei's (2012) study characterized it as rather unimportant. According to them, the most important element was the acquisition of knowledge related to new scientific discoveries.

Finally, they considered that it was important to be able to choose appropriate content for their teaching, as well as to be predisposed to deepen their own epistemological knowledge.

2.2 Component 2: Knowing Teachers' Spontaneous Ideas on Physics and on Teaching and Learning Physics

The second component suggests that for the teachers' training it is important we know their spontaneous ideas on physics and also on the teaching and learning of physics. The most prevailing characteristic is the role of experiments in agreement with an empirical-deductive approach (Aguirre et al. 1990). Educational research highlights a range of physics teachers' conceptions on physics epistemological features, that usually comply to the textbooks and the corresponding teacher instructions. Many of the conceptions that teachers carry are compatible with the positivist tradition of physics. These conceptions have a significant impact on the way students conceive physics as a construct (e.g., Tsai 2007). In this respect, the experimental-inductive approach, during which the formulation of hypotheses and theories is underpinned by free observation and subsequent conclusion drawing, is particularly widespread (Aguirre et al. 1990; Apostolou and Koulaidis 2010). The distorted role of the experiment is consistent with the strict imperatives of an inflexible "scientific method," which predetermines the path to the emergence of established knowledge, mainly through formalistic strategies, therefore obscuring the constant need for creativity that characterizes the construction of scientific knowledge. In the same context belongs the fragmentation of physics into fields, which indeed serve practical purposes, but at the same time distort the unity of science whenever the connections between them are not highlighted. Considering the above, teachers often present physics as a linear scientific achievement, which has not experienced deep crises or reorganizations. Additionally, some general epistemological conceptions that teachers systematically imply, seem to play an important role in the teaching and learning of physics. The reasonings that support scientific knowledge are often treated as "common sense," relying on quick and self-evident answers, which appear as indisputable facts (Ogborn 2008). Another teachers' conception in this respect is the one that projects physics as scientific knowledge "for the few," i.e., mainly for those who can understand the mathematical formalism through which modern science is usually represented. It is therefore not surprising that teachers present the physics construct as the achievement of some genius scientists, who worked individually and acted independently of the socio-economic and technological developments of their time.

Aguirre et al. (1990) studied conceptions of science, teaching and learning held by 74 physics teachers. Concerning their conceptions of physics, 36.2% of the teachers' statements revealed an experimental-inductive conception of science. This outcome was in line with Irez's (2006) results, where 54% of the sample supported the empirical nature of science as a conclusion derived solely from direct evidence. In Aguirre et al. (1990) there was a small percentage (3.8%) who viewed science as a “three-step” process in the sense of the predetermined scientific method. However, the corresponding results in Irez’s (2006) sample gave much higher percentages, as 80% supported the existence of a unique scientific method that, according to 54% of the participants, was involving predetermined stages. For the same issues, in the research of Flores et al. (2008) with 12 pre-service physics teachers, 58% of the sample expressed empirical or positivist views concerning conceptual elements, and 62% expressed such views concerning experimental elements. All conceptions mentioned above were also confirmed by Brickhouse (1989) through the interviews she conducted with three teachers (the whole sample), in combination with the lesson observations in their classrooms. In this study, two of the teacher participants agreed with the “linearity” in the construction of knowledge in physics. This finding is also related to the teachers’ conceptions in Irez’s (2006) study, in which 68% stated that theories and laws are in hierarchical relationships with each other. Finally, one teacher from Brickhouse’s (1989) sample intensively formed an image of scientists as isolated and peculiar personalities during his teaching.

