

Could Physics teaching and Sustainability challenges be linked?

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Abstract. Sustainability is getting mandatory for the continuing human development, where living conditions and resources are used to meet human needs without undermining the integrity and stability of the natural system. Sustainable Development is an interdisciplinary concept, including the Environmental, Health, Energy, Economic, and Socio-Cultural areas. Empowering young learners to create a sustainable future is critical in educating future responsible citizens. Education at Sustainability can also act as a vehicle to inspire the next generation of students to pursue a career in science. Physics plays a key role in the achievement of the SGDs, in particular regarding the sustainability in the Environmental, Health and Energy areas. The Erasmus+ GREEN-EDU project supported the development of new interdisciplinary approaches and teaching practices in science classrooms, enhancing the efficacy of teaching/learning physics by means of novel fields such as sustainable engineering, robotics and green biotechnology. Green education allows connecting abstract physics concepts to real-world technologies that are responding to environmental challenges. Under the umbrella of a green education curriculum, difficult physics concepts can be introduced and explained within a more interesting context, relevant to the everyday (and future) life of the students.

1. Introduction: Sustainability challenges and Green Education

To achieve environmental and climate goals with a socially just transition, there's a critical need for radical changes in production and consumption systems, including those related to food, energy, and mobility.

Environmental issues are inseparable from broader sustainability issues, such as social and economic ones. Significant changes in any one dimension (e.g. environmental) will affect the others (e.g. socio-economic). Changes in the way we produce energy, for example, moving away from fossil fuels, can leave whole regions which were dependent on coal mining prey to unemployment and poverty — if the socio-economic dimensions are not factored in (by retraining the workforce, investing in new workplaces and so on). The change cannot come from traditional policy responses alone or just from a change in technologies. To avoid lock-ins, consumption patterns, individual and collective behaviours



and mentalities need to change as well, moving away from consumerism, individualism and short-termism. For example, changes like moving away from owning a car towards ridesharing or using public transportation can be difficult to adopt for individuals, and car producers could lobby against the new solutions. Strong coordination is needed among the international community [1].

The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs) or Global Goals, which are an urgent call for action by all countries - developed and developing - in a global partnership. They recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests [2].

As outlined in the Chapter 5 “Transformations through science— and in science” of the SDG Report 2023, *“the scientific method, based on observations and testing hypotheses, can reduce uncertainty, identify tipping points, accelerate the uptake of innovations and lay the foundations for the next frontier of ideas. Science also provides the evidence to help dismantle negative pathways or paradigms that counter the rapid acceleration of new technologies and other solutions. In the age of multiple compounding global risks that lead to escalating social vulnerability and increased inequality, the traditional process of production, validation and dissemination of scientific knowledge is not sufficient to result in meaningful processes of change. Transformations to sustainable pathways must be rooted in “socially robust” science.”* Today more than ever, scientists, policymakers and multiple social actors need to work closely together at the science-policy-society interface to build trust, establish the scientific base for progress towards the Sustainable Development Goals, deliver findings and communicate these findings to society at large [3].

The 2030 Agenda and its 17 Goals approach sustainable development in a holistic, integrated manner. Taking an integrated approach is the only way to stem the compounding risks of climate change, disaster, pollution, biodiversity loss and degraded ecosystems as well as their socioeconomic impacts [4].

Education systems have a responsibility for alternative thinking and creating new ideas and challenging the old school of thoughts. This leads to different thinking amongst the students and help them in any kind of social interaction. When such an education culture is brought in it leads to transformation thinking in society. Students need to understand the links between the environment, conserving energy, ecology, and economy. Sustainability challenges in the community should be addressed. Students are provided with the opportunity to study and apply concepts, methods of applying green in all functional areas. If they have an understanding of the issues, it will help in the future to apply solutions. Higher education institutions have a crucial role in the community, namely, through partnerships with schools and teachers’ training centres to raise awareness and disseminate and increase Sustainable Development practices in the community [5]. Educators need to incorporate awareness and adoption of environmentally friendly practices in the learning process. Eco-friendly tools, techniques, and equipment have to be used in the teaching-learning process. The culture of earth conservation has to be an integral part of the curriculum. The education sector should transform itself into a Green Education.

