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Space mishap as a stimulus context for thermal conduction exploration in secondary school

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Abstract. A large body of literature underlines the relevance of personal involvement and in-context assignments in increasing student engagement in physics education at secondary level. The research-based teaching/learning experience offers different kinds of suggestions for physics education on the level of curricular proposals, on the level of feasibility of inquiry-based learning approaches, on the level of strategies and methods for learning environment settings, and on the level of conceptual understanding of students. During the activities, students find a good opportunity to discuss how heat is transferred, both on Earth and in space. Students discover through their own exploration what types of radiation space objects are exposed to in near-Earth orbits. By means of a "flipped classroom" methodology the students analyse radiant heat absorption and reflection. The activity was extended to learn about heat radiation incident on Earth and emitted by Earth. It was interesting to see the reaction of students when they realized that "radiant heat" has a wavelength, and that it is part of the electromagnetic wave spectrum. Tutorials and post-tests were used in order to gauge the students' understanding of the processes involved, and in particular what their conception of heat is. Students proposed different materials for heat shields used in the experiment, and in this way we touched on the subjects of thermal insulation and heat capacity. This leads us to examine the inner structure of materials, and essentially the link between macro- and micro-world. Discussion of heat absorption is a way to introduce the concept of energy, and consequently the role of macro-micro models in material science processes description. Characteristics and main results of the intervention module will be presented together with data of the monitored learning process.

1. Introduction

The complexity of the social and technological world asks for new competences and introduces new ways of learning. To reach this goal momentous innovation is required from teachers in their school work (see [1–2]). The role of the physics in context is to promote learning and motivation [3]. There is a wide literature to underline the different relevant roles played by the physics in context. Let me mention some of the most relevant ones:

- Several papers highlight the relevance of interdisciplinary context to promote learning processes and to relate school physics to the everyday life on one side and to the research on the other side [4].
- It is a general criterion for the evaluation of new learning objectives, to integrate physics and biological thinking [5]. These studies integrate research on students' learnings in particular concerning the role of an interdisciplinary approach for the students' learning and the development of interdisciplinary competencies.

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- Other studies focus on the different epistemological points of view adopted by students in Physics and Biology lessons (see [5] and [6]).

The physics of space is an interdisciplinary context in which a lot of physics is applied, e.g. thermodynamics, electrostatics, semiconductors [7]. Physics in context and in particular physics in space cannot be given as a spontaneous framework: a specific planning is required to select aspects that can be addressed and ways to do that. This work is a research-based experience on learning outcomes in a learning intervention module involving an optional class of students choosing physics at advanced level, it involved in an innovative proposal of space physics.

2. Introducing space physics in the curriculum

The Model of Educational Reconstruction described by Duit *et al* [8] is the theoretical framework used to select and reconstruct physics contents, aspects and concepts of an educational intervention module. The paper by Collins *et al* [9] about its theoretical and methodological issues helped to work out the specific proposal presented here.

The proposal is a vertical path in which different aspects of space physics are integrated in the secondary school physics curriculum, with different roles. In fact, micro-modules of single aspects are in the different parts of curriculum as conceptual referent for space physics.

2.1. The first Hungarian satellite MASAT-1

The successfully launched first Hungarian satellite MASAT-1 is the referent for the different in-context discussions. Some examples of the aspects considered are the following:

- Mechanical vibrations and instruments protection in MASAT-1 during the acceleration in the launch is a topic in which students can explore the large world of not harmonic mechanical vibrations in real apparatuses.
- In the topic of principles of thermodynamics we can discuss space debris, which is a new problem in twenty-first century ([10] and [11]).
- In the framework of electrostatics, namely the research on Faraday cage, is presented to explain how much of research is needed in this field, as for example for the safety of the Ground Control Station of Masat-1 in the top floor of the building E at the Campus of the Budapest University of Technology and Economics [7].
- Solar cell efficiency is a topic discussed during the study of solid state electrical and semiconductors. Students discover how in the preparation of the launch the researchers and designers of the satellite use a theater by means of power light sources with different orientation and distance to study and test the efficiency of cells.
- Students can calculate the mean density of the MASAT-1 using volume and mass data available on the internet as well as how the satellite circuit works and controls the given tasks.
- As regards how electromagnetic signals and communication help research, students explore how radio amateurs can collect data from MASAT-1 and readdress the data to the research center. They also could understand by this example, how citizens can contribute and become involved in the research, nowadays. Even thought, it not more than an isolated lab for special people and a restricted topic, it is an interdisciplinary issue with social relevance, too.