2.3 Component 3: Acquiring Theoretical Knowledge About the Physics Teaching and Learning Process

It is essential for a training program to engage in the introduction and/or negotiation of the teachers’ epistemological conceptions. However, epistemological conceptions directly or indirectly interact with pedagogical conceptions, therefore it is also necessary for a training program to include pedagogical framework elements that concern the teaching and learning of physics in a unified manner (Belo et al. 2014). Regarding the third component, these elements refer to a constructivist view, and especially its socio-cognitive version, which places students’ ideas at the center of the teaching process (Mansour 2009). In this context, it should be highlighted that students have already formed conceptions about the scientific subject to be discussed before they attend a formal education setting and any construction of the scientifically accepted knowledge occurs in accordance with their personal pre-existing knowledge. Consequently, learning is meaningful only if each student succeeds in constructing it in a way that meets their individualized cognitive needs and interests (Watts 2013). Yet, only a few teachers appreciate students’ prior ideas and the way they construct their knowledge (Gil-Pérez and Pessoa de Carvalho 1997). Furthermore, the utilization of student-cooperative teaching and learning can play a crucial role in highlighting scientific knowledge because of social interactions (Mansour 2009). Finally, it is important that the classroom environment is permeated by the evaluative commitments that also characterize realistic scientific research environments, and not by students’ enforcement to engagement with physics (Briscoe 1991).

In Demirci’s (2015) study with a sample of 135 pre-service physics teachers who responded in writing to the question “how should physics be taught?”, only 15% of them felt that students' prior or alternative ideas should be considered in this respect. In the same sample, 11 interviews were conducted and only 9% of interviewees raised this issue on a constructive basis. At the same time, 27% stated that the "transmission" of knowledge from the teacher to the students is how knowledge constructed, while 64% approached the issue with a conflation of traditional and constructive approaches. Accordingly, in of Flores et al. (2008) only 30% had a constructivist approach to students' prior ideas and the way students construct their knowledge. Finally, from Demirci's (2015) interviews, again only 9% emphasized student-cooperative learning and suggested non-traditional ways of assessment.

2.4 Component 4: Teachers' Involvement in Physics Education Research and Innovation

Finally, the fourth component that concerns teachers' involvement in physics education research and innovation has not been sufficiently explored, indicating the distance that often exists between educational research and practice. According to the examined theoretical framework for physics teacher education, a fruitful strategy for introducing and/or negotiating their epistemological and pedagogical understandings is the teachers' involvement in educational research. This strategy can take on various characteristics. First, teachers should embrace the view that such collaboration could bring solutions to the problems they face in the classroom. Secondly, teachers should be open to the changes that their training may bring when challenging established conceptions and practices. Finally, teachers should actively participate in the investigation, innovation, and construction of physics teaching and learning and to join, as much as possible, the scientific community. Aspects of this axis are particularly unexplored at the empirical research level, which reflects, among other things, the distance between educational research and practice (Saha 2009).

3 Research Questions

Although several elements of the theoretical framework under discussion have been already applied and tested in the various contexts presented in the literature review, so far the framework has not been holistically examined. To do so, we utilize thermodynamics as the field of reference for developing a research instrument and, consequently, a training program based on the components and elements of this theoretical framework (Gil-Pérez and Pessoa de Carvalho 1997). We seek to validate the theoretical framework and explore its potential to work also as a methodological framework to meet physics teachers' needs regarding their training. Therefore, our research questions are the following:

- What is the structure of a methodological framework for a physics teachers' training program that addresses their epistemological and pedagogical conceptions on thermodynamics?
- Which items should be included in a questionnaire for the design and evaluation of a physics teachers' training program on thermodynamics epistemology and pedagogy?

4 Method

Based on the four components of the theoretical framework for physics teachers' training and the elements included in each of these components, we developed a questionnaire that included 22 closed-type questions (with a 5-point Likert scale). With the cooperation of the Regional Centre of Educational Planning for the upper secondary school (15–18 y.o. students) science curriculum (central Athens, Greece), we sent an online questionnaire to 150 physics teachers that taught thermodynamics during that school year (2020–2021). Out of them, 42 teachers answered the questionnaire. The participation was voluntary, the answers were anonymized, and the participants gave their informed consent for the use of their answers for the purpose of this study. All questionnaire items as well as the teachers' responses can be found in Meli et al. (2021).

