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Teaching Appropriate Technologies with the Applied Mechanics approach to sensitize students to their future role in environmental sustainability and social justice

Walter Franco [0000-0002-0783-6308]

Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Turin, Italy
walter.franco@polito.it

Abstract. Historically, the engineering courses tend to emphasize the purely technical aspects, reinforcing in students the idea of the duality between technology and society. Appropriate Technologies (ATs), being designed starting from the needs of specific communities, can vice versa help students understand their future role in terms of environmental sustainability and social justice. The paper describes the experience of teaching ATs with the Applied Mechanics approach at the Politecnico di Torino.

Keywords: SDG4, Engineering Education, Industrial Design Education, Humanitarian Engineering, Development Engineering, Social Impact.

1 Introduction

A common approach in teaching engineering derives from the idea that the engineering profession consists exclusively or almost exclusively in making technical decisions regarding technical artifacts [1]. Some definitions of *engineering* confirm this thought. For example, according to the Oxford Dictionary [2] engineering is "the activity of applying scientific knowledge to the design, building and control of machines, roads, bridges, electrical equipment, etc.", and for Passino [3] "the use of science and mathematics to invent, create, design, develop, improve, modify, or apply technologies". The engineering courses thus tend to emphasize the purely technical aspects, making students forget that technologies are developed by people for people, that they have important environmental and social effects on communities, and are in turn influenced by the community for which they are intended.

Among the factors that make the connection between engineering and society invisible are: *(i) unwritten assumptions* that usually underlie the teaching of engineers, such as the fact that the natural job outlet is a large company or civil/military organization, which are to be privileged high-tech solutions [4]; *(ii) mindsets*, such as the myth of objectivity, the definition of problems in narrow technical terms, an uncritical acceptance of authority [5]; *(iii) ideologies*, such as technical/social dualism and depoliticization due to the idea that artifact are neutral [6]; *(iv)* lack or inadequacy of *methods for social impact consideration* [7].

Nevertheless, technology and society are inevitably, intrinsically, and profoundly intertwined and influence each other [8]. Technology is neither neutral nor neuter. Some artifacts even have politics [9], that is, they are capable of directly and independently influencing the relationships between individuals by disposing power and authority to certain categories of people. For example, a bridge designed and built without providing a cycle-pedestrian lane will favour motorists to the detriment of cyclists and pedestrians. Furthermore, many technologies are not gender-neutral; on the contrary they are masculine, oriented towards the total control and manipulation of nature -think, for example, of geoengineering- and they cannot be used in a feminine way without substantial and appropriate revisions [10]. From these simple examples, it is clear that the interconnection between engineering, environmental sustainability and social justice is very close and articulated, and in engineering education this fact should not be ignored.

To bring out this complexity in engineering studies, some propose the introduction of human sciences courses in the curricula of future engineers [11]. The aim is to provide students with basic tools for understanding environmental and social implications due by the application of a defined technology, with particular attention to the development of their critical thinking.

Furthermore, it is important to remember that at least since the 1970s there has been an ongoing debate on the fact that given a need, there is no single adequate technological solution from economic, environmental and social point of view, i.e. that the deterministic model of technology should be questioned. Assumed the social and environmental implications of the technology, it is conversely necessary to pay particular attention to the *technology choice*, which from time to time depends on the contexts, the communities and the relative values [12]. The concept of technology choice implies that: (i) there is almost always a wide range of alternative technological solutions suitable for satisfying the primary requirements within a given context; (ii) the number of alternatives grows over time thanks to conscious design processes; (iii) the various alternative technologies identified as suitable for achieving the primary objectives may satisfy the secondary objectives in a significantly different way or even fail to satisfy them; (iv) the choice of technological solutions deriving from the in-depth evaluation of both the primary and secondary objectives, combined with the conscious planning activity aimed at expanding the range of possible alternatives, is a fundamental element of social, economic and environmental policy [12]. A technology developed as part of a correct process of technology choice by a specific community in a specific place and period can be defined as *Appropriate Technology* (AT).

