# Physics teacher webinars for stem-oriented thermodynamics

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**ABSTRACT**
*Efficient teaching and learning of elementary thermodynamics in upper secondary school science classes are important not only for students who will pursue studies and careers in Science, Technology, Engineering, and Mathematics (STEM) but also for the scientific literacy of the 21st-century citizen. This case study presents a physics teachers' webinar series for a STEM-oriented constructivist approach of elementary thermodynamics in upper secondary school. The pre- and during-webinar results indicated that physics teachers, to a great extent, lacked the epistemological and pedagogical knowledge that would allow them to overcome the traditional instruction restrictions and yet they were very eager to incorporate STEM-oriented constructivist components in their upcoming classes. Post-webinar results confirmed this inceptive conclusion, as teachers expressed their intention to adopt many of the training program suggestions for the development of new thermodynamics teaching and learning sequences.*

**KEYWORDS**
*Science education, secondary school education, elementary thermodynamics, teacher training program*

**RÉSUMÉ**
*L'enseignement et l'apprentissage efficaces de la thermodynamique élémentaire au lycée sont importants non seulement pour les étudiants qui poursuivront des études et des carrières en Sciences, Technologie, Ingénierie et Mathématiques ('STEM'), mais également pour la culture scientifique du citoyen du 21e siècle. Cette étude de cas présente une série de webinaires adressée aux professeurs des sciences physiques concernant une approche STEM constructiviste de la thermodynamique élémentaire au lycée. Les résultats avant et pendant les webinaires ont indiqué que les enseignants bien qu'ils manquassent dans une large mesure des connaissances épistémologiques et pédagogiques qui leur permettraient de surmonter les restrictions d'enseignement traditionnel ils étaient pourtant très désireux d'intégrer des composants STEM constructivistes dans leurs futurs cours. Les résultats post-webinaire ont confirmé cette conclusion encourageante, car les enseignants ont exprimé leur intention d'adopter bon nombre des suggestions du programme de formation pour le développement de nouvelles séquences d'enseignement et d'apprentissage de la thermodynamique.*

**MOTS-CLÉS**
*Didactique des sciences, enseignement secondaire, thermodynamique élémentaire, programme de formation des enseignants*

## INTRODUCTION

Thermodynamics is a significant scientific field closely related to the everyday natural and technological experience, especially as it relates to energy concepts. As such, efficient teaching and learning of elementary thermodynamics in secondary school science classes are important not only for students who will pursue studies and careers in Science, Technology, Engineering, and Mathematics (STEM) but also for the scientific literacy of the 21st-century citizen. However, school students present an inadequate conceptual understanding of this field and its essential energy concepts (Herrmann-Abell & DeBoer, 2018).

This study presents particular elements of a STEM-oriented constructivist approach, introduced within a physics teacher training program for teaching and learning elementary thermodynamics in upper secondary school. We describe how teachers usually approach these elements in their classroom, considering the traditional school physics curriculum guidelines, and the adjustments they intend to make in their instruction after their participation in the program.

## THEORETICAL FRAMEWORK

### *Physics teacher training programs*

In traditional instruction teachers attempt to "convey" their knowledge to students. The didactic transposition of reference knowledge to school knowledge usually reflects a reduction of university textbooks' content and results in a juxtaposition of different frameworks, a heavy load of quantitative representations, and a severe disconnect from any cultural relevance. Contrarily, didactic transposition in a constructivist framework usually takes place after considering students' conceptual understanding, cognitive capabilities, and connections to their everyday experiences (Koliopoulos & Constantinou, 2005).

Training programs for in-service physics teachers can facilitate them in recognizing the traditional approach elements that may hinder their instruction and intervene in the internal didactic transposition for the school knowledge to be taught (Vellopoulou & Ravanis, 2012); 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 thermodynamics courses is vital. First, they must identify the curriculum drawbacks, along with their own potentially outdated practices. Secondly, they have to advance their knowledge of the subject matter epistemology and the pedagogical elements that would make a good fit for this particular content (Gil-Perez & Pessoa de Carvalho, 1997).