The questionnaire was quantitatively analysed in SPSS. We started with parallel analysis (O'Connor 2000) to investigate the factorial structure of teachers' responses. Bartlett's Test of Sphericity ($p < 0.01$) indicated that the correlation between the items is adequate for factor analysis as well as Kaiser–Meyer–Olkin (KMO = 0.577) and Measure Sample Adequacy (MSA about 0.6) revealed that the teachers' answers created a satisfactory factorial structure (Tabachnick and Fidell 2007). Subsequently, we used exploratory factor analysis applying the principal component analysis method (Tabachnick and Fidell 2007). Since the factor analysis indicated non-negligible correlations among the factors, we used the oblique rotation to identify a simpler structure pattern. This analysis revealed four factors that presented satisfactory reliability as Cronbach's Alpha coefficient varied from 0.845 to 0.781 (Table 1). The factorial structure of four factors explains 62.7% of the total variation (Factor 1 = 28.4%, Factor 2 = 13.0%, Factor 3 = 11.5%, and Factor 4 = 9.8%). Factor 1 (*Teacher prior knowledge*) was significantly correlated with factor 2 (*Alternative instructional design*) and factor 4 (*Intention to change*). Factors 2 and 4 were additionally correlated with each other. The one factor that had no statistically significant correlation, and in fact had slightly negative relation with the rest factors, was factor 3 (*Traditional framework perception*).

Table 1 Reliability coefficients and product moment Pearson correlations among factors

	1	2	3	4
Factor 1	0.845[c]			
Factor 2	0.414[a]	0.836[c]		
Factor 3	−0.166	−0.173	0.836[c]	
Factor 4	0.314[b]	0.377[b]	−0.183	0.781[c]

[a] Correlation is significant at the 0.01 level (2−tailed)
[b] Correlation is significant at the 0.05 level (2−tailed)
[c] Cronbach's Alpha coefficients

Table 2 Teachers' education level (N = 42)

Degree	Frequency	Percentage frequency (%)	Cumulative percentage
Graduate	18	42.9	42.9
Postgraduate	19	45.2	88.1
Ph.D.	5	11.9	100.0

Table 3 Teachers' experience in teaching thermodynamics (N = 42)

Thermodynamics teaching experience (school years)	Frequency	Percentage frequency (%)	Cumulative percentage
1–3	6	14.3	14.3
4–10	19	45.2	59.5
≥11	17	40.5	100.0

5 Results

5.1 Research Sample

In terms of gender, the participants were 73% men and 27% women. More than half participants (57%) were holding a postgraduate degree (Table 2). The vast majority (86%) had already been teaching the thermodynamics course for more than four school years (Table 3).

5.2 Factor 1: Teacher Prior Knowledge

The first factor of the final factorial structure included items relating to teachers' prior knowledge, that referred to both epistemological and pedagogical aspects of thermodynamics. Table 4 presents the original theoretical framework elements and the corresponding questionnaire items that included in this factor, in a descending

Table 4 Factor 1: original theoretical framework element (with component and element number) and the respective questionnaire item in descending loading (λ) order

Theoretical framework element	Questionnaire item	λ
Knowing the problems that rose the construction of the knowledge to be taught (1.1)	What is your assessment of your knowledge of the history of thermodynamics concerning the development of its concepts?	0.879
Knowing the methodological orientations employed in the construction of knowledge (1.2)	What is your assessment of your knowledge of the history of thermodynamics concerning the development of its methods?	0.854
Pupils cannot be considered as "tabula rasa" (3.1)	What is your assessment of your knowledge concerning students' conceptions on thermodynamics?	0.769
Acquiring some knowledge of recent scientific developments to transmit a dynamic, non-closed view of physics (1.4)	What is your assessment of your knowledge of the recent scientific developments in thermodynamics (interdisciplinary)?	0.670
A meaningful learning demands that pupils construct their knowledge (3.2)	What is your assessment of your knowledge concerning contemporary constructivist approaches of thermodynamics teaching and learning?	0.639
Knowing the science/technology/ society interactions (1.3)	What is your assessment of your knowledge of the history of thermodynamics concerning the cultural context within it was developed?	0.583

loading order. The elements derived from the first (knowing physics as the subject matter to be taught) and the third (acquiring theoretical knowledge about the physics teaching and learning process) component of the original theoretical framework, indicating that teachers' epistemological and pedagogical conceptions were quite interwind.