Green education is all about creating knowledge, skills, attitudes and values related to the environment. Green Education is at the core of developing a skilled scientific workforce and knowledgeable citizenry who are prepared to design and choose products safe for human health and the environment. Green Education is an important tool to promote ownership of shared values, having an impact on consumer behavior and everyday life. The environment provides typical challenges to the current and future generation in terms of climate change, resources getting depleted, water issues, poverty, food and war issues, environment caused diseases and pollution.

Green education can act as a vehicle to inspire a new generation of students to pursue a career in science in an inclusive way (addressing both boys and girls equally).

2. The “Green Education for a sustainable future” project

Empowering young learners to create a sustainable future is critical in the process of preserving the planet and in educating future responsible citizens.

The “Green Education for a sustainable future” (GREEN-EDU) has been an Erasmus+ funded project that brought together universities and schools from Poland, Italy, Romania, Turkey and Greece (<http://greenedu.uowm.gr/>). The project aimed to connect abstract science concepts to familiar contexts, relevant to everyday life of the students and to real world technologies that are solving environmental challenges. Linking school activities to real-life situations can foster Meaningful Learning, wherein knowledge gained is applied to practical contexts, thus enhancing its significance. In essence, understanding the relevance of learned concepts empowers students, driving their interest. Hence, a key aim of the project has been to engage young minds, raising awareness about pertinent topics for their future, including sustainability, green technology, biodiversity, self-regulation, social behavior, and development. Furthermore, this approach nurtures 21st-century skills such as creativity, critical thinking, communication, and collaboration.

The project introduces opportunities to go green, challenges to go green, consequences of going green, and sustainability in the education sector.

Towards this direction, the GREEN-EDU project aimed at developing an online platform which acts as a repository of STEM green education resources, integrating the micro-MOOC approach. The latter is an innovative approach for developing STEM laboratories that motivate teachers in the creation of flexible personalized teaching/learning paths and to increase students’ interest and involvement, due to the innovative methodology of their learning [6]. The project assisted educators by establishing a supportive community dedicated to green education across Europe. Within this interactive open platform, educators can discover classroom activities, share ideas, and engage in collaboration. GREEN-EDU activities promote responsible citizenship. Activities are designed in a form of lesson plans that include basic theory and laboratory work. Hands on activities as well as virtual labs have been designed. Topics encompass real- life problems in order to engage learners. Up to now, the platform includes a total of 45 learning activities divided in three categories: green chemistry, green biotechnology and green engineering and robotics [7, 8].

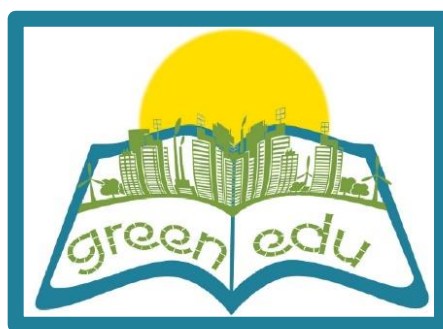


Figure 1. Logo of the project.

2.1 Pedagogical characteristics of Green-Edu educational material

The materials generated through the GREEN_EDU project are readily customizable to align with school curriculum topics and do not require advanced computer science skills. The suggested activities incorporate experiences achievable with readily accessible materials, making the project products valuable for distance learning as well.

The various activities follow pedagogical guidelines that consider the characteristics of students during their developmental age. In particular:

At the primary level (6-10 years), the students need the support of real objects and experiences to build abstract thinking, they are not yet able to collaborate to achieve a goal, have a self-centered outlook and are gratified by personal success. Consequently, the materials produced include

- laboratory activities that start from real life experiences;
- use of materials familiar to the students

and promote a practical method (e.g.: Show/demonstration) that emphasizes the playful aspect, allowing everyone to participate in the activity in person.

During the secondary level (ages 11-14), learners develop the ability to form abstract thoughts, draw conclusions through deductive or inductive processes, and benefit from interpersonal relationships. As a result, the suggested experiences promote a problem-based approach, engaging students in discussions that encourage connectivity and collaboration through group work.

In high school (ages 15-19), students are expected to have attained a level of reasoning maturity that enables them to determine how to construct their understanding. Therefore, an approach that fosters independent thought should be encouraged, such as didactic discussions (e.g., round tables, debates) and practical methodologies like Inquiry and Project-Based learning.

