

SUSTAINABILITY AND PHYSICS EDUCATION

Vera Montalbano

Department of Physical Sciences, Earth and Environment, University of Siena, Siena, Italy

Sustainability plays a central role in present and future for human societies and it has become an unavoidable issue in the policy guidelines of organizations like the EU and the UN. Science education needs to face a future that includes and supports the study of sustainability. Physics education can contribute in introducing sustainability by showing how investigation of the physical world is a necessary step in finding sustainable solutions. On the other side, sustainability can convey the interest from everyday reality to scientific concepts, involving the students in new laboratory activities. Moreover, teachers can be engaged in professional development and in active applied physics educational research. Educational actions were designed to introduce the concept of sustainability through meaningful activities in physics education. Early experiences were reserved to small groups of motivated students and few teachers were involved in laboratory. A relevant outcome was the request of developing learning paths for integrating these issues into ordinary didactic in classroom. An interdisciplinary learning path involved all students of a small high school is reported. The next step was to organize a national summer school focused on developing learning paths on topics in science relevant for sustainability, such as energy, food production and pollution in an interdisciplinary approach.

Keywords: sustainability, active learning, physics laboratory

INTRODUCTION

Sustainability as a concept relevant for human society has its origin in the Brundtland Report of 1987 (WCED, 1987). That document was concerned with the tension between the aspirations of mankind towards a better life on the one hand and the limitations imposed by nature on the other hand (see Kuhlman & Farrington, 2010 for a brief and actual review).

In August 2012, UN Secretary-General Ban Ki-moon launched the Sustainable Development Solutions Network (SDSN) to foster a global network to mobilize academia, research institutes, civil society, and the private sector in pursuit of practical solutions for sustainable development. In 2015, 193 countries adopted the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs) (UN, 2015). In November 2016, the EU also adopted its own sustainable development package.

Sustainability issues, such as climate change, ecosystems degradation, food insecurity and inequalities, worsen during the last decades. In nature, when an animal population manages natural resources in an unsustainable way, the final outcome frequently leads to extinction. When a human society makes use of environmental resources in an unsustainable way, the main effect can be its collapse (Diamond, 2005). In a world seeking solutions to its energy, environmental, and food challenges (Tilman et al, 2009), education for sustainable solutions has become one of the most promising and emerging priorities (McMichael et al, 2007; Wals, 2012; UNESCO, 2014; UN, 2012). The goal of introducing sustainability by using a scientific sight should be a primary issue in education.

Moreover, motivation and interest may facilitate the learning process increasing student involvement both in laboratory and in class discussions. Theoretical and empirical studies on the relationship between interest,

motivation and learning process are widespread in educational research (Alderman, 2013). From the educational point of view, it is essential to understand how and why students are involved in new topics and such approaches are effective (Trumper, 2006).

Sustainability with its multiple social, scientific and educational implications (see Figure 1) is a particularly suitable topic for increasing students' motivation and promoting an active attitude both in learning and in the behaviour of everyday of life.



Figure 1. Sustainability plays a central role in present and future for human societies. Science education needs to face a future that includes and supports the study of sustainability revealing its connections with everyday life, the possible future scenarios of the society in which we live, the elements of scientific literacy necessary to understand it, the need to understand and intervene in complex real-world systems in an interdisciplinary way and the role it can play in the development of scientific knowledge and its dissemination.

Another important aspect in introducing sustainability in education is the development of transversal skills related to the understanding of how knowledge is articulated on this topic (interdisciplinary or transdisciplinary studies), how it is communicated among the possible stakeholders (e.g. use of qualitative indicators as ecological footprints) and the adoption of appropriate transnational policies.

In order to explore if this topic can be useful and effective in physics and more in general in science education, the research questions were:

1. Can sustainability be a relevant issue in motivating student in learning process in physics?
2. Is it possible to design new learning paths in which sustainability issues are useful for clarifying some relevant disciplinary knots in physics education?
3. How to promote these learning paths in classroom practice?

With the aim to answer to the first research question, some educational activities were designed to introduce the concept of sustainability in context in which students from secondary school were oriented towards physics. These experiences are described in the following section. Further actions focused on fostering sustainability as a tool for a richer science education are reported in the next section. Finally, lights and shadows about the full process in classroom will be reported.

SUSTAINABILITY FOR ORIENTING TO SCIENCE

The interdisciplinary aspects and the links with everyday life make sustainability an excellent topic for introducing to the scientific investigation of the world around us.

In particular, a match of a competition between secondary schools, entitled *USiena-Game* and performed at the university on specific themes such as Stem cells, Sustainability or European citizenship, and two summer schools of physics for selected high school students were designed and performed in the last years.