In *general*, an AT is a technology tailored to fit the psychosocial and biophysical context prevailing in a particular location and period [12]. Depending on the contexts, in the literature it is declined in specific ways, and takes on different names, including: intermediate technology [13], community technology [14], convivial tools [15], humanitarian technology [3, 16].

In addition, ATs developed starting from the basic needs of all people of a community, especially in marginal, underserved, disadvantaged, poor conditions, or in sober socio-ecological transition experiences, must meet at least the following *specific* requirements:

(i) psychological, social and cultural: for example, being pleasant to use, controllable by the community, employing local skills, strengthening social cohesion, being compatible with the culture and practices;

(ii) environmental: among others being environmentally and ecologically sound, preferably using renewable energy rather than fossil fuels, having high energy efficiency, being parsimonious in the use of material resources, especially if they are non-renewable;

(iii) cheap: being affordable, requiring low capital investment, having a high employment potential, using local economic resources;

(iv) ease of construction, use and maintenance: being simple to build, maintain, operate, being durable and requiring little maintenance.

From the general definition and the specific characteristics of ATs, it is clear how their teaching can be intrinsically suitable for promoting reasoning within the classes of students on the role of engineering knowledge in the design of technologies in terms of environmental sustainability and social justice of communities.

For some time now, various bachelor's and master's degree programs and individual courses in appropriate technologies and humanitarian engineering have been offered in world universities. At the University of Warwick since 1980 an engineering degree course entitled Engineering Design and AT has been activated, "with the main assumption that technology should be appropriate…implying that engineers should be primarily concerned with the social objectives, and they then acquire and use technical skills in order to achieve them" [4]. Hazeltine et al. have taught ATs at Brown University since 1980 with the aim of "increasing student's analytical ability, their understanding of the contemporary world, their confidence in dealing with complex problems and their ethical and aesthetic sensitivity" [17]. The integration of humanitarianism in engineering education in Australasia is recorded as a phenomenon in the early 2000's, growing from 2007, where "Humanitarian Engineering is taken as the application of an engineering discipline, such as civil or mechanical, to a specific humanitarian or development context or response" encompassing "a wide range of contexts and locations, from disaster response through to community and technology development, both internationally and domestically " [18]. Important engineering programs are also noted at the University of Colorado Boulder [16] and The Ohio State University [3].

At the Politecnico di Torino, the teaching inherent to ATs has a long tradition, especially in the field of Architectural Technologies. Already in 1989, under the guidance of prof. Ceragioli, the School of Specialization in Technology, Architecture and City in Developing Countries was founded [19]. Currently, an AT and Low-Tech Architecture course is offered to architecture students [20]. Both locally and at the Italian level, research and teaching in the field of ATs seen from the point of view of functional mechanical engineering is less usual. About ten years ago, a research group of functional mechanical engineers, called Appropriate Machines Laboratory (AMA-Lab), was born at the Politecnico di Torino. AMALab deals with the development of appropriate devices, mechanisms and machines. Various educational initiatives have then arisen from his research activity.

The purpose of this work is to present some of the teaching activities and experiences carried out at the Politecnico di Torino in the field of ATs, declined with a typical approach of Applied Mechanics, and aimed at improving the students' awareness of their future role in environmental sustainability and social justice. First, the expected learning outcomes and topics of two AT individual courses are described, aimed respectively at students of Energy Engineering and Industrial Design. Subsequently, some details are provided, in particular on the applied lectures/activities specific to each course.

2 Functional mechanics-based courses dealing with ATs

Since 2022, two not mandatory individual courses concerning the study of ATs have been available at the Politecnico di Torino. The teachings, while presenting multidisciplinary characteristics typical of the subject, base their foundations on the tools of analysis, modelling and design of Applied Mechanics.

