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PHYSICS TEACHERS' TRAINING WEBINARS FOR TEACHING AND LEARNING INTRODUCTORY THERMODYNAMICS IN UPPER SECONDARY SCHOOL

Kalliopi Meli[1], Dimitris Koliopoulos[1] and Konstantinos Lavidas[1]
[1]University of Patras, Patras, Greece

This study refers to a training program addressing upper secondary school physics teachers for the development of Teaching and Learning Sequences (TLSs) for introductory thermodynamics courses. To accomplish that, we presented essential epistemological and pedagogical elements of thermodynamics and proposed an alternative approach to the relevant lessons. To investigate the status of teachers' knowledge and approach to teaching and learning of this field, we conducted an online survey addressing physics teachers in the educational district of central Athens (Greece). The pre-webinar results (N=42) indicated that teachers were rather disappointed with the traditional approach that the official curriculum promotes, and they agreed on enhancing their respective knowledge and skills to design and implement a TLS that could improve the course and advance the respective educational research. The training program was held through four webinar sessions that lasted two hours each. The participants were 30 in-service physics teachers from different upper secondary schools in Athens. The webinars addressed the teaching and learning of introductory thermodynamics in terms of (a) epistemology, (b) traditional instructional approach, (c) alternative instructional approaches, and (d) design of a TLS. For the evaluation of the training program, we collected qualitative data during the webinars and after the last webinar, using recordings of four group discussions and five semi-structured interviews accordingly. Our results indicated that participating teachers were willing to change their traditional instruction towards a research-based TLS.

Keywords: physics teacher education, introductory thermodynamics, teaching and learning sequences

THEORETICAL FRAMEWORK

Theoretical framework for physics teachers' training

Contemporary science education research reveals that school students and university beginners engage with thermodynamics courses mostly in a superficial way, memorizing formulas and computational methods but not profoundly constructing essential concepts and laws. The pertinent research indicates that proper changes in introductory thermodynamics at the secondary school level can make a long-lasting difference (Leinonen et al., 2012).

Physics teachers' training can play a crucial role, especially when the official curriculum follows a rather traditional approach, in the sense that it has not been informed by recent research evidence. In such cases, a training program aims to intervene in the internal didactic transposition for the school knowledge to be taught (Christiansen & Rump, 2008); in other words, to facilitate teachers reorganize the content they have to teach to make it truly accessible to the students.

To accomplish that, teachers' readiness to redesign their Teaching and Learning Sequence (TLS) for their thermodynamics courses, is vital (Dunn et al., 2019). A prerequisite for this endeavour is for them to advance their knowledge of the subject matter epistemology and the pedagogical elements that would make a good fit for this particular content (Flores, Lopez, et al., 2000).

Gil-Pérez & Pessoa De Carvalho (1997) describe a physics teachers' training program in this direction, taking into account the theoretical and empirical conclusions that are drawn from educational research. Their framework includes four components that summarize numerous subordinate elements referring to physics as the school knowledge to be taught in general terms. Having these components adjusted to thermodynamics in particular, they are the following: (a) knowing thermodynamics as the subject matter to be taught, (b) knowing teachers' spontaneous ideas on thermodynamics and on teaching and learning thermodynamics, (c) acquiring theoretical knowledge about the thermodynamics teaching and learning process, and (d) teachers' involvement in thermodynamics education research and innovation.

Content of the training program

For the content of a training program addressing in-service physics teachers for the teaching and learning of thermodynamics in upper secondary school, we considered the theoretical components suggested by Gil-Pérez & Pessoa De Carvalho (1997), the empirical evidence deriving from preceding training programs (e.g., Flores, Lopez, et al., 2000; Kanderakis et al., 2011), and the particularities of introductory thermodynamics as knowledge to be taught from both the student side (e.g., Leinonen et al., 2012; Meli et al., 2021) and the teacher side (e.g., Bezen et al., 2016; Tobin et al., 2012).

Taking these elements into consideration, the training program addressed the following four aspects of thermodynamics: (a) epistemology, (b) traditional instructional approach, (c) alternative instructional approaches, and (d) design of a TLS. A detailed description of the proposed TLS can be found in Meli & Koliopoulos (2019). The main principles that penetrated the content throughout the training program were the following: (a) operationalization of the first functional steam engine (Newcomen's) as the object under study, (b) exclusive use of the macroscopic (classical) framework of thermodynamics for the interpretation of phenomena connected to thermodynamics processes, and (c) energy distribution representations (Energy Chain Model) for bridging qualitative and quantitative aspects for the interpretation of phenomena (Meli et al., 2021).