USiena Game: a local competition for student at the university

Initially, some activities in which the scientific sight emerged in exploring problems of sustainability were designed and tested in the competition *USiena-Game*, where about a hundred of students (age 16-17) in two successive editions have studied the materials prepared for the match and answered a series of multiple choice questions on sustainability about energy, food and pollution issues. As a by-product, students were engaged in a deeper understanding of the meaning of numbers given in the context (Is it a measure or an estimate? Or a simulation from previous measurement?).

In Figure 2, an example of educational material is shown. The answer to the question required to use skills and knowledge in physics for the estimate of energy in the involved processes but also in biology for the energy content of a tuna can and how the tuna fish is transformed in an industry.



TONNO TONNO DELLE MIE BRAME...
 Quanta energia è necessaria per produrre il tonno in scatola?
 Si consideri una scatola di tonno sott'olio da 80 g.

A Una frazione trascurabile rispetto al suo apporto calorico di 200 kcal.
 B Più del 10% del suo apporto calorico di circa 150 kcal.
 C Meno del 10% del suo apporto calorico di 700 kcal.
 D Sono tutte sottostimate.

TONNO TONNO DELLE MIE BRAME...
 Quanta energia è necessaria per produrre il tonno in scatola?
 Si consideri una scatola di tonno sott'olio da 80 g.

A Una frazione trascurabile rispetto al suo apporto calorico di 200 kcal.
 B Più del 10% del suo apporto calorico di circa 150 kcal.
 C Meno del 10% del suo apporto calorico di 700 kcal.
 D Sono tutte sottostimate.

Tonno sott'olio (sgocciolato) 192 kcal ogni 100 grammi

inserisci la quantità in grammi CALCOLA

Risultato: 153.6 kcal



Solo la sterilizzazione richiede una quantità di energia di circa 15 kcal per scatola da 80 g. Se la nostra scatola è di tonno sott'olio si deve aggiungere anche il calore necessario a scaldare l'olio che viene messo caldo (80-90 °C) sul tonno per far uscire tutta l'aria dagli interstizi.

Figure 2. Example of multiple choice question on sustainability. On the left, it is shown a question about the energy employed for transforming tuna fish in a canned food ready to be consumed (How much energy is needed to get a tuna can?). The correct answer is showed on the right side, with a short explanation.

Physics for Sustainability in Summer Schools of Physics

Since 2006, about forty students from high school are selected every year to attend a full immersion summer school of physics in Siena countryside (the Pigelleto Natural Reserve or an historical small town, such as Pienza or Vivo d'Orcia). The students (age 16-17) are proposed within the National Plan for Science Degree by a network of schools in southern Tuscany. The focus of the summer school is always on physics laboratories, active and cooperative learning, peer communication (Montalbano & Mariotti, 2014). The 2014 edition, entitled *Physics for sustainability. Science and knowledge for a better world*, was centered on energy, food and marine plastic debris. There was an excellent feedback by students and teachers, thus the first research question obtained a positive answer in this context. In the following year, the summer school was entitled *Let's measure the world. Physical tools for finding sustainable solutions* and reached the same results.

The sustainability was introduced by using analogies for visualizing concepts, for example to distinguish between oversimplifications, sustainable situations near to a breaking point, stable sustainability subject to changes in boundary conditions that can destroy it and finally to a sustainability based to natural laws and active practices (examples are shown in Figure 3).



Figure 3. Examples of material designed for a summer school. On the left, the relevance of unsustainable use of natural resources is outlined for same ancient society collapsed in the past. On the right, different types of sustainable situations are visualized by using the analogy of a system in stable or unstable equilibrium in gravitational field in various situations.

After having introduced the concept of sustainability and why it is necessary to deal with it in order not to run the risk of making our society too fragile to variations in available natural resources, the contribution that physics can make to the understanding of sustainability issues was examined. Particular importance was given to the ability in problem posing and solving in complex real situations and to develop measurement or estimation processes of relevant quantities through the use of the scientific method.

Moreover, a laboratory on problem posing and solving was realized (Figure 4). The initial problem was to estimate a physical quantity in a real context relevant for the theme, that it had to be modeled, approximated, checked and the model had to be refined. Are there hidden variables? Which experiments can be performed for validating or confuting the hypotheses? Search for problems related to the theme in a local, intermediate and macroscopic scales. Is it possible to find sensible solutions? Which action could mitigate the actual unsustainable situation by involving my family and my friends? Or the whole school, or which other community can make the difference by assuming a responsible behaviour? The students discussed for choosing the problem and assess the physical impact.