The first course, *Technologies for Sustainable Development*, is included in the third year of the Bachelor's degree program in Energy Engineering. The second course, *Humanitarian Engineering*, is aimed at third year students of Bachelor's degree program in Design and Communication.

Both courses, although intended for students of different faculties, present similar expected learning outcomes and topics, adapted from case to case. The courses describe and analyse the main ATs of humanitarian engineering, aimed at satisfying the basic needs of people, especially in marginal, under-served, disadvantaged or sober socio-ecological transition communities and territories. The basic tools are provided to understand and develop, starting from the analysis of needs, simple, small-scale, energy efficient, environmentally sound and controlled by local communities technologies, capable of improving the well-being of the citizens of a specific territory with a view to social inclusion, social cohesion, and environmental sustainability.

The main expected learning outcomes of both the courses are:

(i) Knowing the main energy systems suitable for serving small communities and territories in marginal conditions.

(ii) Knowing and understanding the functioning of the different ATs aimed to the inclusive and sustainable development of communities and territories.

(iii) Knowing and being able to employ the fundamentals of Applied Mechanics for the functional design of appropriate machines.

(iv) Knowing and taking into account cultural, social and environmental needs in choosing and implementing a technology to solve a problem in a specific context.

(v) Knowing how to use shared design techniques aimed at improving the well-being of citizens, communities and territories, particularly in conditions of marginality or poverty, or in socio-ecological sober transition.

As for the contents, the main topics, some of which deriving from research activities of the teachers, are:

(i) *Fundamentals*: definition, brief history, and main requirements of appropriate and intermediate technologies; appropriateness assessment.

(ii) *AT design methods* [21]: man at the centre of the project [22]; needs based design; grassroots innovation; informal innovation; technological hybridization; retro-innovation; re-design; co-design; participatory design; co-production; open source platforms for sharing solutions.

(iii) *Energy and prime movers for small communities in socio-ecological transition*: human and animal power and mechanical characteristics of animated engines; biomass energy; small domestic digesters; hydraulic energy: water wheels, mills for grinding [23], saws and hydraulic hammers [24]; wind energy: small wind turbines, wind pumping systems; solar energy: solar cookers and ovens.

(iv) *Mechanics of appropriate machines*: elementary machines; systems and components for motion transmission and transformation; systems for multiplying force or speed; efficiency of intermediate machines [25]; bicycle mechanics; mechanics of animal-drawn machines.

(v) *Appropriate tools, devices and machines*: examples and applications of AT and appropriate machines for small scale agriculture, food conservation and transformation, housework, wood and metal working, self-construction in raw earth [26, 27] and in straw [28, 29].

The two courses have some peculiarities, described in the following sections.

3 Technologies for Sustainable Development

The course, attended by about 120 students of the Bachelor's degree program in Energy Engineering, includes both theoretical lectures on the topics described above (20 hours) and applied activities consisting in a macro-project exercise to be carried out in groups (20 hours for each team).

The lectures, being addressed to engineering students, have both descriptive and analytical contents. Various functional mathematical models of the ATs are taught; students can then use them as a design tool in the macro-project, for example with the support of simulation software such as Matlab/Simulink: functional models of animated engines, micro wind turbines, water wheels, mechanical transmissions, users, such as special hydraulic pumps (hammer pump, spiral pump), millstones, hammers.

