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Perspective

Active Learning, Living Laboratories, Student Empowerment, and Urban Sustainability

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Abstract: In schools and universities, we instructors carry the responsibility of informing and inspiring students. Traditional and more theoretical educational programs (here referred to as passive learning) may be tied to projects and activities (active learning), in which students gain hands-on practical experience with planning, development, implementation, maintenance, and presentation of different solution-focused activities. Complementary to passive learning, the needs for active learning activities and living laboratories have become more pertinent as global trends, such as climate change, weigh heavily on the shoulders of young people. Unless properly guided and given tangible sources of inspiration, the sense of being overwhelmed and incapable of effectively contributing to a more sustainable future may cast a dark shadow over students, their ability to engage in active learning, and their long-term career aspirations. Schools and universities are being evaluated for their "greenness". Accordingly, operational improvements (carbon, water, waste, and nutrient footprints) to meet sustainability targets are being implemented. Structural sustainability improvements represent unique opportunities for students and instructors to engage in active learning. As a broader message to school and university administrators, it is argued that efforts to plan and implement sustainability initiatives should also involve transformations of educational curricula. It is argued that educational institutions could and should be more than sums of buildings and infra-structure and represent living laboratories. Descriptions of topics taught, learning outcomes, and links to examples of student assignments of a specific course, Urban Food and Society, are included and discussed in the broader contexts of urban food sustainability and active learning. The main purpose of this article is to promote the notion that active learning activities and the need for improved sustainability of schools and universities can go hand in hand and provide compelling educational opportunities.

Keywords: sustainability; urban food production; education; active learning; higher education; living laboratories

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1. Introduction

In schools and universities, and throughout educational systems more broadly, we instructors carry the responsibility of informing and inspiring students. In one of his thought-provoking TED Talks, Sir Ken Robinson described this beautifully as the difference between teaching and learning [1]. Moreover, we instructors must expose students to basic information and knowledge in ways that stimulate and create climates of learning. Learning may be characterized as having two overlapping, "passive" and "active", components (Figure 1). Accordingly, passive learning may be viewed as conventional classroom teaching, in which students are exposed to information and taught concepts and theories. Active learning is the process of "doing something" with that acquired knowledge and/or in different ways conceptualizing or actually testing its meaningfulness and use as solutions to societal challenges. Thus, active learning outcomes have a strong focus on student engagement, collaboration and group work, interdisciplinary and generative learning activities, dialogue and discussions, student empowerment, student-driven initiatives and decision making, and practical real-world activities [2–5]. A number of other terms are used to describe similar educational approaches, including [2,6–8] interactive engagement, flipped learning, collaborative learning, flipping the classroom, service learning, and problem-based learning. It has been argued that active learning is lacking in higher education [2]. The term "living laboratories" has been used when such active learning activities involve collaboration with companies, citizens, and non-profit and government organizations [9]. It has been highlighted how the needs for active learning and living laboratories are critical as societies transition from being production-based to being composed of knowledge- and information-based enterprises [10]. Giesenbauer and Müller-Christ [11] stated that there will be a growing need for transdisciplinary research and research-based learning at universities to find solutions to sustainability and socio-economic challenges. Several articles describe educational applications of living laboratories in higher education [12–14].

