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THE SMART AQUAPONICS GREENHOUSE – AN INTERDISCIPLINARY EDUCATIONAL LABORATORY

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Abstract. The aim of this paper is to develop the ability of the students to address interdisciplinary aspects of everyday life. Thus, we have created a solar powered aquaponics system monitored by Arduino microprocessor. The aquaponics greenhouse is a system that combines conventional aquaculture with hydroponic greenhouse in a symbiotic environment. The greenhouse's monitoring system is composed of several types of sensors and an Arduino Acquisition Plate with a Mega 2560 processor. As a power supply for the water pump and the monitoring system, a 50W monocrystalline panel is used. The students can understand some phenomena of biology, physics and chemistry and can also monitor the processes that occur in the aquaponics system.

Key words: aquaponics, interdisciplinary laboratory, Arduino, renewable energy.

1. INTRODUCTION

The task to integrate information from several domains of science in order to explain the phenomena that occur day by day in our lives is a challenge for the students [1–2]. To understand the theoretical concepts associated with various phenomena, it is necessary to learn through experiments and independent activities. The link between different fields of study, such as physics, biology and chemistry can be done by creating demanding and modern laboratories. The use of modern automation and monitoring technique is a mandatory condition, in order to raise the interest of students for study and innovation. By using a platform with a microcontroller for acquisition, processing and analysis of laboratory data in experiments we aim to create inspiration and conscientiousness for the students within the study of interdisciplinary subjects like natural sciences, computer science and technology [3–6]. We may also notice the wide use of computer simulations techniques [7–8], virtual instrumentation and educational software [9–11].

The present paper proposes a smart aquaponics greenhouse, monitored and automated with an Arduino microcontroller, as a multidisciplinary laboratory for students.

Aquaponics greenhouse is a system that combines conventional aquaculture with hydroponic greenhouse in a symbiotic environment. In a conventional aquaculture, animal waste accumulates thus increasing the toxicity of water, so in an aquaponics greenhouse, the fish waste is transformed into plant food by decomposing it into nitrates. Nitrogen is a vital element for all living organisms [12]. The ammoniacal nitrogen excreted by the fishes provides an important source of nitrogen for the development of plants [13]. The water carrying the fish waste is then transported into the aquaculture system, the nutrients are transformed in nitrate by biological nitrification-denitrification and plant assimilation [14–15]. Aquaponics has a great potential to become a sustainable technology for the recovery of high nitrogen-rich waste, synchronized with the production of high-quality fish and vegetables [16]. Three types of aquaponics producers were identified by Love *et al.* [17] like commercial producers, hobbyists and educators that continue research to find out how educators use aquaponics in their classrooms.

Aquaponics has ancient roots; among the first people who used this technology were the Aztecs. They used agricultural islands called "chinampas". The islands were placed downstream on the existing navigation channels, where the waste of the fish was being collected. A major drawback of this primitive system was the impossibility of having a conditioned environment, so the islands were subjected to uncontrolled weather and climate change. Another problem of this system was the difficult accessibility, which was done only with boats [18].

Modern aquaponics began with the study of Jim Rakocy in 1981 [19]. In Europe, aquaponics research really began in 2009 with the work of Graber and Junge [20]. The number of scientific papers is still lower than in hydroponics and green rooftops domains.

Compared to conventional greenhouse agriculture and aquaculture, the aquaponics improves the long-term environmental sustainability. In aquaponics, water and nutrients are used more resourcefully than in aquaculture. Moreover, aquaponics systems influence nutrient cycle strategies that lead to a reduction in the total amount of raw materials for fishing. When it is coupled with low-impact energy sources and fish feed, the closed-loop ecosystem permits a food production strategy that is similar to a natural ecosystem [21].

The study of aquaponics systems from Life Cycle Assessment and Life Cycle Costing point of views has demonstrated that energy consumption is a key issue for achieving sustainability. To heat water and air in the aquaponics system, about 19% of the total energy consumed is used, meaning about 12.5% of the energetic costs. Also, the wall insulation layers and the energy efficiency of the equipment become very important in the design of the aquaponics system. On the other hand, water pumping and artificial lighting consume most of the energy (81%) [22–23].

Our paper proposes a solar panel to power-up the pump and, consequently, solving the problem of greenhouse gases emission. In addition, the students become more familiar with the renewable energies and environmental protection principles.

2. SYSTEM ARCHITECTURE

2.1. AQUAPONIC SYSTEM

Aquaponics has two main parts, the aquaculture system and the hydroponic system. The aquaculture system is represented by the fish tank, as well as the subsystems for filtering and maintaining underwater life. The filtration system may be composed of a simple three-step system in which sand, coal and gravel are used or a vortex filter in which the residue is collected on the bottom of the filter bowl.