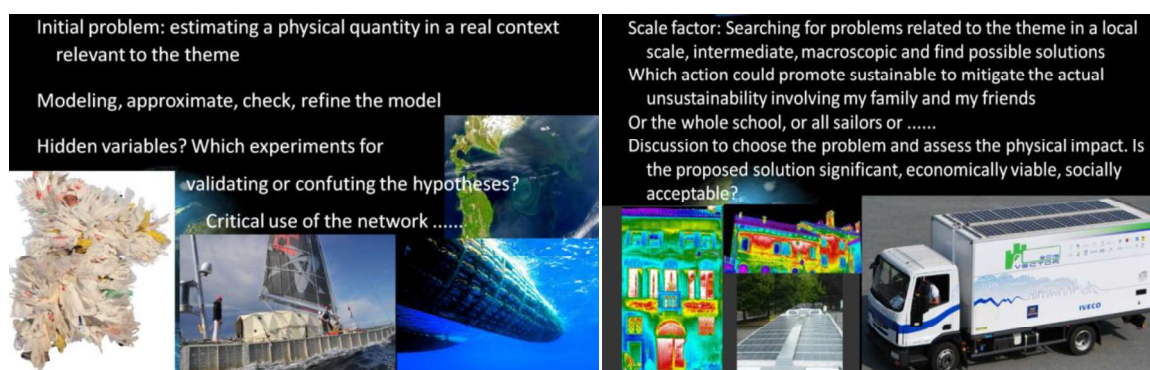


Figure 4. Examples of problem posing and solving: on the left searching for an estimate of the number of plastic bottles necessary for constructing *Plastiki*, a boat made with recycled waste products, and compare it with the consume in the students' family. On the right, some images proposed in the laboratory on how to save energy by improving heat loss in the school's building or if it is sustainable to cover all trucks in the country by solar panels.

The designed activities were discussed with a small group of physics teachers and tested with 83 students. The result was a list of tested problems related to sustainability in which students can be engaged in active laboratories where relevant skills for physics education, such as problem posing and solving in complex situations, measurements, estimates, approximations, modelling, were developed in a very motivating context. Thus, the second research question obtained a very positive answer. Teachers involved in the summer schools appreciated these activities and suggested to realize a learning path on food, energy and sustainability in their school for all students.

SUSTAINABILITY AT SCHOOL: AN EDUCATIONAL CHALLENGE

For answering to the last research question, new learning paths on sustainability issue were designed and tested in two different high school. In a small one (Montalbano, 2016), all students (50 participants, age 14-18) followed an interdisciplinary learning path on energy, food and sustainability. The focus was on developing new laboratories about thermal process, saving or wasting energy in the process of food transformation.

In another high school, a large project on nuclear phenomena and sustainability in energy production engaged 144 students in a wide monitoring of environmental radioactivity.

A clear problem in fostering these new kind of teaching/learning process at school is the necessity loudly invoked by teachers in scientific matters of a professional development in all topics related to sustainability. The lack of disciplinary and interdisciplinary skills is perceived by them like the principle obstacle to a large diffusion of sustainability issues in practice in classroom.

For these reason a national summer school for in-service teachers, Science in 4D, has been designed and will be realized this year. The sustainability is one of best topic in which develop skills and laboratories in an interdisciplinary approach, which is the aim of this summer school for teachers. About forty teachers will be admitted to participate and results in physics education as well as interdisciplinary activities developed in the school will be reported.

A Pilot on Energy, Food and Sustainability.

An interdisciplinary learning path was designed and realized in a small high school with a classic and scientific section (50 students aged 14-18, 2 physics teachers and a science teacher, a lab technician) in collaboration with the university.

The trial was funded by the Regional Government as an annual project for developing and testing new learning paths at school. The main aspect considered in the designing were:

- Motivation through connection to Expo 2015;
- Introduction to sustainability (a missing topic in curriculum);
- Strong interdisciplinary Physics-Science (Chemistry and Biology);
- Revisited Physics lab, new Science and Phys Lab;
- Focus on individual and collective choice in the topic.

The supplied energy to the human body is trivialized by the indication of the calories on the packaging but it is completely disconnected from the students' scientific knowledge. Some examples of activities are the following:

- How much energy is available to the body by eating a food and which relationship with the calories listed on the package? (problem solving and Lab);
- How much energy for food processing, packaging, distribution, preparation and consumption? (problem solving and Lab);
- How much fossil fuel for obtaining a portion of spaghetti? Or a banana? (problem posing and solving);
- Can we measure these energies in laboratory or estimate them by looking for information in database or elsewhere? (Lab)
- Is my favorite menu sustainable? Which carbon or water footprint it has? (problem posing and solving).