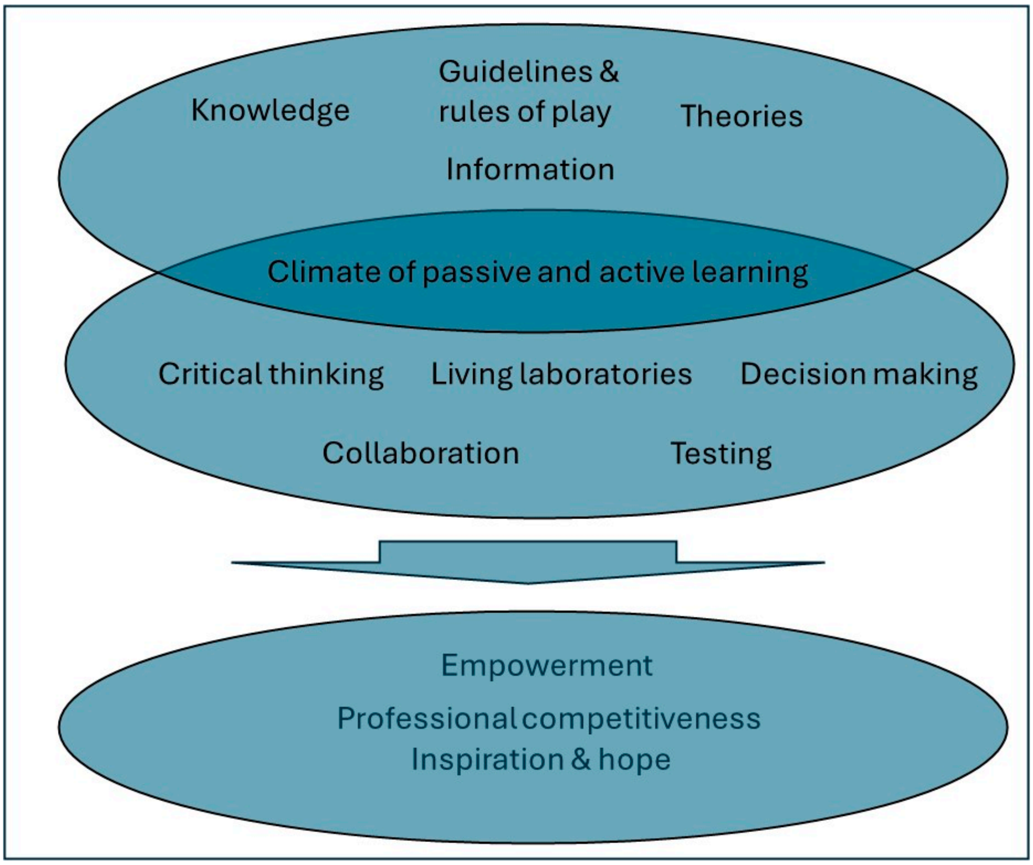

Figure 1. Conceptual definition of passive and active learning. Higher education is presented as a function of passive and active learning. This combination of passive and active learning is predicted to promote student empowerment and success in job markets, and it is predicted to reduce climate anxiety and mental health issues.

The establishment of learning climates and learning outcomes that encourage creativity is an important part of active learning [15]. An analogy to the proposed concept of passive and active learning is handing students a bag of LEGO blocks and providing them with an opportunity to build their personalized structures based on guidelines. Active learning is also about being willing to take risks and overcome barriers of insecurity and discomfort with the unknown. This can be achieved by diminishing notions of failure and viewing learning as a form of play. In science, education has been beautifully described as follows [16]: "*When one adds rules to play, a game is created. This is science: the process of playing with rules that enables one to reveal previously unseen patterns of relationships that extend our collective understanding of nature and human nature. When thought of in this way, science education becomes a more enlightened and intuitive process of asking questions and devising games* *to address those questions*". It should be pointed out that some studies have identified partial resistance among students to active learning [17]. Other studies have demonstrated how active learning may be used to mitigate important achievement gaps for under-represented students [5].

Here, it is argued that the needs for active learning environments and living laboratories in schools and at universities have become more pertinent as global trends, such as climate change, weigh heavily on the shoulders of young people. Published data support claims about such global trends triggering anxiety and other mental health issues, and some authors argue that the young and youth (aged 10–24 years and 15–24 years, respectively) represent particularly vulnerable portions of human demographics [18,19]. Terms such as eco-anxiety and climate change anxiety are becoming recognized by mental health experts and used to describe emotional responses to climate change [19,20]. It is therefore paramount that education, through active learning and living laboratories, gives tangible sources of inspiration and provides a strong sense of empowerment and the ability to drive change. Otherwise, students may feel overwhelmed and incapable of effectively contributing to a more sustainable future, and that may cast a dark shadow over their ability to engage and over their long-term career aspirations.

2. Sustainability Rankings of Universities

It has been argued that higher education institutions can and should serve as models for sustainable practices and societies [8], but students may be unaware of an institution's sustainability footprint [12]. To serve as models, it is important to look beyond what is going on in classrooms and laboratories at higher education institutions. The University of Indonesia ranked 1183 universities from 84 countries based on 39 criteria related to the sustainability of infrastructure, energy and climate change, waste treatment and recycling, water, transportation, education, and research [21]. University of California Davis, with the nickname the "Aggies", is the highest ranked university in the US and fifth in the world [22]. Additionally, University of California Davis has a high international ranking within the broadly defined area of agriculture [23]. Thus, sustainability of food production is a common and important theme across teaching, mentoring, and research in many departments. However, it appears that there is tremendous potential for further promotion of sustainability at higher education institutions at this university and more broadly.