Moreover, to support the didactic process for teachers, as an intellectual output, the project partners created the document “*Pedagogical requirements for the GREEN EDU educational material*” available in the GREEN_EDU website. With the help of this material, teachers will learn how to effectively engage new generations by incorporating biologically inspired engineering and scientific breakthroughs into their courses using the project material. On the project website it is also available an operative guide for teachers, providing understanding of how to use the learning units and upload all the training material.

3. The teaching/learning of Physics under the umbrella of Green Education

Teaching physics involves more than writing formulas on a chalkboard. It involves helping students to see the world in a new way. It involves crafting a learning environment where students are able to explore and understand how the physical world works, and to connect complex scientific concepts to their daily lives [9].

To improve Physics education in schools, more attention should be devoted to developing practical skills. This agrees with current trends in education, that emphasize the need for a progressive switch toward student-centred approaches in which students should participate actively in the learning processes. Active learning is grounded in the principle that students acquire knowledge through active engagement in learning tasks, rather than solely through passive reception of information from the teacher. This approach emphasizes the importance of hands-on experiences, collaborative activities, and problem-solving tasks to stimulate critical thinking, creativity, and deeper understanding among learners. By actively participating in their own learning process, students are more likely to retain information, develop essential skills, and apply their knowledge in real-world contexts. Thus, active learning not only enhances comprehension but also cultivates autonomy, curiosity, and lifelong learning habits. Inquiry-, Project-, Discovery-based teaching strategies, which promote an involvement in activities similar to those carried out by scientists, can provide the students with opportunities to deepen their understanding on how scientific knowledge is produced in real research contexts. The active learning experience should replace the transmissive lecture as a dominant mode including laboratory activities, internships, and collaborative/cooperative learning [10].

Student’s educational experience should “build inquiry, sense of wonder, and excitement of discovery. “Learning by doing” activities have a strong potential in producing and assessing a constructivist learning methodology [11].

Physics is a path for those with the most creative minds, for those with expansive intellects that appreciate multifaceted challenges, for those who want to really make a difference, and in an immediately tangible way [12].

Novel fields such as green chemistry, sustainable engineering and robotics and green biotechnology can be implemented into classroom teaching under the umbrella of green education. And Physics? It is possible studying physics and taking on social responsibility at the same time? Take up climate, environment, and sustainability as topics and actively shape them? This could be made possible, as happens, for example in the new bachelor's degree in Physics of Green Technologies at the University

of Marburg. The combination of physics with the fields of biology, chemistry, geography, and technology promises varied and exciting career prospects. Indeed, education is a key element to address sustainable development goals (SDGs) [13, 14] and as shown in <https://www.iop.org/strategy/physics-climate-change-sustainability/global-green-economy>, physics has an important role in delivering the global green economy. Indeed, physics is the gateway to careers in science, technology, engineering and medicine that are critical to the future prosperity and economic competitiveness of our countries. Sustainability challenges and physics teaching are interconnected. The GREEN_EDU project materials aimed at helping teachers incorporate these concepts into their lessons. The GREEN_EDU approach introduces new ideas and possibilities.

Physics for Sustainable Development has been a guest event connected to the celebrations of the Centenary of the International Union of Pure and Applied Physics (IUPAP) and of the International Year of Basic Sciences for Sustainable Development (IYBSSD), proclaimed by UNESCO for the 2022.

The workshop demonstrated that Physics is instrumental in advancing SDGs, particularly in areas concerning environmental sustainability, health, and energy. The workshop featured various speakers discussing specific themes such as biomedical technologies, green technologies, information technologies, smart cities, water conservation and wastewater management, urban planning and transportation, renewable resources (including solar, wind, and geothermal energy), as well as nuclear fusion energy—all interconnected with concepts from Physics.

(<https://www.nanoinnovation2022.eu/home/index.php/programme/guest-events/physics-for-sustainable-development>)

Moreover, teaching Physics entails instilling confidence in learners to tackle sustainability challenges and empowering them to contribute to a brighter future for themselves and society [15]. The ability to define the conditions for a sustainable development of humankind to keep the Earth system within the boundaries of habitable states or to predict critical transitions and events in the dynamics of the Earth system are crucial to mitigate and adapt to Earth system related events and changes [16].