The macro-project exercise instead consists in the development of a design of a specific case study, different from year to year. In a first brief conducted by the teacher, the historical, social, cultural, productive, technological and environmental context of the development of the technology is described; the target, the location, production and maintenance, background, motivations, specific objectives, timing and costs are defined. For example, a team of students was invited to work on pedal human powered machines, appropriate for people who live in disadvantaged communities and territories, to carry out agricultural work in the field or in the post-processing of food. The choice of cycling technology is motivated by simplicity, cost-effectiveness, diffusion and availability of components, dissemination of knowledge on assembly and maintenance, adaptability to co-design and co-production techniques. Each team is then called to make an initial benchmark and comparison between five possible solutions, identified among concepts, projects, products, self-built solutions available in the scientific literature or on the web. Of the five case studies, the most significant is chosen, on which a detailed analysis is made, including the development of functional models, for example of the animated engine, of the power transmission and of the driven systems. Subsequently, starting from the critical issues emerged in the analysis phase, the guidelines and the concept of an improvement solution are defined. Finally, a preliminary functional design of a new solution is carried out. Any team project is presented and discussed in classroom. By way of example, a team dealt with the optimization of the mechanical transmission of a pedal powered cassava peeler for Brazilian agricultural communities, evaluating the influence of the transmission ratio, transmission efficiency, peeling cylinder dimensions, mass of cassava processed versus the power supplied by the operator (Fig. 1).

Fig. 1. Model of pedal powered cassava peeling machine. Courtesy of Giovanni Artioli, Cesare Barbera, Matilde Cais, Flavia Colì, Pietro Ghibaudo and Serafini Emma students.

4 Humanitarian Engineering

The course is part of a larger atelier, Design for Social Impact, made up of two other teachings: Social Design (skills in the area of industrial design) and Social and Solidarity Economy (skills in economics). Overall, the atelier aims to prepare students of the Bachelor's degree program in Design and Communication to exercise a role and function within multidisciplinary groups and in the context of complex processes aimed at promoting, facilitating, accompanying and monitor interventions and transformations in the social and sustainability fields.

Also the Humanitarian Engineering course, attended by about 30 students, includes both theoretical lectures on the topics described in section 2 (20 hours) and an experimental design/self-construction laboratory to be carried out in teams (10 hours).

The experimental laboratory consists of a brief in which the topics are identified, which differ from year to year, and a general design phase. The students must then self-construct the identified solutions in groups, using low-cost recycled material, with the circular reuse mood. By way of example, Fig. 2 shows a bicycle-blender for the recovery of paper/cardboard materials in the form of papier-mâché pulp and a parabolic solar oven, both designed and realised by the students.

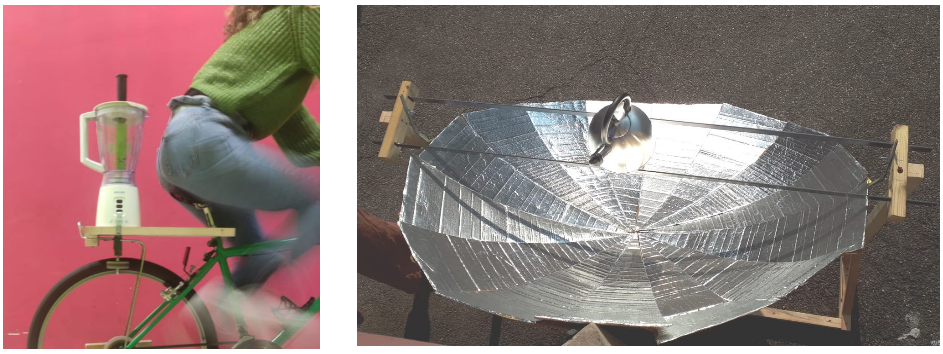

Fig. 2. Bike-blender and parabolic solar oven built in the experimental laboratory.

5 Conclusions

The experience of teaching TAs conducted at the Politecnico di Torino, using an approach derived from functional mechanics, has demonstrated to be valid in providing students with tools to understand their future professional role in the field of environmental sustainability and social justice. Unlike what happens in traditional engineering courses, which are often taught as if technology were a matter in itself, detached from the contexts, in the courses covered by this article students are guided to think about the appropriateness of a technology for a specific community, becoming aware of the fact that technologies and societies are mutually influenced.

The high number of students who freely choose the courses, and the positive judgments collected in the anonymous evaluations at the end of the courses, encourages us to move forward with the development of this teaching approach.

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