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Art and design entanglements for renewable energy education: Renewable energy art and design approach

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ABSTRACT

The ongoing energy transition presents a necessary shift towards renewable sources, such as wind and solar power, in the face of the challenges presented by the changing climates. This change, however, requires an understanding of the operation of renewable energy systems. In other words, the shift towards clean energy generation demands education. By combining art, design, and renewable energy education the renewable energy art and design (READ) approach provides a path for renewable energy education. READ approach is a customizable and flexible process developed to enable the creation of solar-powered devices while sharing knowledge on diverse subjects such as art, design, electronics, electricity, and computer science. Due to its versatility, READ is expected to enhance energy education and contribute to the transition towards a renewable-powered society.

Keywords: renewable energy, energy education, art & design, electronics, steam, sustainability

INTRODUCTION

The ongoing change in climate requests us to adapt and act, as highlighted by the latest report published by the intergovernmental panel on climate change (IPCC). To limit the adverse impacts of climate change it is crucial to decrease anthropogenic CO_2 emissions, most of which are due to the burning of fossil fuels (IPCC, 2022). Traditionally CO_2 emissions from fossil fuels are associated with two sectors, energy generation and transportation, which usually rely heavily on fuels such as coal, oil (i.e., non-renewable liquid fuels), and natural gas. Worldwide, the emissions from these two sectors are expected to decrease, due to the electrification of the transportation sector, and the widespread adoption of renewable energy sources (Dale, 2023). Such a transition away from fossil fuels is already happening, as more electric vehicles hit the road, and the use of coal and oil for electricity generation is decreasing (IEA, 2022)

It is also expected that solar and wind, two clean energy sources, become even more ubiquitous since they are already more economically viable than traditional fossil-based sources (EIA, 2021). Solar energy, for instance, is already blended with urban settings across the globe, and its adoption has been growing consistently over the years worldwide (REN21, 2022). The growth in adoption, however, may not be enough to create a social understanding of how renewable energy works. For instance, Kishore and Kisiel (2013) found that young students tend to know what solar photovoltaic (PV) systems are, but they generally do not understand their operation. This indicates a possible educational gap, which, if left unfilled, might cause delays in the adoption of renewable energy sources, thus possibly slowing down the needed response to climate change. Perhaps even worse is the fact that the education gap can lead to misinformation and not-in-my-backyard (NIMBY) reactions (Rai & Beck, 2015; van der Horst, 2007). Energy education is therefore essential to prepare our society for the ongoing energy transition. However, as Lowan-Trudeau and Fowler (2022) pointed out, energy education is still entangled with colonial practices and fossil fuel perspectives. We propose a path for renewable energy education based on Freirean practices and climate change perspectives. Our path resides in developing solar-powered educational devices through the entanglement between environmental awareness, modern electronic devices, art, and design, resulting in the renewable energy art and design (READ) approach.

Despite many possible educational paths, one involving sensations of touch and active involvement, more than just vision, enables a deeper connection with the subject matter (Haury & Rillero, 1994). And since solar energy is modular–the size of the system does not change its main characteristics–building knowledge through touching and assembling small-scale solar-powered devices has the potential to promote a strong understanding of the subject. We developed our practices to be implemented in various learning environments beyond–but without excluding–the classroom environment as long as the knowledge is shared in a way that the instructor becomes endogenous to the group, an element that receives and shares knowledge, inspired by the work of the Brazilian pedagogue Freire (1967), and by the concept of science as social knowledge (Longino, 1990).

Furthermore, often when dealing with a group of students, this group is a collective set of elements with a diverse background -thus the teaching practices should be inclusive to resonate with as many people as possible. That is, where art plays a major role in renewable energy education: it promotes new experiences and different angles to look at subjects. For instance, solar PV systems might be perceived as strange rectangular shapes, mysteriously capable of generating power (Dimitrokali et al., 2015). The service that solar energy conversion systems provide (electricity or heat) is invisible to the eye–different from other power sources, where movement is always present. Through art, we can change the rectangular shape of solar panels into other angular or organic shapes and forms, such as the ones found in nature to which the public might pay more attention. We consciously developed READ approach with natural elements in mind, using nature around us (e.g., flowers, insects) as inspiration for our designs. Thus we purposedly tried to break the barriers associated with traditional engineering, hoping to invite more people to discover and intra-act with READ systems (Barad, 2007; Rautio et al., 2022).