4. GREEN_EDU-based lesson plans in Physics: the results of the workshop “*Teaching Green Physics at school*”

The aim of the examples provided in Section IO-6 of the project website is to streamline and enhance teachers' experiences in creating teaching content, ensuring simplicity and positivity, and furnishing all necessary information for the utilization of learning units.

To design an active Physics learning path, based on GREEN-EDU materials, it is possible to use several digital and non-digital tools. Furthermore, the incorporation of the remote/virtual laboratories, as a didactical instrument for practice-based learning, can capture the students' imagination and motivation, effectively engaging them in Physics education.

A significant portion of physics revolves around the examination of energy and its conversions, with energy serving as a central element in pivotal environmental concerns and sustainability dilemmas. The climate is influenced by the interactions of solar energy with the movement of the atmosphere and oceans, and their subsequent distribution of energy across the globe. Physics plays an important part in all our lives and particularly in our understanding of the climate. Pioneering efforts to reduce energy consumption, diminish pollution, and develop more efficient processes are currently being researched and developed by teams of physicists and colleagues from neighbouring disciplines [17].

As an example, starting from the materials developed in the learning unit “*The sun and the Green Chemistry*” (belonging to the section “Green Chemistry”), it is possible to realize a lesson plan focused on the “*Heat: the energy transfer*” for the secondary level or on the “*Electromagnetic spectrum*” for the high-school level (see IO-6 A3 Example IO1 in the project website).

Another interesting example starts from the lesson plan “*The frictional force*”, belonging to the Section “Green Engineering and Robotics”. The teacher can decide to use the lesson plan as it is written or find (in the file containing information and instructions) other ideas for a new lesson focused on Physics content. Table 1 shows how this second possibility could be exploited (see IO-6 A3 Example IO3 in the project website):

Table 1. Three different learning paths on the physical concept of “Friction”

<i>Friction in daily life</i> (Primary level)	<i>Friction measures</i> (Secondary level)	<i>Friction and conservation laws</i> (High-school level)
Step 1: Engagement: Watching a video (~ 15 min)	Step 1: Engagement: Watching a video (~ 3 min)	Step 1: Engagement: Watching a video (~ 15 min)
Step 2: Activity lab on friction to fix the concepts explained in the video (~ 10 min)	<i>What is friction?</i> Step 2: Exercises to fix the concepts explained in the video (~ 7 min)	Step 2: Activity lab on friction to fix the concepts explained in the video (~ 10 min)
Step 3: Exercises with Flippity.net (~ 15 min)	Step 3: Activity lab: friction measures (~ 90 min)	Step 3: Exercises with Flippity.net (~ 15 min)
Step 4: Assessment (~ 20 min)	Step 4: Assessment (~ 20 min)	Step 4: Assessment (~ 20 min)

Organized by the Department of Physics and Chemistry “E. Segré” of the University of Palermo, the “*Teaching Green Physics at school*” workshop took place on Thursday 27 October 2022 at the ICS Mare Dolce Institute in Palermo. The final Multiplier Event of the “GREEN_EDU – Green Education for a sustainable future” project saw the participation of thirty teachers of STEAM disciplines (in particular Physics), coming from various schools of all levels. After listening to a short presentation of the project's aims, the participating teachers worked in groups to “explore” the learning units in Sustainability, Environmental, Health and Energy areas created by the Consortium partners. In particular, we asked them if the materials could be used for effectively teaching Physics. With the aim of optimizing the final products, their comments and needs have been collected.

Table 2 reports the questions that were asked to the teachers who took part in the workshop. The ease of implementation in the classroom, the clarity in the description of the lesson plan, the effectiveness of materials for teaching STEM subject and, in particular, for teaching Physics and the suitability for the corresponding age group have been rated by using a 1-5 Likert scale, with 1= absolutely not; 2= slightly, 3=neutral; 4= moderately; 5= extremely, reflecting the degree to which the educators appreciated the collection of GREEN_EDU lesson plans.

Table 2. Survey administered to the teachers who took part in the workshop.

LESSON PLAN EVALUATION	
Lesson Plan Name	
Category	
Description	
How easy is the lesson plan to implement in the classroom	
How clear is the description of the lesson plan	
How effective is the lesson plan for teaching STEM topics? Does it meet the described goals?	
How effective is the lesson plan for teaching physics?	