Examples of Active Learning Challenges with a Focus on Sustainability

The following specific suggestions are drawn from what could be done at University of California Davis and other universities as ways to improve sustainability and as possible active learning activities to engage students: (1) Ways to effectively use cow manure from veterinary schools in conjunction with food waste from dining halls to produce natural gas to run campus busses and other vehicles. (2) The roofs of lecture halls, laboratories, and administrative buildings could be converted into roof gardens to produce the food served at the campus restaurants. (3) Water catchment systems could be developed to capture rainwater from a wide range of buildings and structures and used to automatically irrigate (based on soil moisture sensors and weather models) landscapes and athletic fields. (4) "White 2.0" is the most reflective commercially available paint, and it could be painted onto roads to increase heat reflection and lower temperatures. Thermal monitoring could be installed inside and around buildings to gather temperature data for modelling of the impacts on the air conditioning efficiency of buildings and outdoor ambient temperatures. (5) Innovative building materials and multi-species designs [24] could be developed to both produce energy (solar panels) and minimize the use of energy for temperature regulation inside buildings. (6) Renewable materials, like cork, can be used to increase the energy efficiency of buildings, and can be used in the production of electric vehicles and in many other innovative and sustainable applications [25]. (7) The development and testing of different approaches to "green walls" and living buildings [24,26,27] could be promoted. (8) Development of urban architecture in which conservation and biodiversity are incorporated into the very fabric of household structures [24]. (9) Phone apps could be developed to connect students and community members facing food insecurity with kitchens (i.e., dining halls) and other resources to mitigate economic and social inequalities. These examples fall under the umbrella of living laboratories and represent an approach to education in which active learning is at the forefront.

3. A Course Curriculum—Urban Food and Society

An existing course, entitled Urban Food and Society, is described with the intention of providing specifics and inspiration to instructors. The course syllabus was developed as an attempt to address four converging challenges, which affect university students both directly and indirectly: (1) Urban development and food production being in conflict, and some cities having designated "food deserts" [28,29], in which people have increased health risks [30,31]. (2) Poor nutrition, lack of exercise, and obesity are realities affecting many people, especially in urban environments [32]. (3) Pollution and resource mis-management in cities arise from accumulation of waste, because of poorly developed recycling of nutrients, water, and energy. (4) Many students want to "change the world" but feel powerless about the looming consequences of climate change. The course is intended to enable students to reflect on and discuss research efforts and societal solutions to mitigate all four challenges. International examples are included to underscore the importance of viewing sustainability through a global prism. This course is part of an interdepartmental teaching program, entitled Science and Society [33], which offers students opportunities to discover connections that link the social, biological, and physical sciences with societal issues and cultural discourses.

Table 1 outlines the course schedule. Students attending this course (about 40–50 students) major in a wide range of disciplines, and the course is delivered with two weekly 80 min lectures. Students submit weekly reviews of reading assignments and class discussions as either written reports (minimum of 400 words) or as 3–5 min videos. The course syllabus, learning outcomes, and examples of students' short video assignments (with permission from students) are available online [34]. Both written reports and videos are graded based on five criteria: (1) description of the general topic discussed that week, (2) main findings/results/conclusions from reading assignments, (3) summary of and take-aways from class discussions, (4) ways and reasons the weekly topic relates to what students are interested in as part of an academic career path, and (5) brief discussion of a different but related scientific article. The following topics are discussed in this course.

Table 1. Urban food and society—lecture schedule.

Lecture #	Lecture Topic	Reading Assignment
1	Course introduction	Course syllabus
2	Scientific approaches	Instructor notes
3	Sustainability concept	[35]
4	Climate change and news and opinion	[36,37]
5	Env. footprint of food production	[38]
6	Env. footprint of food production	[38]
7	Climate change and food security	[39]
8	Households and carbon footprint	[40]
9	Food strategies and UN's SDGs	[41]
10	Food strategies and UN's SDGs	[41]
11	Urban farming yields	[42]
12	Urban farming and food production	[43]
13	Urban water footprint	[44]
14	Urban water footprint	[44]
15	Re-thinking food waste	[45]
16	Urban farming and GHGs	[46]
17	Urban systems—the Plant	[47]
18	Urban systems—European analysis	[48]
19	School of food	[49]
20	Nutrition and home cooking	[50]

"UN" refers to United Nations, "SDGs" refers to sustainable development goals, and "GHG" refers to greenhouse gasses. Accompanying reading assignments for lectures are referenced.

3.1. Science versus Opinion

A major challenge, especially for young people, is to process, interpret, and filter through the barrage of information available on social media, news outlets, scientific journals, etc., and from what they learn via discussions with family and friends. Accordingly, it is paramount for students to learn that research and innovation of sustainable crop production in urban environments must hinge on a basic understanding of science principles, such as hypothesis-driven experimentation, experimental designs, quantitative data, and controlled and statistical analyses. Additionally, and for comparative contrasts, students are exposed to opinion-based news articles with opposing biases [36,37], and they are asked to identify and contrast these biases. From discussions, students are also exposed to the diversity of views among their peers, which are used to highlight some of the challenges we are facing when attempting to promote the implementation of sustainable solutions.