In the context of the questionnaire, the epistemological conceptions reflected to the teachers' self-assessment of their existing knowledge on the historical development of thermodynamics concerning conceptual, methodological, and cultural aspects, as well as on the recent developments in the field of thermodynamics. The pedagogical conceptions reflected to the teachers' self-assessment of their knowledge on constructivism, with a special focus on the students' prior knowledge, which is fundamental for applying such approaches.

5.3 *Factor 2: Alternative Instructional Design*

The second factor included teachers' ideas for approaching thermodynamics through an alternative instructional design, mostly based on the epistemology of the field and the impact it can have on a broad student audience. Table 5 presents the original theoretical framework elements and the corresponding questionnaire items that included

Table 5 Factor 2: original theoretical framework element (with component and element number) and the respective questionnaire item in descending loading (λ) order

Theoretical framework element	Questionnaire item	λ
A rigid view (algorithmic, exact, infallible… dogmatic) (2.2)	Do you believe that it would be useful to present more historical elements for the development of thermodynamics (e.g., inventions, creative solutions)?	0.909
An individualistic view (2.7)	Do you believe that it would be useful to present the scientists' collaborative work that historically led to the development of thermodynamics (and not just the persons' that were directly connected to the ultimate results)?	0.813
A socially 'neutral' view (2.8)	Do you believe that it would be useful to present the connection of thermodynamics with social issues (historical and recent)?	0.795
A merely accumulative vision (2.4)	Do you believe that it would be useful to present the scientific methods that historically led to the development of thermodynamics (and not just the ultimate results)?	0.792
An exclusively analytical vision (2.3)	Do you believe that it would be useful to present thermodynamics as an interdisciplinary scientific subject?	0.523
A "veiled" and elitist view (2.6)	Do you believe that thermodynamics is a scientific subject that should be it promoted as a meaningful and approachable one for all students?	0.437

in this factor, in a descending loading order. All elements derived from the second component (knowing teachers' spontaneous ideas on physics and on teaching and learning physics) and formed a group of the most prevailing teacher ideas.

In respect to the questionnaire items, teachers were prompted to reveal how deeply they were attached to these ideas and if they would open to overcoming them in the context of an alternative (constructivist) instruction. The focus was shifted toward the most accurate presentation of thermodynamics as a field that has been developing within a cultural and social context throughout a long period and with a variety of interactions among scientists and among relevant fields.

5.4 Factor 3: Traditional Framework Perception

The third factor clustered the items that referred to teachers' evaluation of traditional teaching and learning sequences of thermodynamics, including their own self-assessment for implementing such sequences in their classrooms. Table 6 presents the original theoretical framework elements and the corresponding questionnaire items that included in this factor, in a descending loading order. Most elements derived from the third component (acquiring theoretical knowledge about the physics teaching and learning process) and one from the fourth one (teachers' involvement in physics

Table 6 Factor 3: original theoretical framework element (with component and element number) and the respective questionnaire item in descending loading (λ) order

Theoretical framework element	Questionnaire item	λ
The construction of scientific knowledge has axiological commitments (3.5)	What is your assessment of the traditional methods that are used for the introduction of thermodynamics to students?	0.933
To construct knowledge pupils need to deal with problematic situations which may interest them (3.3)	What is your assessment of the traditional methods that are used for the students' penetration of thermodynamics?	0.821
Be conceived in an intimate connection with the teaching practice itself (4.1)	What is your assessment of your teaching of the school knowledge of thermodynamics up to now?	0.812
The construction of scientific knowledge is a social product (3.4)	What is your assessment of the level of group learning during your thermodynamics courses?	0.683

education research and innovation). These refer to the way students approach and construct their knowledge and how teachers act as facilitators in this process.