How appropriate is the lesson plan for the corresponding age group?	
How appropriate is GREEN_EDU materials to connect physics and sustainability challenges?	
Please provide any comments	

4.1. The teacher's point of view

According to our teachers, the material is described as clear and straightforward, adaptable, conducive to online implementation, and readily deployable. The suggested activities are designed to be executed by students using everyday materials, ensuring accessibility and ease of comprehension. They also asserted that more detailed descriptions could help (possibly including partially video-based tutorials).



Figure 2. Teachers at work during the Multiplier Event.

The didactic material prepared within the GREEN_EDU project is simple in its graphics but, at the same time, captivating. They appreciated the form of comics and animated characters; the short and direct school deliveries; the fact that all the materials that pupils should use for carrying out the experiments are highly available also in the home environment and responding to the most innovative meta-cognitive teaching methodologies. The teaching material is structured so that it can be used as a starting point for a discussion with students or inserted in an asynchronous lesson in flipped classroom mode because it includes short, fast paced videos with eye-catching graphics. The didactic cards on laboratory experiences are colourful and simple in their instructions, accompanied by tests to be administered to students and grids for the evaluation of face-to-face or distance learning.

For what concerns the effectiveness of the learning materials to teach Physics, the 80% of the teachers answered that the lesson plans are extremely effective for teaching physics; for 10% the lesson plans are only moderately effective. Only 70% of the teachers think that the GREEN_EDU materials allow to connect physics teaching and sustainability challenges in a very effective way, 20% think that they could moderately introduce and discuss Sustainability challenges. In both cases, the remaining 10%, answered

they felt not adequately qualified to rate the learning units because they did not teach Physics at school (see occurrence of the answers in Table 3).

The full and detailed analysis of the answers to all questions (not only in Italy, but also in the other countries of the project Consortium) is still in progress and it will be the subject of a forthcoming paper. This new study will focus on identifying the integration models and practices that STEM teachers should utilize to incorporate environmental topics and issues into their classrooms, as well as the potential challenges they may encounter during this integration process.

Table 3. Teacher satisfaction with the proposed material.

Question	Occurrence		
	<i>Extremely</i>	<i>Moderately</i>	<i>Not adequately qualified to answer</i>
How effective is the lesson plan for teaching physics?	24	3	3
How appropriate is GREEN_EDU materials to connect physics and sustainability challenges?	21	6	3

5. Discussion and conclusion

Over the past four years, the teaching approach has undergone changes in response to the pandemic situation. As a result, the utilization of the educational online resources provided by the GREEN EDU project could also cater to the needs of teachers involved in distance learning. These e-learning activities may be planned for self-study, or even as group projects under a mixed perspective and can be integrated with other material as the laboratory activities or a Project-Based Learning (PBL) methodology.

Thanks to the application of the educational method of acquiring knowledge through experience, it is possible to develop in children the enthusiasm for acquiring knowledge and a willingness to learn in practice [18]. Thanks to the STEM approach, it is also possible to change students' approach to science and math. It also assists students in preparing themselves to navigate the labor market effectively as graduates, equipping them with practical skills aligned with their education, aptitudes, and occupational interests. The EU GREEN-EDU project supported the development of new interdisciplinary approaches and teaching practices in science classrooms, enhancing the efficacy of teaching/learning physics by means of novel fields such as sustainable engineering, robotics and green biotechnology. The relevance for physics teaching is established through the development of essential skills such as critical thinking, hands-on experiments, and the connection of physics to everyday life, as well as its importance for technical development. Preliminary results of a survey administered to STEM educators attending the final multiplier event in Italy show that this innovative methodology is very appreciated by the Physics teachers. They observed that the educational resources developed within the project can be efficiently utilized in order to increase the efficacy of physics concepts learning process and also to introduce and discuss Sustainability topics.

The Green Edu project ended in October 2022, but the Consortium decided to take it a step further by:

1. expanding the lab kits and activities in order to create a full green curriculum;
2. connecting activities with realistic problems deriving from the SDGs in a problem-based learning approach.

The updated version of the project (with the inclusion of the Augmented Reality - AR) will be presented as a KA220-HED proposal at the Call of October 2024. We hope that the updated version incorporating AR will enhance the existing methods and contribute to the coherence of the argument.

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