2.2. The first American space station Skylab

Skylab Orbital Workshop, the first American space station lost its thermal protection shield during launch on May 14, 1973. Without heat shield, the temperature inside the Orbital Workshop became dangerously high, rendering the workshop uninhabitable and causing deterioration of internal insulation and adhesives. Engineers and scientists developed an emergency repair procedure. The Skylab crew was sent up to the space station within 11 days, and they successfully deployed a twin-pole sail parasol sun-shade during their spacewalk. This context and the difficulties associated with this event is taken as a stimulus to devise an explorative activity for students to study, under Earth conditions, how a thermal shield can protect objects from heat produced by a radiant source, such as a space heater. The space accident of the Skylab space station is taken as an opportunity to discuss and treat several of physic disciplines:

- One of the more relevant aspects considered and actively involving the students is thermal protection.
- On this question, the students were engaged in a specific experimental problem solving to study the thermal conduction of different materials and to interpret data. On that problem, I organized a specific intervention module involving different groups of students for experimental explorations and data interpretation.
- The microscopic description of processes by means of phonon model is the last point planned and tested during the intervention modules.

Research presented here involves the experimental planning, data collection, data analysis and interpretation inside of a group of students on thermal conduction and interpretative phonon model.

3. Goals and research questions of the present study

My goal was to test a possible approach to the topic of heat conduction. I analysed the students' problem solving behavior, their plans, results and interpretation, as well as their reaction to the notion of phonons. The main research questions were:

1. How do the students imagine the concept of heat conduction?
2. How can the experiment of a space accident help in the learning process of students?
3. How and which kind of models, representations use student in interpreting the heat conduction?
4. How students profit of the proposed phonon interpretative model in explaining phenomena?

In accordance with Nersessian's methodology [12], in order to answer the above research questions, I compiled and had the students complete a prequalification questionnaire (pre-test) at the beginning, and a post-test questionnaire at the end of the classes. The pre-test and the post-test contained open questions. I intended to draw a conclusion on the results of these tests whether the practice-based education developed by me and based on space physics has proven to be effective, especially in relation with the research questions mentioned above.

4. Sample and context

In the framework of the optional topics in the school system, ten 16-year-old students planned the proposal for the problem solving in a preliminary phase. Three classes of Balassi Bálint secondary school in Budapest (about 90 fourteen-year-old students) were involved in the proposed experiment for 45 minutes. Another group of 22 sixteen-year-old students carried out the experiment.

The 16-year-old students planning the experiment together with the group of 14-year-old students performed the experimental analysis of all of the data. In the physics lab we conducted an experiment which attempted to demonstrate under Earth conditions how thermal shields can protect objects from radiant heat (figure 1).

The materials and devices used in the experiment were:

- a space heater and a model of Skylab made of metal with plastic elements;
- sunshades made of various materials, some well-suited for thermal protection, others not so well (textile, paper, glass, metal, and the actual space thermal blanket, "mylar");
- a digital thermometer, a laptop and LabCam software.

Figure 1. The experiment with our model of Skylab.

The students improved their skills in problem solving and team work by modeling real physical problems and developing experiments on their own (Figure 2). They found that the "space blanket", a special material developed by NASA in 1973, was the best thermal insulator. This was a research-based experience with spontaneous learning outcomes involving basic physics concepts identified in an innovative context of space physics. Innovation is needed in today's society because the desegregation of the society of the system,the complexity of the system and the complexity of the natural framework.

Figure 2. A sunshade of textile in preparation.

The interpretation based on the phonon model was discussed with the group of 22 sixteen-year-old students, because they studied physics at an advanced level. During these lessons, I felt that the concept of the phonon is quite hard for more than the half of the class; therefore, just a few students engaged deeper with the phonon model afterwards. One of them asked: How can we determine the number of phonons? I asked them to find the answer to this on the Internet. This was an attempt to apply one aspect of the inquiry-based learning approach. Some of them could find an acceptable answer at the high school level, that is, the number of phonons is not a constant. The phonons are created when an atom oscillates, and we can determine the probability of having phonons at a fixed temperature.

So far there has been a lack of didactical paths to teach heat conductivity from the micro world aspect. I think that now, when material science is one of the most progressive areas of physics research, it is important to discuss heat conductivity with our students in this way. My goal was to test a possible approach of this topic. I analysed the students' reaction to the existence of phonons, and I think that the concept is more understandable if the student gets to know it as early as the high school. They can be more receptive at this age.