3.2. Food Insecurity and Climate Change

To mitigate the effects of climate change, the needs for higher levels of food production sustainability are virtually undeniable. Concerns about carbon, water, waste, and nutrient footprints as well as concerns about food safety and healthiness are key drivers behind the growing numbers of consumers opting for organic food [51,52]. Detailed economic analyses, mainly of European faming systems, support claims about organic food production being more profitable than conventional systems due to lower production costs and higher market prices [53,54]. However, Durham and Mizik [53] highlighted how a considerable portion of profit by organic farming systems (up to 20% of their income) is directly linked to different types of subsidies. Organic food is generally 10% more expensive than conventional food items [55], and it is important to recognize and discuss how the transition towards improved (urban) food sustainability may create unintentional socio-economic inequalities. Accordingly, a reading assignment is included, in which potential trade-offs between the need for climate change mitigation and risks of food insecurity are analyzed [39]. Based on six economic models and four climate scenarios, the authors demonstrated that there was an overall positive correlation between the risk of people facing food insecurity and implementation of climate policies [39]. Increases in food insecurity were predicted to be most severe in Asia, Africa, and the Middle East. There are possible ways to offset such increases in food insecurity via subsidies to growers [39] and via consumer incentives and food vouchers [39,41]. Students majoring in economics, political science, and social science attend the course, and their perspectives are of critical importance in discussions of how to not only develop but also implement initiatives that lead to enhanced sustainability of food production and food availability in urban environments.

3.3. Food Waste

One of the single most important challenges, and also one of the easiest to mitigate as part of promoting more sustainable food production and consumption, is the minimization of food waste. As a specific topic, food waste has been discussed in a wide range contexts, including the elimination of hunger [56]. Furthermore, food waste is a topic that students can relate directly to and also have almost complete control over in their daily lives. The reading assignment for these lectures quantified values of daily per capita food waste in 151 countries based on indicators of embedded nutrition losses and indicators for environmental impacts [35]. The authors provided staggering statistics on how and why food waste is a significant contributor to unsustainability and climate change; some quotes from the article include the following: "*Globally, on average, 65 kg of food is wasted per year by one person of which 25% is through wasted vegetables, 24% through cereals and 12% through fruits*" and "*The embedded environmental footprints in average person's daily food waste are: 124 g CO_2 eq., 58 Litre freshwater use, 0.36 m^2 cropland use, 2.90 g nitrogen and 0.48 g phosphorus use*". A highly innovative component of the author's analysis was their calculation of what is referred to as "Wasted Diet Days" (WDD). That is, the authors estimated the total food waste in individual countries, and they estimated the relative composition of food waste.

From that, they estimated the amounts of essential nutrients and calories being wasted, and they divided the food waste amounts by the minimum requirements for a person. From the statistics on population sizes in individual countries, the authors calculated the number of days for which populations in individual countries could be fed a healthy diet meeting the daily required nutrient intake of all 24 essential nutrients and calories. In some countries, WDD values exceed 40 (USA, Canada, and Australia), meaning the entire population in those countries could be fed a healthy diet for >40 days per year based on food waste alone! Of course, some of these countries also have elevated rates of food insecurity, which adds to concerns about high WDD values, and which is the topic of a separate lecture. The reading assignment describes global data, but the analytical approach used to calculate WDD values and compare countries can readily be applied at smaller geographical scales to separate dining halls on a campus or dormitories with their own kitchen facilities. At the high school level, it may even be possible for students to gather data from individual households. That is, the process of learning how to collect quantitative and repeatable (directly comparable) data on food waste, which assumptions need to be made, and how to analyze such data involves a reliance on theory, the deployment of creativity, and critical thinking, and will in many important ways lead to active learning. If oral, visual, or written presentations of results and possible solutions are added to assignments, then students are also acquiring critically valuable knowledge about and experience with communication. Furthermore, by taking an article describing global data and encouraging students to apply methodology to a small geographical scale (which is relevant to them), students are learning how published methods and analyses can be made applicable more broadly.

3.4. Environmental Footprint of Crop Production

It is emphasized to students that large-scale crop production (major crops such as wheat, corn, rice, soybean, and most fruits) is obviously necessary to sustain human populations, so some environmental degradation is inevitable. But a comprehensive and highly innovative analysis of global food production is used to highlight some remarkable spatial trends in the environmental footprints of crop production [38]. Moreover, Halpern, Frazier, Verstaen, Rayner, Clawson, Blanchard, Cottrell, Froehlich, Gephart and Jacobsen [38] calculated what is referred to as the cumulative (environmental) pressure, in which they quantified four pressures: greenhouse gas emissions × freshwater use × habitat disturbance × nutrient pollution. This exercise is in itself innovative, as the authors collected data from 151 countries. But a truly unique aspect to their analysis is that they mapped environmental pressures to 36 km^2 pixels of these countries. With this spatial mapping of environmental pressures, the authors were able to demonstrate the following: (1) land crop production far exceeds environmental pressures created by mariculture, (2) the relative importance of environmental risk factors varies among countries, and most importantly (3) nearly all pressures (92.5%) are exerted in just 10% of pixels. The latter result is of considerable importance for at least two reasons: (1) in some countries, crop production is possible with limited adverse environmental impact, so their crop production practices should be investigated and translated into adoptable practices in other countries, and (2) international collaboration could focus on reducing the adverse environmental impacts of crop production in those 10% of pixels, as that would have considerable global benefits. Moreover, rather than each country independently developing their own solutions, the planet would benefit comparatively more from focusing on "hot spots" with high degrees of adverse environmental impacts of crop production. Halpern, Frazier, Verstaen, Rayner, Clawson, Blanchard, Cottrell, Froehlich, Gephart and Jacobsen [38] provided a compelling analytical framework, which with minor adjustments, could be applied at virtually all spatial scales and be used by students to investigate and quantify trends in their own communities.