In this respect, we integrate a STEM-oriented educational approach in a physics teacher training program as leverage for teaching and learning elementary thermodynamics (Avery & Reeve, 2013) in upper secondary school. For each STEM component, we present (a) common traditional curriculum approaches that apply for the Greek school and other educational systems as well (Leinonen et al., 2009), and (b) constructivist approaches that take into consideration students' conceptions and can be seamlessly integrated into instruction.

### *STEM-oriented teaching and learning of elementary thermodynamics*

We approach the component of *Science* in terms of thermodynamics as a physics field; *Technology* through educational simulations; *Engineering* with the representation of engines; and *Mathematics* for the symbolic expression and manipulation of the respective theory.

(a) *Science (thermodynamics as a physics field): microscopic vs. macroscopic framework*. More often than not, traditional instruction conflates the macroscopic and microscopic frameworks of thermodynamics. Exposing students prematurely to microscopic explanations hinders their understanding of basic energy concepts. The microscopic framework demands fluent manipulation of mathematical representations, sophisticated reasoning patterns, and highly abstract conceptual understanding. On the other end, macroscopic thermodynamics offers a transparent form of school knowledge that aligns with secondary school students' scientific mastery (Meli & Koliopoulos, 2019a).

(b) *Technology (educational simulations): pragmatic vs. constructivist models.* Interactive simulations are a resourceful addition to the physics classroom. However, in thermodynamics most simulations incorporate this micro-macro framework conflation and do not account for students' intuitive linear causal reasoning. *IGasES* (Ideal Gas Educational Simulation) is an alternative simulation that presents basic thermodynamic processes macroscopically as energy chains; a constructivist model that complies with students' reasoning patterns and yet challenges them to progressively adopt more complex, non-linear interpretations of energy-related phenomena (Meli & Koliopoulos, 2019b).

(c) *Engineering (engine representations): theoretical vs. functional engines.* Negotiating abstract phenomena usually fails to facilitate students' conceptual understanding of energy concepts. Physics teachers can use the blueprint or miniature model of the rather simple Newcomen's steam engine to bring a real-life example of thermodynamics into their classrooms. As a technological, yet also cultural, element, this engine can prompt students to formulate their own driving questions and meaningful representations.

(d) *Mathematics (symbolic expression/manipulation of the theory): quantitative vs. semi-quantitative approaches:* Mathematical expression can be an opaque form of knowledge for students, especially because teachers move too fast from phenomenological fields to theoretical levels without intermediate stepping-stones. A semi-quantitative approach of mathematical expressions, which is in-line with the energy chains mentioned above, would allow students to gradually shift from qualitative aspects of energy to quantitatively describing the phenomena (Tiberghien, Psillos, & Koumaras, 1995).

## METHOD

### *Research sample, conditions, and strategy*

The coordinators of the Regional Center of Educational Planning for the upper secondary school science curriculum (central Athens, Greece) invited 150 physics teachers to participate in a 4-part webinar series for the teaching and learning of elementary thermodynamics. The webinar content was developed around the STEM-oriented components that are analyzed in the Theoretical Framework. Initially, 42 teachers declared their interest and, ultimately, 30 of them participated in the training program. A substantial percentage of 80.7% had already been teaching Kinetic Theory of Gases and Thermodynamics at the second grade of upper secondary school for more than four

school years. The webinars were held for two hours every other week in November-December 2020 via WebEx and included presentation sections and time for group discussions.

Due to the relatively small and localized research sample, but also for penetrating into physics teachers' reality and intervening with a call to action, the design of a case study has been followed (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.

### *Data collection and analysis*

To identify how physics teachers perceived their knowledge of thermodynamics epistemology and pedagogy and the extent to which they were willing to explore new STEM-oriented constructivist approaches, an online questionnaire was developed based on the framework for physics teachers' training programs (Gil-Pérez & Pessoa De Carvalho, 1997). The questionnaire included 22 closed-type questions with a 5-point Likert scale. The 42 teachers, that had taken an interest in the training program, filled the questionnaire and their responses were quantitatively analyzed in *SPSS*.