The respective questionnaire items adhered to the traditional approaches thermodynamics is introduced to students and worked through by the students. It is interesting that the teachers' self-assessment of their instruction, including the level of group learning during their respective courses, made its appearance within this factor. This may indicate that in their everyday practice they found more common ground with the traditional approach of teaching and learning thermodynamics rather the alternative (constructivist) one presented in Factor 2.

5.5 *Factor 4: Intention to Change*

Finally, the fourth factor represented the teachers' intention to deepen their knowledge of the epistemology and pedagogy of thermodynamics and help bridging the gap between educational research and practice. Table 7 presents the original theoretical framework elements and the corresponding questionnaire items that included in this factor, in a descending loading order. The elements derived from almost all components (knowing physics as the subject matter to be taught, teachers' involvement in physics education research and innovation, and knowing teachers' spontaneous ideas on physics and on teaching and learning physics) except for the third (acquiring theoretical knowledge about the physics teaching and learning process). The elements comprising this factor showed teachers' inclination toward new, research-informed, knowledge on teaching and learning. The emergence of the teachers' "extreme inductivism" within this factor was exceptionally intriguing.

As for the respective questionnaire items, teachers appeared to interwind their potential training with the development of new teaching and learning sequences

Table 7 Factor 4: original theoretical framework element (with component and element number) and the respective questionnaire item in descending loading (λ) order

Theoretical framework element	Questionnaire item	λ
Oriented to favor the experiencing of innovating proposals and explicit teaching reflection (4.2)	Are you interested in approaching the school knowledge of thermodynamics with a new teaching and learning sequence?	0.867
Designed to incorporate teachers to the investigation and innovation and involve them in the construction of the specific knowledge body of science teaching (4.3)	Are you interested in approaching the school knowledge of thermodynamics with a new teaching and learning sequence that will be implemented to contribute to the pertinent educational research?	0.845
Knowing how to choose appropriate content (1.5)	What is your assessment of your potential to restructure, enrich, or alternate the standard suggested school knowledge of thermodynamics?	0.705
Being prepared to deepen the knowledge (1.6)	What is your assessment of your readiness for the enrichment of your knowledge of thermodynamics as a subject to be taught?	0.575
Extreme inductivism (2.1)	Do you believe that it would be useful to further utilize experiments for the school knowledge of thermodynamics?	0.434

on thermodynamics, that would require a shift from the traditional approach. The teachers' inductivism may require a different interpretation in the context of this factor, as it seemed that teachers included the role and extent of experimental work in class subjected to change in agreement to their alternated instruction.

6 Discussion

In this study, we utilized a theoretical framework for physics teachers' training (Gil-Pérez and Pessoa de Carvalho 1997) to develop an online questionnaire as a research instrument that would facilitate physics teachers' training programs. Our aim was to examine in-service physics teachers' conceptions on physics epistemology and pedagogy to validate the theoretical framework and use it as a methodological framework as well. Instead of approaching physics as a "generic" subject matter to be taught, we utilized thermodynamics as a field of reference. At a great extent, we validated the elements of the initial framework (Aguirre et al. 1990; Flores et al. 2008; Fadaei 2012); however, our exploratory analysis indicated a different structure for the included elements when the theoretical framework was put into practice. We used the results for the design and evaluation of a training program on thermodynamics teaching and learning in upper secondary school in Greece (Meli et al. 2021).