The underwater life support system consists of an air pump and a heater.

Most fish need more air in the water than the existing ones in the backwater, so the system requires an air pump. In a controlled environment, the water needs to be heated or cooled, depending on the type of environment created, unlike in the natural environment, where the optimal temperature is self-maintained.

The hydroponic system is represented by growing plants in water. The great advantage of such a system is the consumption of water required; in hydroponic greenhouses, the water consumption is up to 95% lower than in conventional greenhouses with soil.

Another great advantage is the growth time of plants in a hydroponic system. The experiments show that growth time is twice as low as in conventional soil system. For many plants, constantly keeping roots in water is not recommended. Thus, in order to maintain healthy plants, water must be circulated in cycles, where the water level increases and decreases. A solution for creating cycles of operation is the vacuum bell drain.

Aquaponics greenhouses have a layered structure: on the lower level the fish tank is placed and above it, the greenhouse space with the plant tank is installed. This structure accomplishes the ergonomic principle and also reduces the need for pumps, as water recirculation will be done by gravity, as it is shown in Fig. 1.

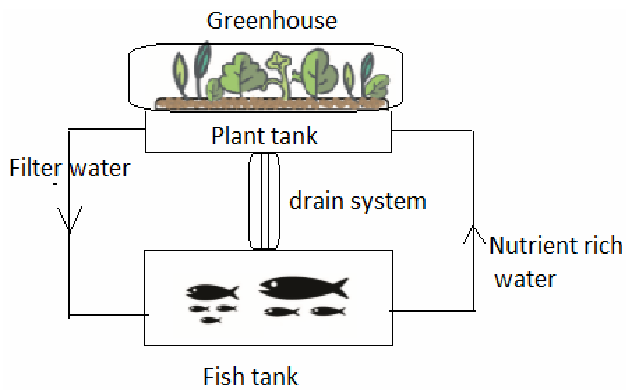
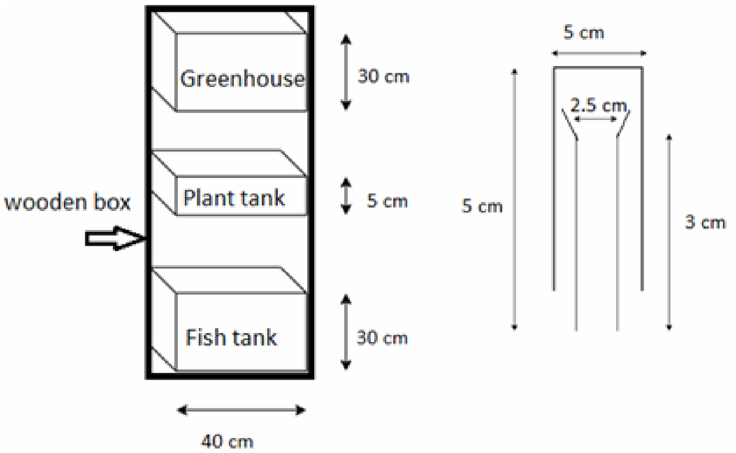


Fig. 1 – The schematic aquaponics system. The colored versions can be accessed at http://www.infim.ro/rrp/.

The developed aquaponics system is divided into three stacked layers. The first layer that represents the structure of the greenhouse, has a height of 30 cm, enough to grow small plants such as aromatic plants. The second layer is the plant tank, of 5 cm height, that contains clay balls and the upper part of the bell drain. The 30 cm tall fish tank is the last layer. All layers have a width and length equal to 20 cm and 40 cm respectively. The upper structure of the greenhouse is made of Plexiglas (3 mm thickness) and has got a straight roof (20 × 10 cm) with ventilation. The total structure is embedded in a wooden support, providing a rigid structure and support for the electrical side of the system, as it is shown in Fig. 2a.

The plant tank has a capacity of 2.5 liters. To ensure a water supply in the circuit, it is necessary that the fish tank has got at least twice the capacity of the plant tank. Thus, in order to ensure the water demand, a tank with a volume of 20 liters was chosen. 10% of the total volume is reserved for sand and sediment.

The drain system is placed in the plant tank that is filled with water about 80% of the total volume, to a height of 3 cm. The design of the vacuum bell drain is shown in Fig. 2b. For optimum drain, the outside pipe diameter is twice than the inner pipe one and also the system drain has an external filter to prevent accumulation of any impurities that could block it.