These principles significantly contradict the traditional approach of thermodynamics, namely the one introduced by the official physics curriculum and the respective textbook. Overall, the traditional approach replicates the structure of standard university physics textbooks (e.g., Young & Freedman, 2012), simply omitting all the "difficult" parts (mostly related to advanced mathematics) instead of attempting an appropriate didactic transposition for the secondary school level. Typically, this approach gives prominence to the following aspects: (a) the microscopic (statistical) framework of thermodynamics, introduced mostly through the kinetic theory of gases, precedes the macroscopic (classical) framework that focuses on energy-related concepts and principles, (b) symbolic and quantitative representations of phenomena are presented without qualitative and semi-qualitative intermediate models that justify the formulas, and (c) real-life applications of thermodynamics and respective cultural dimensions are illustrated as “decorative” elements that do not organically connect to the knowledge to be taught. Educational research suggests that these traditional epistemological and pedagogical features are in great contrast to contemporary constructivist frameworks since they do not take into account the students’ prior knowledge and cognitive needs/capacities for this particular education level (Meli et al., 2021).

RESEARCH QUESTIONS

Our research objective is to explore the impact of the training program for teaching and learning thermodynamics on in-service upper secondary school teachers. We are particularly interested in the alternative elements they would be willing to introduce in their TLS for the respective thermodynamics courses because of their training. Therefore, the research questions are the following:

1. Which were the physics teachers’ epistemological and pedagogical conceptions of thermodynamics before their participation to the training program?
2. What were the subjects (connected to the conceptions) that were most frequently discussed during the training program?
3. What were the subjects (connected to the conceptions) that were most frequently discussed how did they inform the teachers’ views for the design of an alternative TLS?

METHOD

For better understanding physics teachers’ existing conceptions and intervening with a call to action, we follow the design of a case study (Cohen et al., 2007). As Nisbet & Watt (1984) suggest for the phases of a case study, the training program (a) commenced with a wide field of focus, addressing physics teachers of the entire regional area and sharing an online questionnaire with broad epistemological and pedagogical context to interested teachers, (b) progressively focused to narrower fields during the webinars, and (c) checked the draft conclusions with a limited number of participants during the interview phase.

To identify how physics teachers conceived their knowledge of thermodynamics epistemology and pedagogy and to what extent they were willing to explore new approaches, the coordinators of the Regional Centre of Educational Planning for the upper secondary school science curriculum (central Athens) sent an online questionnaire to 150 physics teachers that taught thermodynamics during that school year (2020-2021). 42 teachers (73% males) answered the questionnaire; the vast majority (86%) had already been teaching this course for more than four school years and more than half (57%) were holding a postgraduate degree. The questionnaire included 22 closed-type questions (with a 5-point Likert scale), that derived from the components of the theoretical framework for physics teachers’ training, and was quantitatively analysed in *SPSS*.

In addition to the questionnaire, the coordinators invited teachers to participate in a 4-part webinar series for the teaching and learning of introductory thermodynamics. 30 of them participated in the training program. The webinars were held for two hours every other week (November-December 2020) and included presentation sections and time for group discussions.

Within a week after the completion of the training program, we conducted 5 interviews that each lasted 30-45 minutes. They were semi-structured with 9 questions that covered the components that had been raised in the closed-type questionnaire. As with the group discussion passages, all interviews were recorded, transcribed, and qualitatively analysed in *NVivo*.

RESULTS

Physics teachers' conceptions of thermodynamics before to the training program (questionnaire)

Tables 1-4 present the questionnaire items and the results for each component of the theoretical framework for physics teachers' training.

Table 1. Questionnaire items and results (*N*=42) for the first component of the theoretical framework for physics teachers' training (knowing thermodynamics as the subject matter to be taught).

		1	2	3	4	5
1.1*	What is your assessment of your knowledge of the history of thermodynamics concerning the development of its concepts?	4,76%	16,67%	42,86%	28,57%	7,14%
1.2*	What is your assessment of your knowledge of the history of thermodynamics concerning the development of its methods?	9,52%	23,81%	47,62%	16,67%	2,38%
1.3*	What is your assessment of your knowledge of the history of thermodynamics concerning the cultural context within it was developed?	19,05%	30,95%	26,19%	21,43%	2,38%
1.4*	What is your assessment of your knowledge of the recent scientific developments in thermodynamics (interdisciplinary)?	9,52%	35,71%	42,86%	11,90%	,00%
1.5**	What is your assessment of your readiness for the enrichment of your knowledge of thermodynamics as a subject to be taught?	,00%	2,38%	23,81%	50,00%	23,81%
1.6**	What is your assessment of your potential to restructure, enrich, or alternate the standard suggested school knowledge of thermodynamics?	,00%	2,38%	28,57%	38,10%	30,95%

* *1=I know nothing about it* up to *5=I know everything about it*
** *1=I could not do it at all* up to *5=I can absolutely do it*

Table 2. Questionnaire items and results (*N*=42) for the second component of the theoretical framework for physics teachers' training (knowing teachers' spontaneous ideas on thermodynamics and on teaching and learning thermodynamics).