The first factor we extracted (*Teacher prior knowledge*) included elements from both the epistemological and pedagogical aspects of thermodynamics as a subject matter to be taught, indicating that teachers may need to deal with these aspects in a unified manner. This factor combined teachers' knowledge of thermodynamics as a history-dependent scientific field and of students' initial ideas as they start the course. As for the epistemological aspect, previous studies (e.g., Irez 2006; Fadaei 2012), indicated that teachers thought higher of the conceptual development of thermodynamics in comparison to its methodological and cultural one. This finding agreed with their interest in any new developments in the field, suggesting that they may were more comfortable dealing with the scientific content rather than its epistemology. However, in our research these two elements (conceptual development and new developments) were grouped along with the methodological and cultural development, and also with the science-technology-society interactions. As for the pedagogical aspect, our literature review showed teachers' low engagement to constructivist approaches (e.g., Flores et al. 2008; Demirci 2015), but our results indicated that the teachers focused on their awareness about two crucial parameters: students' prior knowledge and the way students construct their knowledge.

The second factor (*Alternative instructional design*) formed a group of the most persistent "traditional" teacher ideas when they come to instruction. The teachers gave prominence to the rigid, individualistic, socially "neutral", accumulative, and analytical views of thermodynamics that may characterize them as scientists and interfere with their instruction. These views were sporadically identified in the literature (e.g., Brickhouse 1989; Irez 2006), yet they had not been correlated with each other. The teachers in our sample unified these views under one factor that reflects a very narrow perspective of science as a culturally isolated product which progresses almost randomly, depending on the immediate success of solitary scientists, and concerns only "gifted" individuals (Apostolou and Koulaidis 2010). However, the respective questionnaire items were formulated in a way that prompted teachers to identify and revise them in order to move toward a constructivist approach of thermodynamics teaching and learning.

The third factor that was formed (*Traditional framework perception*) reflected teachers' conceptions on the traditional they commonly introduce and elaborate thermodynamics in their respective courses. In this context, students are prompted to construct knowledge ignoring the attached axiological commitments or problematic situations relevant to that knowledge that may interest them. In addition, they mostly work individually in the classroom. These elements clearly interacted with teachers' self-assessment of their usual instruction and therefore they were grouped together. This finding was in-line with the results of previous studies (e.g., Flores et al. 2008; Demirci 2015) and highlight how teachers conceive the learning obstacles students encounter in a thermodynamic course, but also the teaching difficulties that teachers face in the context of a traditional approach.

Finally, the fourth extracted factor (*Intention to change*) indicated the connections that physics education research can have with the everyday teaching and learning practices. The teachers saw the development of their instruction in terms of the content they incorporate in relation to the deepening of their thermodynamics epistemological and pedagogical knowledge. An element that interestingly made its appearance within this factor is the teachers' "extreme inductivism" as a prominent idea they bring to their instruction and is mostly presented through an intense focus to experiments, as it has often presented in the literature (e.g., Aguirre et al. 1990; Irez 2006; Flores et al. 2008). In the context of this factor, however, teachers probably demonstrated their need to inform their experimental instruction with education research-based ideas (e.g., replace the "recipe-like" approach). The findings that fall under this Factor may imply that the "gap" between educational research and practice is not as wide as previously perceived (Saha 2009); at least from the teachers' point of view.

Future studies should test the questionnaire to larger populations of in-service physics teachers and, additionally, to pre-service physics teachers to indicate possible similarities and differences between these samples. Considering that the choice of thermodynamics as a field of reference may have impacted the teacher's answers (in comparison to *physics* in general or any other field, e.g., *mechanics*) it would be interesting to adapt it for different physics fields (beyond thermodynamics) to explore its generalization potential. Consequently, the reframed theoretical framework as a methodological one can be used for the design and evaluation of future physics teachers' training programs. A limitation inherited in all questionnaires that uses self-reports is that they have a risk of socially desired responses and measurement bias (Lavidas et al. 2022). A comparison of the instrument presented in this study with ones with similar content can define the criterion validity for such questionnaires that explore teacher conceptions.

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