3.5. Households and Carbon Footprint

There are about 70 million detached residential homes in the US [57], and about 3.2 million solar systems had been installed on residential properties by 2021 [58]. Thus, nationally, about

4.5% of detached residential homes have solar panels. Why is this number so low, and how could the adoption threshold be lowered? University of California Davis has constructed a large solar panel farm, which generates over 33 million kilowatt-hours per year (about 14% of the campus's electricity needs) [59]. Additionally, solar panels are mounted on some student dorms and on some roofed parking lots [59]. Figure 2 shows a satellite image of the central portion of University of California Davis, and it is seen that none of the buildings have roof-mounted solar panels. Why is a research university like University of California Davis only producing 14% of its electricity from solar panels—why is it not an exporter of energy to local adjacent communities? In class, discussions are guided towards views on possible constraints/bottlenecks and about what would be needed to lower adoption thresholds for solar panels by household owners, businesses, and higher education institutions.

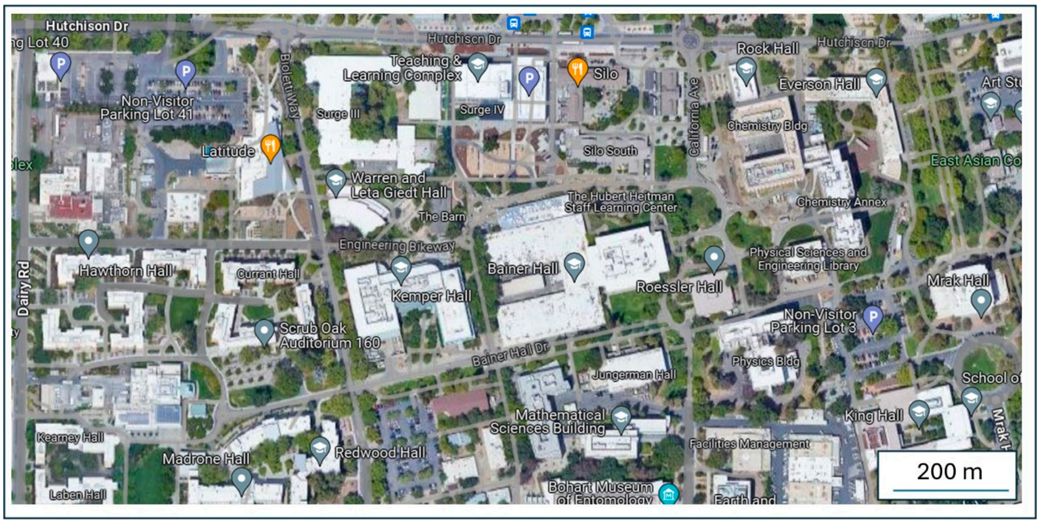

Figure 2. Part of University of California Davis campus. Satellite image of 150 ha of the central portion of the University of California Davis campus.

3.6. Food Strategies and UN's 2030 Agenda for Sustainable Development

In two lectures, discussions are based on a fascinating reading assignment about the implementation of UN's 17 sustainable development goals (SDGs) in five major cities in North America [41]. A truly unique and inspiring aspect of this article is how the author linked broadly defined SDGs with a comprehensive series of very specific and implementable activities. The specific suggestions provided by Ilieva [41] emphasize a critical aspect of sustainable food production and consumption, which is how community efforts, innovative solutions, and implementation and adoption are underpinned by legal and financial landscapes. That is, students (and their instructors) need to understand that the successful development and implementation of sustainable solutions cannot be achieved without engaging with financial institutions, lawyers, and politicians. Additionally, class discussions further elaborate on how activities could be implemented and how students from different academic disciplines could contribute to their implementation. A central educational objective is therefore to create an environment of active learning in which global goals of sustainability are made less abstract by linking them to activities students themselves could implement. And by making SDGs less abstract and more tangible, it is possible to mitigate possible mental health concerns related to eco-anxiety and climate change anxiety [19,20].

3.7. Urban Water Footprint

How is the "water footprint" measured/estimated? How to distinguish between green, blue, and grey water footprints? What are the important distinctions between renewable and fossil water? And finally, how can water footprints be traded similarly to carbon as a way to establish and finance more equitable access to water resources on local and global scales? These are some of the questions addressed based on a pivotal reading assignment [44]. Most students are not familiar with the concepts of green, blue, and grey water footprints. Green water is rainwater and the largest freshwater resource [60], and blue water is water in rivers, lakes, groundwater, and glaciers [61]. Grey water refers to wastewater from households (i.e., bathing, dish washing, washing of clothes), and it is distinguished from more heavily contaminated "black water" from toilets [62].