Art and energy have a long history of intersectionality as the latter has propelled human endeavours since its infancy. The discovery of fire is perhaps the earliest of such intersections, but its consequences are still present in our society through activities such as agriculture and cooking (Pyne, 2012; White, 1943; Wrigley, 2013). It also allowed people to represent their world in the form of primitive cave paintings (Marchant, 2016). Descriptions of harvests, farm animals, and sailboats were common among the ancient Egyptians, Greeks, and Romans (Chatterton, 2010). The ancient civilizations also had energy deities, such as the Anemoi or Venti, the gods of wind for the Greek and Roman mythologies, whom they revered (British Museum, n. d.). In more recent times, in 1839, Joseph Mallord William Turner painted *The Fighting Temeraire*, a metaphor for the decline of the sailboat and the rise of the faster steamboat (Lord, 2014; Sullivan, 2021). In short, the functioning of human society is entangled with the history of energy and the many transitions that are part of it. However, besides energy, our society is experiencing a climate transition that can impact essential services and natural processes (Ornes, 2018; Schiermeier, 2018; Serdeczny et al., 2017). These challenges demand action from all sectors of our society.

Dealing with complex and systemic challenges such as energy transition and climate change demands effective solutions. Thus, it is fundamental to have people well-trained in the diverse forms of renewable energy generation (Kandpal & Broman, 2014; Negro et al., 2012) and who understand the importance of this energy transition to the continuity of life on earth. Energy education, despite often lacking a broad systemic approach (Ciriminna et al., 2016; Jorgenson et al., 2019), is fundamental for developing solutions and group thinking about the subject. To be effective, energy education should be presented within a sociotechnical innovation context tied to the environment (Hasnain et al., 1998; Jorgenson et al., 2019; Kandpal & Broman, 2014). Moreover, energy education should propel the interest for collective action, through programs dedicated to renewable energy (Ciriminna et al., 2016), or by occupying spaces that can be used for knowledge sharing. In this process, innovative tools and approaches can aid the learning process by creating interactions and discussions between learners and educators. Furthermore, for younger audiences, tools that enable the possibility of a hands-on experience can significantly enhance their learning experience (Mylonas et al., 2019).

READ approach was thought for hands-on education hoping to address some of the challenges of energy education. The purpose is to guide the construction of versatile solar-powered devices for renewable energy education, tied to a climate change context, through the form of art and design. The approach is based on customizable structures that can be easily deployed through fusion deposition modelling (3D printing). Moreover, READ promotes the use of electronic parts based on their availability and ease of assembly, aiming to lessen the time spent building the models, which makes READ suitable for discussions on topics other than renewable energy or climate change, such as art, design, electronics, electricity, and computer science.

MATERIALS AND METHODS

READ approach is intended for rapid implementation, having clear goals for each development stage, following principles taken from system engineering (Wasson, 2015). The approach dialogues with subjects such as electronics, additive manufacturing (i.e., 3D printing), and computer programming. **Figure 1** illustrates the steps taken to develop the approach.

For coherence purposes, the remainder of this discussion follows the steps listed in **Figure 1**.

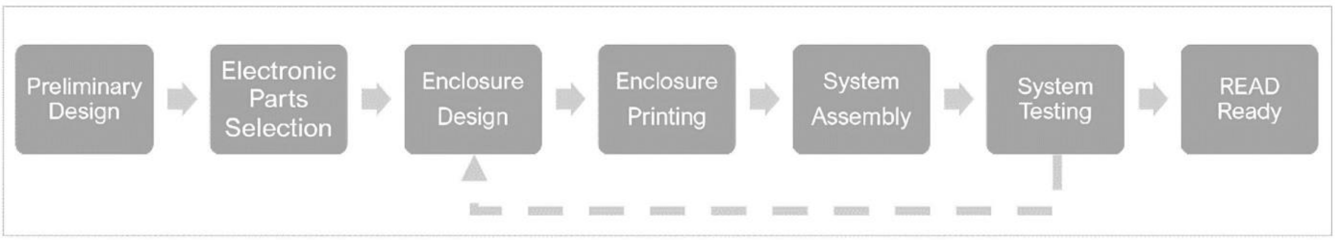

Figure 1. READ approach (Source: Authors' own elaboration)

