Heat, temperature and energy: a formative experiment-based module including the use of infrared cameras

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Abstract. The historical development of the concept of energy can be brought back to the early studies of heat, suggesting that a unified treatment of heat, temperature and energy can be a possible route for teaching these complex subjects altogether. Here we present an experiment-based module centered on heat and temperature and on their relation with energy which was proposed to a class of prospective primary school teachers. The intervention redesigns a previously developed approach to include the concept of energy and use of infrared cameras. Learning outcomes are investigated through pre-/post-assessment questions, worksheets and final interviews.

1. Introduction
Research literature has widely addressed the problem of how the concept of energy should be introduced and treated at the school level and the debate is still open [1,2]. The importance of addressing it already at the primary school level has also been recognized [3]. On another side, the historical development of the concept of energy can be brought back to the early studies on heat by Mayer and Joule [4], suggesting that a unified treatment of heat, temperature and energy can be a possible route for teaching and learning these complex subjects altogether. As a matter of fact, the concepts of heat and temperature have also been deeply investigated from the point of view of Physics Education [5]. To this respect, the use of infrared cameras has recently acquired increasing interest [6].

In this context, we projected and experimented a pilot intervention that integrates the concept of energy with the concepts of heat and temperature and investigated the corresponding learning outcomes. The formative module was proposed to a class of 90 prospective primary school teachers (PPTs) at the second year of the combined bachelor and masters' degree in Primary School Education of the Italian University of Verona, and integrates content reconstruction and active learning strategies inside an experiential and situated modality [7]. The activities were proposed as part of the Lab module (1 cfu) of the Physics Education course (9 cfu) offered after the course on Mathematics Education (9 cfu) and other courses in the Human Science fields. No previous treatment of the subjects of Heat, Temperature and Energy was done in the Physics Education course.

The intervention redesigns a well-run approach previously developed at the Udine University [8,9] that was focused on the concepts of heat and temperature and on the use of online sensors. The present approach extends it so as to highlight the concept of energy by including the use of thermal cameras.

In this work, we investigated how much the proposed path and methodologies can help PPTs in learning and teaching the concepts of heat, temperature and energy as related to the use of online sensors and/or of thermal cameras. To date, the study has been conducted on the 65 PPTs (from now on also...
referred to as "students") who all answered to the pre- and post-assessment questions, worksheets and final interviews.

2. Learning path and methodologies
The intervention was organized into four phases including interactive lectures and laboratory activities. The first and third phase were developed as interactive experiment-based lectures following active learning and inquiry-based strategies, while in the second and fourth lab-work phases four experiments were autonomously carried out by the students divided into groups.

In the first phase, we introduced the concept of thermal equilibrium and the operational definition of temperature through the use of online sensors (0.1°C sensitivity in the range from -10°C to 100°C) that allow real-time simultaneous measurements of temperature using a graphical computer interface. The instrument, called "Termocrono", was developed at Udine University [8].

In the second phase, students were conducted into the concept of heating as a process leading to “increase of temperature” by autonomously carrying out two experiments in the Prediction-Experiment-Comparison (PEC) modality using the online sensors: 1) heating of water with a boiler; 2) heating of water by irradiation with the light emitted by a halogen lamp (Figure 1).

In the third phase, starting from the results of the former irradiation experiment with the halogen lamp, students were interactively guided, through discussions in the form of a "Socratic dialogue" with the teachers as facilitators, into the concept of energy as “what is capable of heating”, to associating the concept of “amount of heating” with the concept of “transferred energy”, and to recognizing that light carries energy. Then, the thermal camera was introduced as a two-dimensional remote sensor of the energy emitted by all bodies in the form of non-visible (infrared) light which is in turn related to the temperature. In our intervention, we utilized a FLIR C2 thermal camera equipped with a bolometric sensor (80x90 array) sensitive in the long IR range 8-14 micron that we had previously calibrated in temperature. The FLIR camera acquires also a visible image (320x240 pixels) superimposed to the thermogram. An interesting option for this proposal is the possibility of visualizing in real-time on the display the thermogram, the visible, or a blending of the two images. Students were introduced both to the qualitative and quantitative use of the pre-calibrated FLIR camera allowing the visualization as well as the measurement of bidimensional temperature maps, as shown in Figure 2.
In the fourth phase, students first repeated the two experiments done in the second phase using the thermal camera in place of the on-line sensors. The thermal camera allowed them to visualize heat propagation by conduction and convection. Then, they carried out two other experiments, always in the PEC modality, using both the online sensors and the thermal camera. 3) Thermal interaction of different masses of water, reaching thermal equilibrium and 4) the so called “Locke experiment” about thermal sensation [8,9] (Figure 2). Given three glasses of warm, hot and cold water, fingers first immersed in hot water and then in warm water feel it cold, while fingers first immersed in cold water feel warm water as hot. Students were left free to explore the use of the sensors and of the thermal camera in investigating and measuring the proposed processes.