The satellite image of University of California Davis (Figure 2) shows an area equivalent to about 150 ha, which, under the assumption of an average total annual rainfall in Davis being about 500 mm [63], would have the potential to collect as much as 7.5 million L of rainwater, if roof-based water catchment systems were installed and combined with the collection of run-off from streets and sidewalks (ignoring ground with vegetation and assuming near 100% collection efficiency). Even if this estimate of potential rain catchment is somewhat optimistic and only 5 million L of rainwater could be collected, this seems to represent missed opportunities. Moreover, active learning could be tailored to directly involve plans for the construction and implementation of ways to sequester, store, pump, and efficiently use rainwater for irrigation of landscapes and athletic fields on campus and for campus utilities, such as the flushing of campus toilets.

On a global scale, students are introduced to the following quote about WF (water footprint) [44]: "Given that WFs have passed levels of what is maximally sustainable in half of the world's major river basins, one may conservatively assume that the WF of humanity as a whole—currently averaging at 1400 m^3/y per capita—should at least not increase in the future. Future population growth implies that the maximum sustainable level per capita will decline.". Meaning, it is paramount to develop and adopt methods to monitor water footprints. Additionally, it is necessary to develop and promote smart irrigation systems in crop and livestock productions and find ways to maximize the use of renewable water resources.

On a highly local scale, the concept of water footprint is presented to students through a case study of the author's own backyard rain catchment system (Figure 3). Moreover, this example is used to illustrate how the roofs of individual households can be used to sequester large amounts of green water and use it for vegetable gardening and to provide water for chickens. Under the assumption of 500 mm of total annual rainfall [63], a house roof of 100 m^2, and 100% capture efficiency, 50,000 L of water can be collected and used for green water irrigation. As the house has solar panels, the pumping of water to/from water tanks and to perform irrigation is carbon neutral. Roof gutters have been modified so that all rain falling onto the house is initially transferred to a 4100 L (1100 gallon) tank.

This means that most debris (dust, sand, leaves, etc.) settle in this water tank (**b**), before it is pumped to a second water tank (**c**) with a storage capacity of 9500 L (2500 gallon). In total, about 13,600 L of green water is stored. The water pump is configured with valves, so that water can be pumped between tanks, and water can also be drawn from each of the two water tanks to irrigate a vegetable garden of about 40 m^2. Thus, the current water catchment has the capacity to provide about 340 L m^{-2} to the existing vegetable garden. Importantly, this rainwater storage capacity is only about a quarter (27%) of what would be needed to take full advantage of the total annual rainfall. As part of the lectures, students are introduced to FAO statistics on dryland crop production [64], so that students can calculate how many m^2 of different vegetables can be grown based on roof size and average rainfall data. As an example, dryland cabbage requires 380–500 mm of irrigation (equal to 380–500 L m^{-2}) and yields range from 2.5 to 3.5 kg m^{-2}. As cabbage is mostly grown during the rainy season, only supplemental green water irrigation is needed, so the stored water is mainly used to extend the vegetable growing season 2–3 months after the end of the rainy season (May). Agro-economic statistics suggest that annual per capita fresh cabbage consumption in the US is, on average, around 3 kg [65]. Thus, as many as 100 people may have their annual fresh cabbage consumption covered from green water irrigation of 100 m^2. The main reason for introducing students to such "simple" and/or mundane calculations is that they underscore how even small houses on small plots of land may be used to produce significant amounts of food. Thus, students are empowered to critically assess their access to resources and options to make profound changes to the water footprints of their own food consumption. Vacant lots and strips of land along streets are just some of the many opportunities to grow food in urban areas, and this message is delivered to students via compelling examples from Detroit [66] and Los Angeles [67].