5. Results

5.1. Learning results

In the context of the aforementioned educational environment, I introduced the students — who had not had any previous exposure to learning about heat transport — to a teaching method at the advanced level, including the pre-test and the post-test phases.

The 3 selected questions of the tests were the following:

1. Take a metal fork and a piece of paper in your hand. Which of the two feels cooler? Why?
2. What does it mean that the Sun's heat is absorbed by materials?
3. What are the thermal exposures of a satellite on a near-Earth orbit?

I classified the answers of the students in three groups. The results are as follows:

- Answers to question 1
  1A - the fork is cooler, and the reason is the material: 14
  1B - the fork is cooler, because metal responds slower: 5
  1C - the fork is cooler, because metal conducts the heat better: 3
- Answers to question 2
  2A - the material does not reflect heat: 15
  2B - during a chemical reaction the material absorbs the heat: 4
  2C - the energy of Sun becomes heat: 3
- Answers to question 3
  3A - only the radiation of the Sun: 4
  3B - the radiation of the Sun and the reflected heat by the Earth: 16
  3C - the radiation of the Sun, the reflected heat by the Earth and inner heat: 2

5.2. Interpretation of results

After my lessons the students answered the same questions in the post-test. The results of the post-test are the following (presented in figure 3):

- Answers to question 1
  1A - the fork is cooler, and the reason is the material: 2
  1B - the fork is cooler, because metal responds slower: 5
  1C - the fork is cooler, because metal conducts the heat better: 15
- Answers to question 2
  2A - the material does not reflect heat: 1
  2B - during a chemical reaction the material absorbs the heat: 0
  2C - the energy of Sun becomes heat: 21

- Answers to question 3
  3A - only the radiation of the Sun: 2
  3B - the radiation of the Sun and the reflected heat by the Earth: 11
  3C - the radiation of the Sun, the reflected heat by the Earth and inner heat: 9

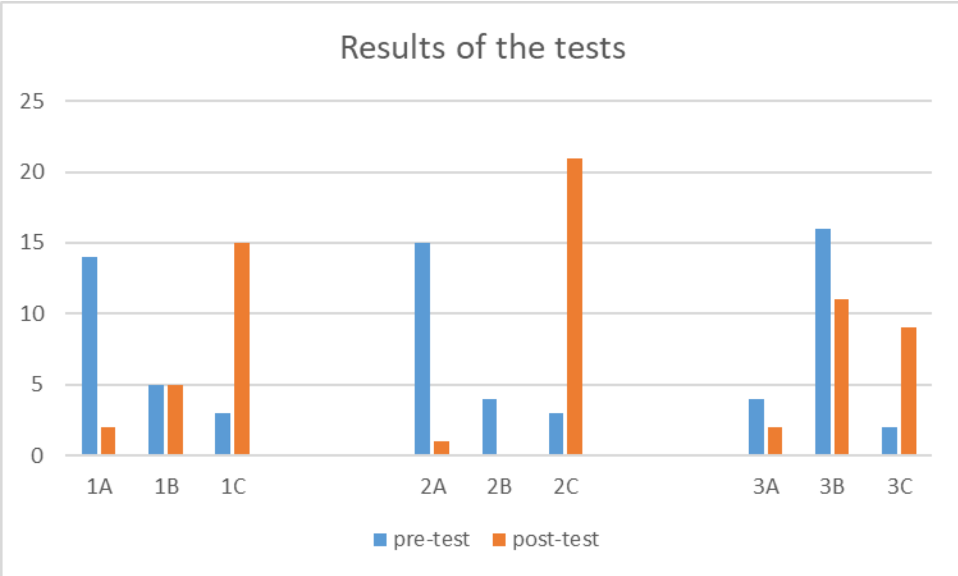

Figure 3. The results of the tests

We can see that the results were quite varied, but the students' knowledge improved and became more complex and sophisticated concerning these topics. The space-science-based experiment made some of the students interested in space research. After the discussing the heat conduction from microscopic aspect some other students started to detail with the particle physics.

6. Conclusion

My final conclusion of the research is, that the concept of heat is still not an easy issue at high school. It is not a coincidence, if we look at the developing of the concept of heat during the centuries. Of course the introduction of phonon in teaching can help the students to form the right approach.
In summary, the comparison of pre-test and post-test results suggests that the space-based practice-focused physic education, which I have elaborated and taught in the classes significantly improved the understanding of students in the field of heat and heat transfer.

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