Table 1. List of electronic components used in READ models

Function	Component	Function	Component
Power source	0.5 V-400 mA solar photovoltaic cells	Control unit	Adafruit gemma M0
Energy storage	Lithium batteries: 3.7 V & 500 mAh	Light	Adafruit mini LED light
Change controller	Solar battery charger	Sensor	Light sensor-

Preliminary Design

The preliminary design phase began with the definition of the main educational purpose of READ device. (e.g., the functioning of PV systems or the importance of renewable energy for lowering the impacts of climate change, etc.). In this step we also defined the learning outcomes and the form of student engagement, opting to maximize the hands-on experience for the students, who should be able to describe and understand the outcomes of the approach–the renewable energy-powered educational devices (READ systems, or READ tools), and the functioning of the educational tools. In our case, since the goal was to use READ system to teach students about solar PV energy, the preliminary design followed the logic of PV systems as described by Brownson (2013). Finally, we developed the concept of the operations of READ systems.

Electronic Parts Selection

Following the preliminary design step, READ approach moved towards more practical steps, beginning with the selection of the electronic components. We selected the electronic parts based on requirements such as:

1. **Affordability:** Low-cost sensors and other electronic components were preferred to minimize the cost.
2. **Availability:** We preferred components available for purchase in multiple stores (or e-stores).
3. **Easiness of integration:** We preferred components that were relatively easy to integrate with the remaining parts of the system.

We included the first two items to ensure that the replicability of READ approach. Since we want READ to become a tool for renewable energy education, minimizing the cost and using parts that are relatively easy to find might facilitate the adoption of the approach. Moreover, since the system operation, rather than the system assembly, is the focus of the approach, we opted for a relatively easy assembly process. Finally, we required the system to run for about three hours without sunlight (provided the battery was fully charged). To achieve that, we had to consider the power consumption of the electronic parts of the system and choose a battery capable of delivering the power needed for the system to operate according to the expected running time. The three-hour of system runtime was agreed upon based on the anticipation that at some point we would expect to showcase READ approach, which could potentially involve indoor environments.

The electronic components used in the development of READ approach are listed in **Table 1**.

Enclosure Design & Printing

Once defined the size and type of the electronic components are, the next step in the process was the design of the enclosure for the electronic components. To assist with the design process we used Autodesk Fusion 360, a computer-aided design (CAD) modelling tool, due to its reasonably smooth learning curve, high-quality outcomes, and the fact that Autodesk provided free access to the tool for educators. The tool can also render the design, enabling us to have a fairly accurate sense of the physical shape and general aesthetics of the models.

After we concluded the digital design of the models, we used fusion deposition modelling (aka 3D printing) for prototyping since it's a relatively fast and affordable way to create physical designs; 3D printing enabled us to print multiple versions of the models in a matter of hours, thus adding flexibility to the design process (easy to reiterate through the steps, if needed). We used the Ultimaker Cura software to translate the digital CAD design to the 3D printing file format (a process known as "slicing") and the Crealty CR-6 SE 3D printer for prototyping the models.

System Assembly & System Testing

As the name suggests, the system assembly and the system design phases are related to the testing of the physical models. In our case, this phase happened more than once since often the models required further adjustments that could not be captured in earlier stages. Thus, the steps were an opportunity to refine the design of the tools. The two phases proved to be a valuable opportunity to ensure that the initial requirements set in the previous steps of the approach were met (such as the system running time, for instance) and that the parts fit together. Both the system assembly and the system testing phases were valuable teaching opportunities, as will be further discussed in the following section.

RESULTS AND DISCUSSION

Preliminary Design

During the preliminary design phase, we developed the concept of operations of READ systems, based on the initial considerations (and requirements), as shown in **Figure 2**.