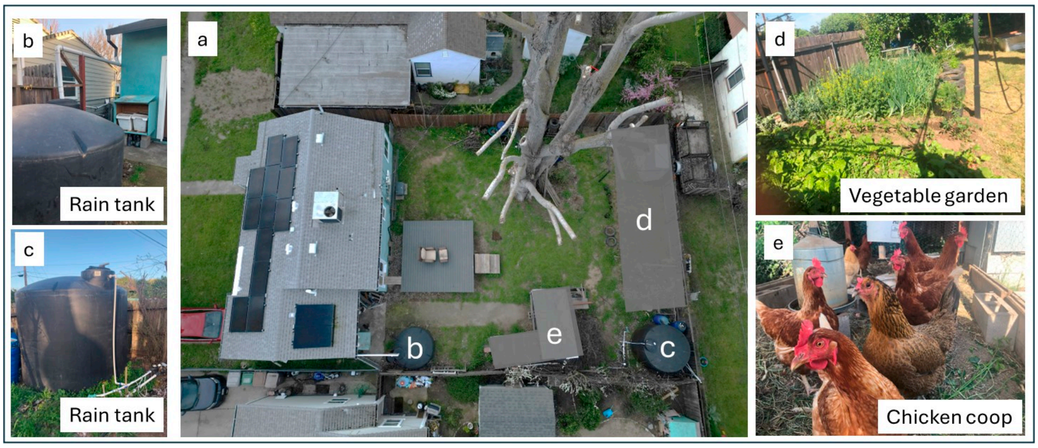

Figure 3. Example of backyard rainwater catchment system. On both sides of a household (**a**), gutters are connected so that rainwater from the roof flows into a 4100 L (1100 gallon) water tank (**b**). Tank (**b**) is connected to a second 9500 L (2500 gallon) water tank (**c**). Using a pump (which is electric and powered by solar panels on the household), rainwater is transferred from Tank (**b**) to Tank (**c**). Thus, a total of 13,600 L of rainwater can be stored and used for irrigation, equivalent to 340 L m^{-2} of the existing vegetable garden. Additionally, there are about 50 m^2 of vegetable garden (**d**) and a chicken coop (**e**).

3.8. Re-Thinking Food Waste

The concept of "waste" is scrutinized throughout this course, as it in many ways represents the ignorance and consequences of "linear productions" (as opposed to circular productions or production networks). That is, a waste stream from one production represents an economic cost and an environmental threat, unless it is viewed as an opportunity and potential input for another production. Thus, the sustainability of society, and of urban food production in particular, may be viewed as the fundamental challenge of modifying infrastructure and creating water, nutrient, and energy flows or networks that are practically feasible and economically viable. At University of California Davis, construction of a Renewable Energy Anaerobic Digester (READ) was completed in 2014 [59]. This digester was designed to process up to 50 tons of organic waste per day, and it is currently running at about one-third capacity. READ is fed by the Davis campus' pre-consumer food waste and food waste from a supermarket chain and other external customers. At full capacity, READ is predicted to produce about 40,000 MMBtu of biogas and about 25 tons of nitrogen fertilizer per year. However, it does not appear that the input and production data are used in courses and/or made publicly available for modeling and educational purposes.

The reading assignment for a lecture about food waste asks the simple and very important question [45]—what is the true value of food waste? To put their question in context, the Food and Agriculture Organization estimates that food waste represents about 27% of agricultural production of both food and non-food items [68]. The study by Wen, Wang and de Clercq [45] provides detailed quantitative data on the potential of using food waste to generate biogas and diesel in a major metropolitan area in China. How to use food waste as resource in energy production is extended further by presenting students with a news clip describing how the town of Grand Junction, Colorado, USA is producing biogas to run a fleet of garbage trucks [69]. That is, food waste and dairy cow manure are mixed in controlled ratios and fed into modified biodigesters to produce natural gas. Concurrently, a fleet of garbage trucks has been modified so that they can run on natural gas. In other words, the trucks are collecting their own fuel! As a consequence, money is being saved and both a waste problem and a fossil fuel challenge (garbage trucks traditionally run on diesel) are mitigated. The class discussion focuses on how waste collection in towns like Grand Junction could serve as a model for universities, cities, and other entities worldwide. Furthermore, we discuss how courses in micro-biology, biochemistry, and engineering could be tailored around active leaning activities, in which READ and similar facilities are included.

In lectures, it is also discussed how insects may be used as bio-converters [70]. That is, agricultural waste streams, such as pomace from fruit processing, hulls from almonds and pistachios, and skins and seeds from tomato processing, can potentially be fed to insects. Compared to traditional livestock animals, production of insects is associated with a number of important advantages: they have an impressive bioconversion rate (gain in body weight per weight of food consumed). As an example, if 100 kg of restaurant food waste was fed to black soldier fly larvae, chickens, or a cow, the food waste would yield 58 kg of black soldier fly larvae, 25 kg of chicken, or 2.9 kg of beef [70]. Insects require orders of magnitude less water, entire bodies can be processed and consumed (no non-edible bones), and effective production is possible at much smaller scales and with minimal upfront investment costs. Insect biomass is harvested, processed, stored, and distributed before being used as precursors for the production of jet fuel, pharmaceuticals, nutritional additive, pet food, fish meal or other high-value products [70]. And in the very near future, insect biomass will likely also become integrated into human diets on a much larger and broader scale. Due to the potential of insects as bio-converters of agricultural waste streams, there is considerable investment capital going into insect farms [71]. Thus, on multiple scales, students are introduced to think differently about food waste—not as a problem, but as a resource that, based on existing technology, on-going entrepreneurship, and simple adaptations of our lifestyles, can be converted directly, and on large scales, into energy and fertilizer, or indirectly, and on the micro scale, into vegetables and eggs (using food waste as feed for chickens).