A group observation took place during the webinars, where the researchers were part of the group (participant-observation). 30 teachers participated by placing questions, having discussions with each other, and interacting with both the researchers and coordinators. Within a week after the completion of the training program, 5 participants volunteered to give an interview. The interviews were semi-structured with 9 questions, covering the issues that had been raised in the closed-type questionnaire, and each lasted 30-45 minutes. The group discussion passages and the interviews were both recorded, transcribed, and qualitatively analyzed in *NVivo*.

## RESULTS

### *Pre-webinar online questionnaire*

The results of the online questionnaire ($N$=42) indicate that the majority of physics teachers in this sample evaluated as "poor" or "very poor" their knowledge of thermodynamics epistemology (34.9%) and alternative instructional frameworks (46.4). The same evaluation stands for the current traditional approach for introducing and engaging students to thermodynamics (57.1%) and their commonly applied instruction (52.4%). At the same time, physics teachers opt for deepening their knowledge and changing their instruction accordingly. They "agree" or "strongly agree" with the enhancement of instruction with historical elements (62.5%) and dealing with thermodynamics as an interdisciplinary subject (64.3%). They give the same statement for their readiness to deepen their subject matter knowledge (70.2%) and the potential to change their instruction content by developing a new teaching and learning sequence (69.0%).

### *During-webinar group observations*

During the webinars, group discussions ($N$=30) were oriented to both epistemological and pedagogical issues, focusing more clearly on the STEM-oriented approaches of thermodynamics. For the component of *Science*, the participants extensively debated on the effectiveness of the microscopic framework at the secondary education level, supporting that this framework assists

students in understanding gas state and mechanics-related variables, but not energy concepts and principles. Regarding *Technology*, the use of educational simulations appeared to be quite popular, although the teachers clearly had not considered the distinction between pragmatic and constructivist tools. As for *Engineering*, teachers recognized various thermal engines as a key feature for students' motivation; however, they rarely used them as an integral teaching and learning element. Finally, considering *Mathematics*, teachers perceived it as a "language" physics cannot do without; nevertheless, they emphatically mentioned that it should be introduced with profound qualitative explanations.

***Post-webinar interviews***

The analysis of the interviews ($N$=5) indicated that the training program facilitated physics teachers in putting existing and new knowledge of thermodynamics epistemology pedagogy in a different instruction perspective. Three trends were found among the interviewees: no intention to change their instruction (1 teacher – Case 1), intention to partially change their instruction (1 teacher – Case 2), and intention to radically change their instruction (3 teachers – Case 3). As for *Science*, Case 3 teachers embraced the idea of giving prominence to macroscopic thermodynamics to empower the energy dimension of the field. In respect to *Technology*, Case 2&3 teachers were eager to use the proposed constructivist simulation (IGasES) in class. Regarding *Engineering*, all teachers recognized the importance of operationalizing functional thermal engines (e.g., Newcomen steam engine) and Case 3 teachers discussed putting them in the center of their instruction. Finally, about *Mathematics*, Case 2 & 3 teachers agreed on emphasizing the qualitative perspectives before presenting the practical formulae.

## DISCUSSION

Although thermodynamics is a privileged field for applying integrated STEM education, in this study we operationalized STEM education as the means, and not the purpose, for physics teachers' training. Such innovative frameworks should empower and not hinder teachers' clear orientation toward an efficient negotiation with students' conceptual understanding of essential energy concepts (Gil-Pérez & Pessoa De Carvalho, 1997). Through this research-based design, we post that there are viable options available for physics teachers to holistically revise their teaching and learning in the scope of elementary thermodynamics. Although the results of this case study cannot be generalized for the entire population of in-service Greek physics teachers, they still offer valuable insight on the current condition of thermodynamics teaching and learning and indications of the steps that need to be taken. It appears that most teachers themselves recognize this need and are open to suggestions. From our point of view, this new approach of the field could substantially facilitate physics teachers to enhance their instruction and, ultimately, contribute to students' awareness and knowledge, especially concerning energy matters. To follow up with the participants, we are further working with the cases that embraced the change in their instruction to develop and implement a STEM-oriented sequence for the upcoming academic year.

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