Teaching energy focusing on transfers and fields

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Abstract. Energy is both a fundamental concept of the sciences and a huge challenge to students. Two concepts that are especially difficult for students are potential energy and energy conservation. In the literature, it has been suggested that a focus on transfers of energy between systems instead of transformations of energy forms may help students. Recently, the *Next Generation Science Standards* have adapted this perspective. We present the conceptual framework of such a systems-transfer approach of energy and demonstrate experiments to introduce the key concepts.

1 Challenges in teaching energy

Energy is a fundamental concept of science and a key aspect of scientific literacy. Classically, energy is taught with a focus on transformations of different forms of energy. However, a number of studies have shown that students struggle with the energy concept [1]. The concepts of potential energy and energy conservation are especially difficult: the first because potential energy is inextricably linked with the concept of systems making it notoriously hard to localize, the latter because students rarely observe isolated systems. A number of different approaches have been described in the literature to address parts of these issues, however, there is still a lack of consensus in the literature about how best to teach energy [2].

Recently, a number of authors [3,4] and the *Next Generation Science Standards* suggest that in middle school, a focus on transfers of energy between systems is useful. In such a systems-transfer approach, phenomena are discussed in terms of transfers of energy between systems. When energy is transferred, it only changes its location. Dissipative phenomena can easily be discussed in terms of energy transfers out of the relevant systems into the surroundings. Students' experience of real word phenomena such as e.g. a ball that bounces and then stops bouncing can be reconciled with the ideas of energy conservation because from a systems-transfer perspective it is clear that energy is transferred from the relevant system, the ball which slowly stops bouncing, but is neither created nor destroyed as it is simply transferred into the floor, air, etc. which make up the surroundings. Further, within such an approach potential energy must be discussed in terms of fields which would resolve the issue of potential energy's location while remaining scientifically correct.

We have developed and evaluated a systems-transfer curriculum unit for middle school and found evidence that this approach, and with it the concepts of systems and fields, can support middle school students in developing a deeper understanding of energy. In this workshop we present key activities that we use to introduce the concepts of systems, transfers of energy between systems, and fields.

2 The systems-transfer approach

At the beginning of the unit students look at phenomena with the lens of identifying what systems are involved, how each system changes, and how they interact. An energy transfer model (see in Fig. 1) will be established as a tool to represent graphically the involved systems, the process happening within each system when they interact and the direction of energy transfer. By use of energy transfer models students recognize that in each phenomenon there are at least two interacting systems involved, that each system undergoes a process and that energy is transferred from one system to the other.

Subsequently, in phenomena such as colliding carts and hot/cold objects in thermal contact, energy conservation will be implicitly introduced, demonstrating that an increasing energy process of one system is always accompanied by a decreasing energy process of another system.

One of the most crucial steps is the introduction of fields which is accomplished by an experiment of two repelling carts that are held together, each one with a magnet on his top. When they are released, both systems increase their speed and, according to their energy transfer model, they both increase energy and require an arrow of energy transfer in their direction. Through the lens of energy transfer there must be a decreasing energy process, so students need a new system to be involved in the phenomenon. This is the field. As each system must change with energy transfer, students use iron filings to establish that it is the shape of the field that changes as the carts move apart. From a systems-transfer perspective potential energy can be described more accurately as it is stored in fields and is involved in phenomena in which energy is transferred from or into fields.

A central principle of the approach is that energy must be somewhere. Thus, dissipative phenomena like a pendulum that slows down can be consistently explained: as energy is missing in the system of interest, students need to recognize that a new system, like for example the surroundings, is needed for the energy to transfer to. In this way, students can be surer that they have accounted for all systems involved.

3 Aim of the workshop

The workshop aims at introducing the key features, concepts and activities of the systems-transfer approach and how they address students' persistent difficulties in the learning of energy. Thereby, participants will explore the approach by undertaking themselves the experiments, their reasoning and the activities, and at the end of the workshop launch into an in-depth-discussion about strengths and possible improvements to this novel approach to teaching energy.

References

[1] K. Neumann, T. Viering, W. J. Boone, and H. E. Fischer, J. Res. Sci. Teach. **50**, 162 (2013).

[2] N. Papadouris and C. P. Constantinou, J Res Sci Teach **53**, 119 (2016).

[3] G. Swackhamer, *Cognitive Resources for Understanding Energy* (2005).

[4] E. Brewe, Phys. Rev. ST Phys. Educ. Res. **7**, 020106 (2011).

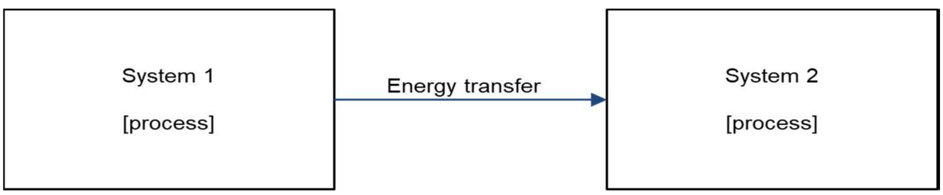

Fig. 1 The energy transfer model