		1	2	3	4	5
2.1*	Do you believe that it would be useful to present more historical elements for the development of thermodynamics (e.g., inventions, creative solutions)?	,00%	14,29%	14,29%	40,48%	30,95%
2.2*	Do you believe that it would be useful to present the scientific methods that historically led to the	2,38%	14,29%	28,57%	33,33%	21,43%

	development of thermodynamics (and not just the ultimate results)?					
2.3*	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)?	2,38%	16,67%	21,43%	35,71%	23,81%
2.4*	Do you believe that it would be useful to present the connection of thermodynamics with social issues (historical and recent)?	4,76%	14,29%	16,67%	33,33%	30,95%
2.5*	Do you believe that it would be useful to further utilize experiments for the school knowledge of thermodynamics?	,00%	2,38%	23,81%	28,57%	45,24%
2.6*	Do you believe that it would be useful to present thermodynamics as an interdisciplinary scientific subject?	,00%	14,29%	21,43%	47,62%	16,67%
2.7**	Do you believe that thermodynamics is a scientific subject that should be it promoted as a meaningful and approachable one for all students?	14,29%	16,67%	33,33%	23,81%	11,90%
2.8**	Do you believe that students' real-life conceptions of thermodynamics interact with the scientific ones that are introduced as school knowledge?	9,52%	33,33%	38,10%	16,67%	2,38%

**1=That would not be useful at all* up to *5=That would be absolutely useful*
***1=I don't believe that at all* up to *5=I absolutely believe that*

Table 3. Questionnaire items and results (*N*=42) for the third component of the theoretical framework for physics teachers' training (acquiring theoretical knowledge about the thermodynamics teaching and learning process).

		1	2	3	4	5
3.1*	What is your assessment of the traditional methods that are used for the introduction of thermodynamics to students?	14,29%	42,86%	35,71%	7,14%	,00%
3.2*	What is your assessment of the traditional methods that are used for the students' penetration of thermodynamics?	14,29%	42,86%	40,48%	,00%	2,38%
3.3*	What is your assessment of the level of group learning during your thermodynamics courses?	35,71%	33,33%	21,43%	9,52%	,00%
3.4**	What is your assessment of your knowledge concerning contemporary alternative approaches of thermodynamics teaching and learning?	9,52%	38,10%	35,71%	11,90%	4,76%
3.5**	What is your assessment of your knowledge concerning students' conceptions on thermodynamics?	7,14%	38,10%	28,57%	21,43%	4,76%

**1=Not satisfactory at all* up to *5=Completely satisfactory*
***1= I know nothing about it* up to *5=I know everything about it*

Table 4. Questionnaire items and results (*N*=42) for the fourth component of the theoretical framework for physics teachers' training (teachers' involvement in thermodynamics education research and innovation).

		1	2	3	4	5
4.1*	What is your assessment of your teaching of the school knowledge of thermodynamics up to now?	,00%	52,38%	26,19%	19,05%	2,38%

4.2**	Are you interested in approaching the school knowledge of thermodynamics with a new teaching and learning sequence?	,00%	4,76%	23,81%	38,10%	33,33%
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?	,00%	4,76%	26,19%	38,10%	30,95%

***1=Not satisfactory at all* up to *5=Completely satisfactory*
***1=I am not interested at all* up to *5=I am absolutely interested*

Summarizing, the above results indicated that physics teachers considered the level of their existing knowledge of thermodynamics epistemology below average, although they were positive in introducing such elements in their formal instruction. Regarding the pedagogical perspective, they believed that the official curriculum was rather inadequate in introducing and delving into thermodynamics concepts but, at the same time, they characterized their knowledge of alternative teaching and learning approaches as rather insufficient. Therefore, it was somehow expected that they agreed to participate in a training program for the design and implementation of a TLS for thermodynamics to make use in their classroom as well as for informing the relevant educational research.

Physics teachers' conceptions of thermodynamics during the training program (group observation)

Table 5 summarizes the most prevailing conceptions in terms of frequency (minimum 5 references) as they surfaced during each of the four webinars of the training program. These correspond to the respective questionnaire items (as presented in Tables 1-4).

Table 5. Frequency of references (5 references min.) to the questionnaire items during the four webinars (*N*=30).

	1st	2nd	3rd	4th	Total
1.1	5	0	2	0	7
1.5	3	0	0	2	5
1.6	1	7	10	8	26
2.1	5	0	3	0	8
2.2	2	0	0	3	5
2.4	1	3	1	2	7
2.5	0	6	0	0	6
3.1	4	5	1	1	11
3.2	1	9	0	0	10
3.5	0	5	6	1	12
4.1	1	0	2	3	6
4.2	0	0	1	8	9

During the webinars, group discussions (*N*=30) were oriented to both epistemological and pedagogical issues. Concerning thermodynamics epistemology, the participants mainly focused on the distinction between the macroscopic and microscopic approach and the non-linear historical events/ scientists' interactions that gave rise to the theory and the applications of the field. In reference to the pedagogy, they were concerned about practical issues, such as the constraints that the official curriculum sets, the different experiments that can be efficiently executed in the classroom, and the way alternative approaches can be implemented.