The learning path ended with final considerations that emerged from the discussion with all the students conducted in an interactive guided modality with the teachers as facilitators:

- measuring temperature means "finding a way of associating a number to a state of thermal equilibrium"
- heating means "causing an increase of temperature"
- heating is energy transfer
- heating can be obtained through conduction, convection and irradiation
- thermal sensation is related to the rapidity of heating or cooling
- heat is transferred energy related to heating or cooling
- temperature is a measure of an energy which is internal to bodies (internal energy)

3. Research methods

In this work, we investigated how much the utilized learning path and methodologies can help students in understanding the proposed concepts through the following research questions:

1) Which concepts and corresponding activities do PPTs choose in constructing their educational path for their students on thermal phenomena?
2) Do PPTs cite thermal cameras among the possible instruments for measuring temperature?
3) Do (or would) PPTs propose the use of thermal cameras in their activities and, if so, related to what concepts?

The study has presently been conducted through pre- and post-assessment questions, worksheets and final interviews on the 65 PPTs that answered to the final worsheets and interviews. The pre- /post-assessment questions were:

1) Which ways do you know for measuring temperature?
2) Which ways do you know for heating/cooling?
3) What difference/relation is there among heat, temperature and hot/cold sensation?

In the worksheets, students were asked to plan a learning path on thermal phenomena highlighting the addressed concepts and the corresponding related activities.

Final interviews, based on the worksheet answers, were mainly focused on whether and how PPTs used or would use a thermal camera in their proposed activities and, if so, related to which concepts.

4. Results

Quantitative data analysis was performed based on content analysis of the teaching plans and interviews by focusing on the instruments cited in the post-assessment questions or utilized in the proposed activities (termocrono and thermal camera) and on the addressed concepts. The latter were grouped into three main categories that we identified from students' answers (given in the worksheets as well as in the final interviews) as particularly meaningful for the purposes of the present investigation: temperature/thermal equilibrium/thermal sensation; heat and energy; heating through irradiation.

As a general comment, we found that almost all PPTs proposed activities aimed at introducing the concepts of thermal equilibrium and temperature, mainly using the "Termocrono", while only few proposed activities aimed at introducing the concepts of heat and energy, which were considered too difficult for children.
As regards the use of a thermal camera, most of the students didn’t propose its use in their planned activities: they tend to consider it an expensive and specialistic instrument, not easy to be found in a primary school. In addition, the thermal camera is viewed as useful not so much for measuring temperature but rather for visualization purposes, either of the temperature distribution or of “heat” as energy transfer. On the contrary, interestingly, the "Termocrono" is not seen as a specialistic instrument and its use is in fact often considered in the proposed activities.

Going into more details, in the post-assessment questions the "Termocrono" is cited among the possible instruments for measuring temperature by almost all the 65 students (64/65); in the planned didactic path, it is utilized by 41/64. Among these: 37/41 propose it for introducing the concept of temperature through the difference between thermal equilibrium and thermal sensation; 28/41 for addressing the concept of heating through irradiation; 26/41 propose its use for both these purposes (figure 3).

On the other hand, the thermal camera is less cited (42/65) than the "Termocrono" among the possible instruments for measuring temperature. In the planned didactic path, the thermal camera is utilized (or would be possibly utilized if available, as it emerged from the interviews) - always for visualisation purposes- by 28/42, of which 13/28 for addressing the concept of heating through irradiation and 19/28 for introducing the concepts of heat and energy; 8/28 propose its use for both these purposes. It can be useful to recall here that the use of the camera to quantitatively measure the temperature had been shown to the students in the third phase but they were left free to explore its qualitative and quantitative use in the fourth experiential phase of the learning path.