3.9. Urban Farming and Food Production

YouTube videos about vertical farming, roof top gardens, small greenhouse production, indoor veggies, and balcony crops are presented to students. A recent article provides compelling insight into multi-species architecture (focus on establishment of more than just humans) through the integration of plants and animals [24]. Irga, Torpy, Griffin and Wilkinson [27] provided an inspiring review and discussion of vertical green structures. Furthermore, the authors reviewed existing types of structures and highlighted their limitations. One of the reading assignments describes an analysis of 13 small-scale organic farms and gardens in Sydney, Australia [42]. The authors calculated average annual yields to be 5.94 $kg \cdot m^{-2}$, which is close to twice the yields of typical Australian commercial vegetable farms. The concept of “emergy” (embodied energy—meaning the total energy needed to produce a given item) is described and used in the calculations of benefit-to-cost ratios and the sustainability of urban farming systems. In class and based on the reading assignment, it is discussed how engaging in urban farming has a number of indirect benefits, including the following: (1) Maintenance of an urban garden implies physical activity. (2) Replacement of lawns with organic gardens generally reduces environmental risks of leaching of agro-chemicals into sewer systems and ground water reservoirs, and it may increase biodiversity. (3) Growing food has the potential to elicit an interest in home-cooking and human nutrition. (4) Growing food and sharing food with neighbors and members of local communities. (5) There are significant mental health benefits to engaging in growing vegetables and mushrooms, maintaining composting systems, collecting rainwater, and having chickens. Many people are unable to have their own gardens, but schools, churches, community gardens, and other local entities have the potential to embrace urban farming as a vehicle of engagement. And students at high schools and universities can develop and implement technologies and programs to lower adoption thresholds of urban farming systems. University of California Davis has a student farm, which provides students with opportunities for internships, and it runs a gamut of educational outreach programs [72]. Thus, there are on-campus opportunities for students to acquire hands-on experience with crop production, either through field research, greenhouse and lab experiments, or through student farm internships.

3.10. Industrial Symbioses and Urban Community Pillars

Footprints (of water, energy/carbon, and nutrients), circular economies, life cycle analysis, emergy, and material flow analysis are all concepts at the root of sustainability. They underpin the notion of the connectedness of production units and of how sustainability is largely about resource management. An intriguing article about "The plant" in Chicago is used to illustrate the value of industrial symbiosis [47]. This is a former meat-packing facility (12,000 m^2), which was repurposed into a collaborative community of inter-connected food businesses committed to reducing waste. Using fairly basic data on the usage of water and energy, the authors conducted a material flow analysis and demonstrated a methodology that is widely applicable at multiple spatial scales and highly adoptable in active learning sustainability exercises. Powerful TED Talks describing engaging and thought-proving initiatives in Detroit [66] and Los Angeles [67] are shared and discussed with students.

4. Conclusions

Through transformational educational programs that include a focus on active learning and living laboratories, it may be possible for students to acquire important skill sets, which address the universal problem of knowing–doing gaps [73]—how to effectively translate science and knowledge into solutions to societal needs [74]. We as instructors should not focus exclusively on the alarming consequences of climate change. We also need to promote a positive message, in which it is highlighted how research discoveries and technologies represent ample potentials for solutions, innovation, and entrepreneurship. A strong educational focus on active learning and living laboratories is also believed to promote student empowerment and mitigate growing concerns about mental health and climate anxiety among young people.

As educational institutions lower their current footprints (carbon, water, waste, and nutrient footprints), structural improvements represent unique opportunities for students and instructors to engage in active learning with a strong focus on sustainability. Schools and universities could install networks of sensors to monitor water usage, rainfall, energy consumption, temperatures, and inorganic and organic waste production in individual buildings and facilities, and such databases could be made available to students. Students could be involved in the development and maintenance of sensor networks. Using such databases, students could engage in optimization analyses and learn about the processing and analyses of environmental data. Outputs from such analyses could be compared with green policies at the city, county, state, or national levels, or more broadly by comparing them with United Nation's sustainability goals [41]. Such datasets could be used to engage students in active learning related to a wide range of topics, including calculations of environmental footprints [38] and/or material flow analyses [47]. In summary, this perspective article intends to promote the notion that a focus on active learning and living laboratories can go hand in hand with the improved sustainability of schools and universities. The overall message to school and university administrators is that efforts to plan and implement sustainability initiatives should go beyond physical sustainability improvements (carbon, water, waste, and nutrient footprints) by also involving transformations of educational curricula. The intended take-home message is that educational institutions could and should be more than sums of buildings and infrastructure. Structural sustainability improvements represent unique opportunities for students and instructors to engage in active learning with a strong focus on sustainability.

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