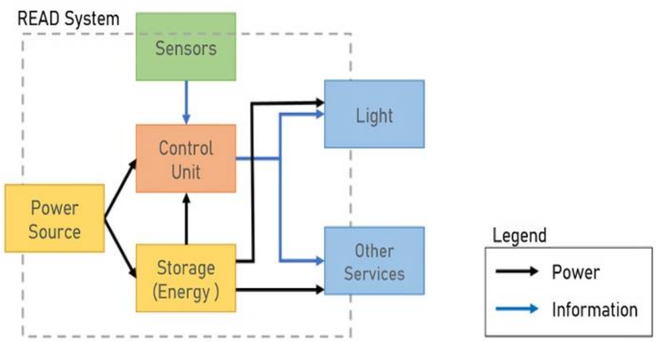

Figure 2. READ concept of operations (system remains flexible, other services can be incorporated later, if needed) (Source: Authors' own elaboration)

The systems were composed of five main blocks: a power source (PV cells), sensors (mainly light sensors), control unit, storage (battery) and services (mainly light). As shown in **Figure 2**, the control unit and battery were designed to be completely enclosed within READ systems, while sensors, the power source, and services are located at the interface between the systems and their surroundings. We purposely have a box labelled "other services" in our concept of operations, representing electronic components other than light that could be incorporated into the system at a later stage, if needed–thus we designed with flexibility in mind.

It is worth mentioning that the preliminary design step was developed with the students rather than for the students. Thanks in part to the fact that the university has an undergraduate solar energy club, we connected with the students in this club and invited them to engage in the development of READ systems after we had our goals defined. The feedback we heard from these students was that having clearly defined goals and expectations, contributed to their understanding of what they were supposed to achieve, and the importance of their participation. We noticed that the responsibility of being part of the development of the project encouraged the students to proactively participate in the remaining steps of the process.

Electronic Parts Selection

This step of READ approach served different purposes. First, at the beginning of this step, we developed a timeline for developing READ systems (and the remaining steps of the approach)–a necessary step that would likely fit better with the previous stage of the approach. Second, since the students were not familiar with electronic components, this step proved to be a valuable opportunity to engage in discussions about the functioning of the electronic components and their role in the system's operation.

It is worth mentioning here that our meetings with the students were not solely based on discussions. Although we tried our best to form a cohort of people (students and instructors/researchers) to co-develop the approach, we could not escape from exposition entirely. We would begin our meetings with a short presentation to the students, followed by mixing instructors with the students. We noticed that, despite allowing time for questions after the short presentations, most of the questions (and often the more complex ones) would rise when instructors and students were sitting at the same desk, discussing the subjects of interest. Nevertheless, we noticed that the short presentations were valuable to provide the foundation for the discussion that would follow.

We also noticed that the participation of individual students in the discussions varied according to the topic. We realized that this was simply related to the personal interests of the students, thus, for instance, while some students were very interested in the design portion of the approach, others were more interested in programming the control unit, while others still demonstrated higher interest in assembling the system. Although we needed to discuss all the aspects of the approach with the whole group, we respected personal choices and let the students be free to choose their focus of interest in the approach. This also highlights the flexibility of READ approach, which can be used beyond renewable energy education, to facilitate the learning of subjects such as electronics and computer programming.

Finally, since the electronic parts selection step is relatively time-intensive, we suggest that this step is better suited for longer courses or interactions. For shorter courses, the educators could, for instance, mention the importance of this step to the performance of the system and spend more time on the system assembly or system testing phases.

Also, the parts listed in **Table 1** should be seen as a reference; other combinations of electronic components could be more appropriate depending on the services that READ systems are expected to provide.

Enclosure Design & Printing

This step proved to be another valuable opportunity for collective learning and knowledge sharing, although we could not develop it entirely with the students due to the limited time we had on our weekly meetings (around three-four hours per week during one semester). Therefore, the designs were developed by the instructors and refined with the entire cohort. Still, the discussions around CAD modelling and 3D printing motivated some students to raise questions and engage in learning about the materials and methods used in this step of READ approach.

Similar to the previous step, the enclosure design and printing phase are recommended for longer interactions since it can be expected that a series of iterations (i.e., redesign and re-prototyping) are required to improve the models.

System Assembly & System Testing

Figure 3 shows a READ device inspired by the firefly insect. During the assembly of the devices, the instructor only intervened when needed and worked collaboratively with the group either by participating in the assembly process or by making comments or questions that enabled group thinking on the subject.