Usually a preliminary discussion in class was followed by activities of problem posing and solving and/or through experimental activities in laboratory.

In science laboratory students designed and realized a device for measuring the caloric content of small quantities of a food (Figure 5). The apparatus consists of a metal support for the food, the combustion is initiated by a piezoelectric gas lighter away from the test tube in which there was a known amount of water. The measures of the burned mass, the initial and final temperatures of the water allowed to estimate the calories in the food.

The quantitative analysis of the data collected with the apparatus allowed to distinguish the caloric intake of the main types of food but the measures were not repeatable (they had caloric contents lower than those of the database up to even 40 times). The students identified a first problem in the water content of the food, but even by doing so the measures were not reproducible and compatible with the database.

At this point the problem was analyzed in the physics laboratory, using an apparatus similar to the Mahler calorimetric bomb with which these measurements are usually carried out. The modified bomb calorimeter allowed to obtain reproducibility in measurements and quantities were in good agreement with calories in database.

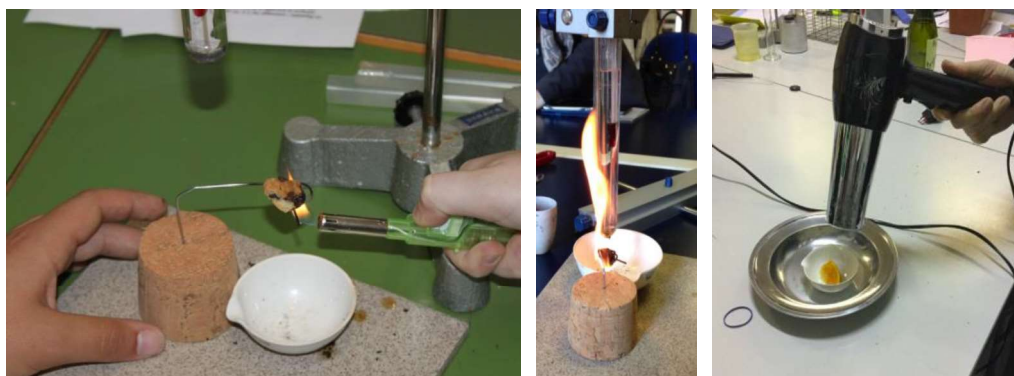


Figure 5. The experimental apparatus for evaluating the calories of foods made in the science lab, where a student was starting the combustion, on the left side. The apparatus during the combustion, on the centre. On the right side, students dehydrated food by using a flow of hot air.

The learning path showed clearly that Science Lab is focused on qualitative observations (useful and good for distinguish main contents of a food, in terms of lipids, sugars and proteins). In fact, usually teacher never proposed to estimate uncertainties for any quantity determined there. On the other side, Physics Lab is focused on quantitative measurements, uncertainties are almost every time estimated.

The two different experimental points of view are complementary and together give a much deeper insight in natural phenomena.

Thus, a clarification in basic topics was achieved, such as differences in estimates and measurements, or in qualitative lab compared to quantitative lab.

Monitoring Environment: Nuclear Phenomena and Energy Sustainability

A large project on nuclear phenomena and sustainability in energy production involved in another high school 6 classes (participants 144 student age 16-18 and 11 teachers).

This time again, the trial was funded by the Regional Government as an annual project for developing and testing new learning paths at school. The main aspect considered in the designing were similar to the pilot:

- Introduction to sustainability (a missing topic in curriculum);
- Interdisciplinary Physics-Science (Biology) and Physics-History;
- Revisited Physics lab, new Phys Lab;
- Wide monitoring of environmental radioactivity;
- Focus on individual and collective choice in the topic.

The project included, after the introduction to energy sustainability and nuclear phenomena, a monitoring of natural radioactivity extended in the school both indoors and outdoors.

The project included, after the introduction to energy sustainability and nuclear phenomena, a monitoring of natural radioactivity extended in schools both indoors and outdoors. Last year students designed a fog chamber to view ionizing radiation and a series of measurements were made in a disused mine.

Some materials produced by the students for an exhibition set up at the end of the project are shown in Figure 6.



Figure 6. Some materials produced by students for an exhibition is showed. On the left side, the experimental set-up used for monitoring natural radioactivity is shown together with some steps in lab for designing a fog chamber by using Peltier cells. On the right side, a poster summarizes the series of measures in the mine.