Physics teachers' conceptions of thermodynamics after the training program (interviews)

Table 6 summarizes the most prevailing conceptions in terms of frequency as they surfaced during the interviews for each of the interviewees. These correspond to the respective questionnaire items (as presented in Tables 1-4).

Table 6. Frequency of references (5 references min.) to the questionnaire items during the interviews (*N*=5).

	#1	#2	#3	#4	#5	Total
1.5	4	1	2	2	3	12
1.6	7	4	2	4	2	19
2.1	9	1	2	1	0	13
2.4	5	0	0	1	2	8
2.7	3	2	4	2	1	12
2.8	2	2	0	1	0	5
3.1	4	2	0	2	2	10
3.2	1	1	2	0	2	6
3.5	2	4	1	1	2	10
4.1	1	0	2	3	1	7
4.2	0	0	1	8	0	9

The qualitative analysis of the interviews (*N*=5) indicated that the training program facilitated physics teachers in putting existing and new knowledge of thermodynamics epistemology in a pedagogical perspective. The most prevailing elements of this holistic approach are related to the clear distinction between the macro/micro frameworks with prominence to the macroscopic energy concepts, the use of technological components as case studies for introducing concepts/laws, and the introduction of socio-economic context to justify the significance of the field. Indicative passages from the interviews, that suggested a differentiated approach to the TLS, are the following:

To begin with, we should omit the microscopic framework, it comes out of the blue, it creates misconceptions. We should instead focus on the cultural perspective, on small-range research so the students learn where the various thermodynamics principles are applied… I would give prominence to the way knowledge was developed, the historical perspective of thermodynamics, by adopting elements from the training program. I would possibly use passages that demonstrate the difficulties (scientists) faced when constructing steam engines and the method they used while constructing them and how this method was improved. (Teacher #1)

Well, what hadn't occurred to me before (the training program) is that I can at first bypass the kinetic theory of gases… I could go straight to the First Law of Thermodynamics and work towards the thermodynamics processes. I liked this suggestion very much… You gave me many ideas, because I used to start with the kinetic theory and then move on to the processes and I usually faced many problems there. Now I believe that I can seamlessly go straight to teaching the energy part, I mean the First Law, and work all concepts through that chapter and this is *extremely positive. I wouldn't decide doing this change on my own, but since you propose a ready-to-go idea, this is pivotal.* (Teacher #5)

CONCLUSIONS

In-service physics teachers that participated in the training program confirmed the trend shown in the relevant research worldwide that there is a growing scepticism over the epistemological and pedagogical approach of introductory thermodynamics at the secondary school education level (e.g., Bezen, 2016; Flores, López, et al., 2000; Gil-Perez & Pessoa de Carvalho, 1997). Official physics curricula do not yet apply a didactic transposition that properly fits the requirements of thermodynamics school knowledge, turning a blind eye to educational research recommendations for the adaptation of a constructivist approach. During formal instruction, several issues concerning thermodynamics epistemology and pedagogy come on the surface, making instruction even more challenging.

The training program for thermodynamics school knowledge attempted to reconstruct teachers' conceptions of thermodynamics epistemology, indicate the problematic spots on the traditional teaching and learning approach and introduce alternative ways for the design of a TLS. Pre-webinar results indicated that teachers' knowledge on these aspects, that would allow them to redesign their TLS was rather limited, however they demonstrated a positive learning attitude. During the webinars, the conceptions appeared to be somehow destabilized and change-oriented. This repositioning was more obvious during the post-webinar interviews, where the participants indicated in which direction they would adjust a training-informed TLS. The feasibility of the proposed approach was especially important for them, therefore it was essential that they seemed confident to go rather seamlessly from theory to practice.

LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

The main limitation of this research is the lack of further results deriving from the class environment that would justify the training program impact on the participants. Due to the restrictions enforced due to the pandemic, it was impossible for the researchers to observe the respective courses in order to identify how the webinars affected in practice the design of alternative TLSs for thermodynamics courses and/or what was the learning outcome for the students.

A possible extension of this research is the broader use of the pre-webinar questionnaire to investigate physics teachers' epistemological and pedagogical conceptions in a national level or as part of a comparative study between countries with similar approach to the school science curriculum for units of thermodynamics. In addition, this instrument can also be easily adjusted for the exploration of teachers' conceptions on another specific physics field (e.g., mechanics, electromagnetism) or physics in general, for the design of respective training programs and beyond.

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