Depending on factors such as the educational focus and the age of the participants the discussions at this stage of the process can be focused on the technical or theoretical aspects of the systems (e.g., the system components and their

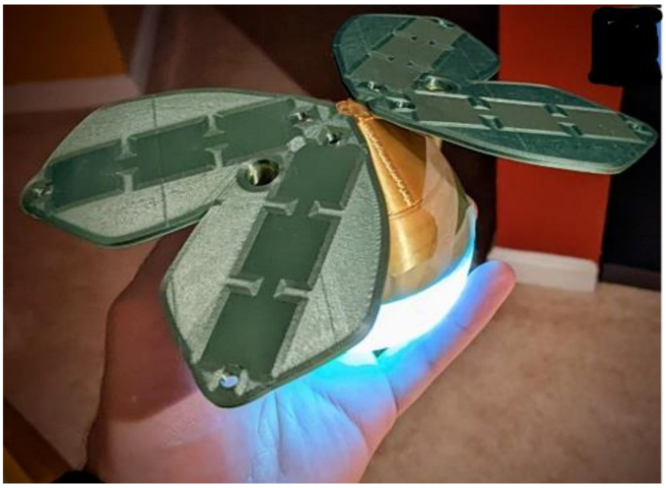

Figure 3. A READ device inspired by firefly insect being tested in a low-light environment (Picture taken by Paulo Soares)

functions or the physics behind the components and their interactions). The depth of the discussions around the specifics of renewable energy and climate change, for instance, should be adjusted according to similar criteria. In another example, depending on the goal, the learners could actively program the system processing unit, or it could come to them pre-programmed. Independent of the depth of discussions or the level of complexity around the system assembly, it is crucial to engage the audience in the testing of the system, motivating them to think critically about the operation of the device.

We did some relatively simple exercises to test the systems, such as testing PV system response to sunlight and the system runtime. The latter was conducted by assembling the devices, then completely charging their batteries, and leaving them working without any other source of power. We also included in our discussions topics such as UN sustainable development goals (UN, 2019), to highlight the importance of renewable energy in the context of climate change. Although this could be done at any (and each) step of the approach, we noticed that the conversation was richer once the students completed the system assembly.

Although READ approach was originally envisioned for longer interactions, such as a semester-long course, it can be adapted according to the audience and time availability. For instance, when working on shorter workshops, courses, or even single classes, it is possible, for example, to minimize the time spent assembling the systems (by pre-assembling the system or parts of it) and focusing on the operation of the devices, thus skipping most of the steps of the approach while still using the tool to facilitate discussions and knowledge sharing.

We noticed that the most complicated part of this step was the construction of the solar panels due to the brittleness of the raw solar cells and the delicate tabbing process. Such a complication can be avoided by opting for pre-assembled solar panels, without compromising the experience.

Finally, we also noticed that the art component of READ approach contributed to disarming people from any fear or negative feeling they might have related to the more traditional STEM subjects. Therefore, the art and design elements are foundational for making READ approach an inclusive educational tool.

CONCLUSIONS

This study described the development of READ approach and discussed its implementation. The approach was co-created in a university setting in the United States by a cohort composed of undergraduate students and researchers/instructors. During the semester-long interactions, the members of the cohort were encouraged to explore the various topics being addressed while having the autonomy to focus on a certain topic, such as system design or electronics. The hands-on experience provided by the approach is likely to facilitate learning about renewable energy generation and related subjects.

READ approach was devised within the context of renewable energy and climate change, with an explicit effort to break with the aesthetics paradigm as much as possible, playing with forms and shapes, to make READ tools resemble the elements found in nature, such as the North American flower Laurel, and the firefly insect. By explicitly including art and design as crucial to the approach, it is anticipated to generate curiosity and invite more participants to the act of knowledge creation and sharing.

Moreover, educators can customize the design according to their teaching focus. For instance, one could focus more on the power side, using different combinations of lights or batteries to show the effect on the system's performance. One could also use READ to enable discussion on energy efficiency and computer programming, exploring the intersections with other areas of knowledge. Therefore, READ devices are versatile educational tools, in line with the need for training professionals versed in renewable energy generation, and who can understand the systemic connection between energy and the challenges that our society is facing.

In terms of cost and anticipating that READ devices could be adopted by educators located in various countries, where cost might be a limiting factor, the device cost was kept as low as possible also considering that parts should also be easy to integrate to minimize the assembly time.

In summary, READ approach reached its goal of providing a path for renewable energy education through solar-powered educational devices. The resulting systems were successfully tested and displayed at a local gallery exhibition. READ also was awarded in the International Design Competition under the category of Education for Social Change.

Finally, READ approach will continue being tested and refined with diverse participant groups for the development of metrics to quantify its effectiveness for energy education.

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