From the point of view of the treated concepts, our analysis pointed out three most significant aspects.

The comparison between temperature and thermal sensation is addressed by 57/65 and is associated to the use of the Termocrono by 37/57. In the other cases, the use of more traditional thermometers is foreseen. The comparison between temperature and thermal sensation is never associated to the use of a thermal camera.

![Figure 3. Use of the "Termocrono".](image-url)
Figure 4. Use of the thermal camera.

Figure 5. Addressed concepts and instruments proposed for related activities.

The process of heating through irradiation, addressed by 43/65, is associated to the use of both the "Termocrono" (28/43) and the thermal camera (13/43). In the case of the thermal camera, 6/43 actually proposed an activity while 7/43 would possibly propose it if the thermal camera would be available in the classroom, as it emerged from the interviews.
Heat and energy are considered as important concepts to be treated in an educational path by 28/65. Of these, a total of 19/28 actually proposed (only 7/28), or would possibly propose (12/28) an activity with the thermal camera if it would be available in the classroom. The remaining 9/28 proposed either an alternative visualisation with sawdust or ink or even no activities at all. The concepts of heat and energy are never associated to the use of the "Termocrono".

5. Conclusions

The importance of addressing the concept of energy even since the primary school level is well recognized in research literature [3] and the debate on how it should be introduced is still open [1,2]. Following the historical development of the concept of energy as introduced in the early studies on heat by Mayer and Joule [4], we experimented a possible route for a unified treatment of heat, temperature and energy and proposed it for the first time to 90 prospective primary school teachers of the University of Verona. The formative pilot intervention integrates content reconstruction and active learning strategies inside an experiential and situated modality and is organized into interactive lectures and laboratorial activities based on the use of online sensors and infrared cameras.

In this work, we investigated through worksheets and interviews to what extent the utilized learning path and methodologies can help students in understanding the proposed concepts of temperature, heat and energy by analysing how PPTs planned a personal didactic project on thermal phenomena.

The present study, conducted on 65 PPTs, suggests a kind of exclusive correspondence between addressed concepts and chosen instruments, which seems based on the fact that, differently from the online sensors, thermal cameras have been considered as instruments for visualisation purposes rather than for measuring temperature.

The proposed activities are mainly concentrated on thermal equilibrium, temperature and thermal sensation with a corresponding use of online sensors that excludes infrared cameras. This suggests that the comprehension of heating and cooling as processes leading to a common equilibrium state is better gained using the online sensors, indicating that these processes are better understood in terms of measurements of temperature.

On the other side, PPTs tend to discard the use of thermal cameras - not so much because they do not understand its use or its didactic potentialities, but rather due to its cost and to the supposed difficulty of having it in a primary school classroom, as it emerged from the interviews – and, in parallel, they tend to omit addressing the concepts of heat and energy transfer, which they consider particularly difficult for children.

When the concept of heat and energy are addressed in the planned educational path, there is a corresponding use of the thermal camera that excludes online sensors (and traditional thermometers as well). This suggests that the comprehension of heat in terms of energy transfer and the distinction between temperature as internal energy and heat as variation of internal energy is more easily grasped using an infrared camera.

It can be concluded that this study confirms the need of finding a suitable way for introducing the concept of energy at the primary school level and shows that the proposed approach with the use of a thermal camera can indeed be useful in helping primary school teachers in this task (otherwise considered too difficult), because infrared cameras allow associating the concept of energy to the concept of heat (which is, in turn, related to a variation of temperature) through related experimental activities.

From this point of view, the process of heating through irradiation, that was understood by PPTs both in terms of measuring temperature (use of the online sensors) and in terms of heat transfer (visualization through the infrared camera) represents a good solution for introducing such association.

On the other hand, our results also suggest that the use of less expensive thermal cameras, such as thermal imaging cameras designed for Smartphones, could also make this potentially successful approach more appealing for primary school teachers.
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