A National School for Science Teachers

The 2017 edition of a national school for science teacher professional development *Science in 4D* is dedicated to sustainability and science education (participants 27 Science teacher of secondary school). The school was entitled *Science for sustainability. Sustainability for Science*.

The main activities were:

- plenary lessons
- disciplinary and interdisciplinary laboratories (active learning)
- lab sharing in a final plenary session.

The lack of disciplinary and interdisciplinary skills is perceived by science teachers like the real obstacle to a large diffusion of sustainability issues in classroom practice. This school is only a first step in the right direction.

REMARKS AND CONCLUSION

The first 2 RQ obtained a positive answer from the students' and teachers' feedback in summer schools. Food and energy were a good choice for introducing students to sustainability. Motivation and interest were enhanced in students and in teachers too. New paths in laboratory were designed and remain available for curricular education.

A clarification in basic topics was achieved:

- Differences in estimates and measurements,
- Qualitative Lab vs. Quantitative Lab,
- Which means sustainability in this context.

Are we fostering best practice in the school? All teachers declare that they will continue these experience in the next years.

The real situation is different, good proposals can be postponed or missed for many good reasons by teachers, even the more motivated ones:

- Lacking of disciplinary and interdisciplinary skills in sustainability,
- Science teachers' team in the school,
- Previous positive experience in designing and testing new learning path.

Our experiences showed that seeding interest and new learning paths in this field can be very difficult. Summer school for students could work if teachers are involved in designing the new labs. Competition are useless, the weak interest and motivation awaked in some students is usually ignored by their teachers. Specific projects in the school could work or not, depending by teacher team. In-service (and pre-service) professional development could be really a good starting point for answering in a positive way to the last RQ, but further investigations are needed.

ACKNOWLEDGEMENT

Few activities would had been developed and tested over the years without the careful contribution of a group of teachers of secondary school and academic colleagues. The author would like to thank Emilio Mariotti, Federico Pulselli, Ilaria Corsi, Antonella Porri, Giovanni Bianchi, Barbara Rossi and Alice Severi.

REFERENCES

- Alderman, M. K. (2013). *Motivation for achievement: Possibilities for teaching and learning*. Routledge.
- Diamond, J. M. (2005). *Collapse: How Societies Choose to Fail or Succeed*, New York, NY: Viking.
- Kuhlman, T., & Farrington, J. (2010). What is sustainability? *Sustainability*, 2(11), 3436-3448.
- McMichael, A. J., Powles, J. W., Butler, C. D., & Uauy, R. (2007). Food, livestock production, energy, climate change, and health. *The lancet*, 370(9594), 1253-1263.
- Montalbano, V. (2016). Energy, Food and Sustainability. In A. Király & T. Tél (Eds.), *Teaching Physics Innovatively* (pp. 223-228). Budapest: Eötvös Loránd University Press.
- Montalbano, V., & Mariotti, E. (2014). A multipurpose action for learning-teaching process: The Pigelleto's Summer School of Physics. In C. P. Constantinou, N. Papadouris & A. Hadjigeorgiou (Eds.), *E-Book Proceedings of the ESERA 2013 Conference: Science Education Research For Evidence-based Teaching and Coherence in Learning*, Part [9] (co-eds. G. Garvalho and M. Mortensen Foss), (pp.[218-227]) Nicosia, Cyprus: European Science Education Research Association. ISBN: 978-9963-700-77-6
- Tilman, D., Socolow, R., Foley, J. A., Hill, J., Larson, E., Lynd, L., ... & Williams, R. (2009). Beneficial biofuels - the food, energy, and environment trilemma. *Science*, 325, 270-271.
- Trumper, R. (2006). Factors affecting junior high school students' interest in physics, *Journal of Science Education and Technology*, 15(1), 47-58.
- UN (2012). *The Future We Want: Outcome Document of the United Nations Conference on Sustainable Development (Rio+20)*. United Nations.
- UN (2015) General Assembly Resolution A/RES/70/1. *Transforming Our World, the 2030 Agenda for Sustainable Development*. *Seventieth United Nations General Assembly*, New York, 25.
- UNESCO (2014). *Shaping the Future We Want. UN Decade of Education for Sustainable Development (2005-2014). Final Report*. Paris: UNESCO. Retrieved January 31, 2017, from <http://unesdoc.unesco.org/images/0023/002303/230302e.pdf>
- Wals, A. E. J. (2012). *Shaping the Education of Tomorrow: 2012 Full-length Report on the UN Decade of Education for Sustainable Development*. UNESCO, DESD Monitoring & Evaluation.
- [WCED] World Commission on Environment and Development, B. C. (1987). *Our common future*. Report of the world commission on environment and development.