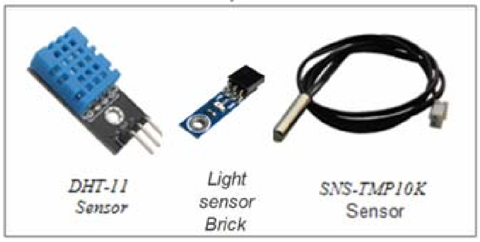


a) b)

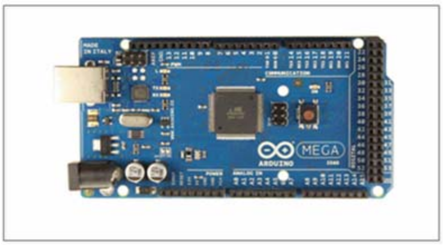
Fig. 2 – a) Aquaponic layer structure; b) drain system.

2.2. MONITORING SYSTEM

To develop a smart aquaponics system that synergize fish farming and plant growth into greenhouse by continuously recorded data from several sensors, monitoring the sensor information, and controlling the system consequently, an Arduino acquisition board with a Mega 2560 microprocessor was used, as it is shown in Fig. 3.



a)



b)

Fig. 3 – Components of the monitoring system: a) Data acquisition unit; b) Arduino unit. The colored versions can be accessed at http://www.infim.ro/rrp/.

This acquisition card has 54 digital and 16 analog pins. The maximum output voltage is 5 V and the recommended input voltage is 7–12 V. The intensity per pin is 20 mA for the input voltage and for the output voltage of 3.3 V is 50 mA.

Three types of sensors are used to monitor the system. Two DHT-11 sensors are used to monitor air temperature and humidity. They need an input voltage from 3.3 V to 5 V and an intensity of 0.3 mA. Every two seconds, these sensors broadcast data.

The water temperature is monitored with an analogue sensor SNS-TMP10 made of metal and encapsulated with resin. This type of sensor works between 30ºC and +110ºC with an accuracy of 1% and requires a 10 kΩ resistance to read the received data. The light sensor is used, in order to observe the light intensity of the environment.

2.3. POWER SOLAR SYSTEM

We used a water pump with an input voltage of 12 V and a flow rate of 0.4 L/min with a diameter of 6 mm at the inlet and outlet for circulation of water, as it is shown in Fig. 4. A 5 V relay is used to drive the pump that runs in cycles of five minutes every half an hour. The pump transports the water enriched with nutrients from the tank fish to the greenhouse.

Fig. 4 – The recirculation water system. The colored versions can be accessed at http://www.infim.ro/rrp/.

The solar collector system that powers the recycling and monitoring systems consists of a solar battery with 12 V output voltages and a capacity of 33 Ah, a solar inverter that has a 12 V output voltage and a USB module with a 5 V output voltage, as it is shown in Fig. 5.

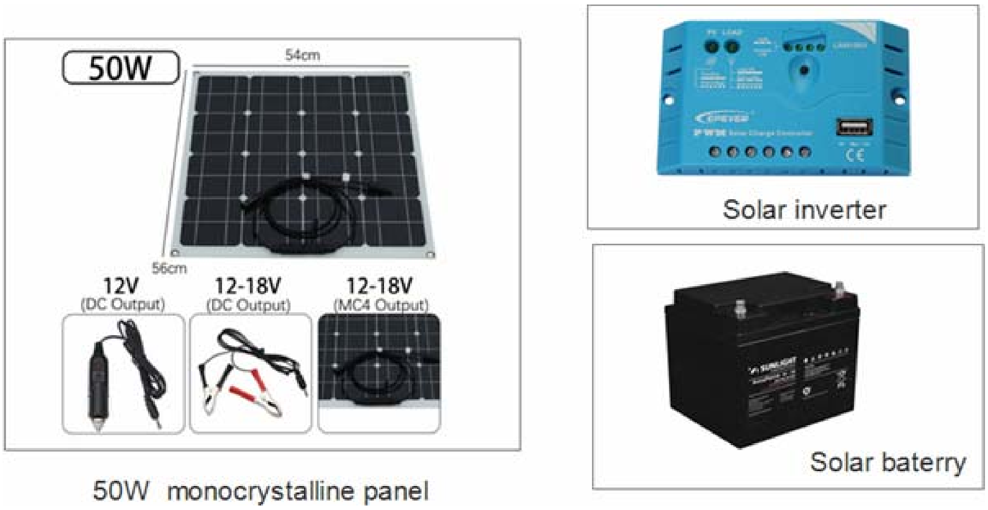


Fig. 5 – Power supply solar system. The colored versions can be accessed at http://www.infim.ro/rrp/.

The electric scheme of the monitoring system is showed in Fig. 6 and the assembly scheme of aquaponics system is presented in Fig. 7.

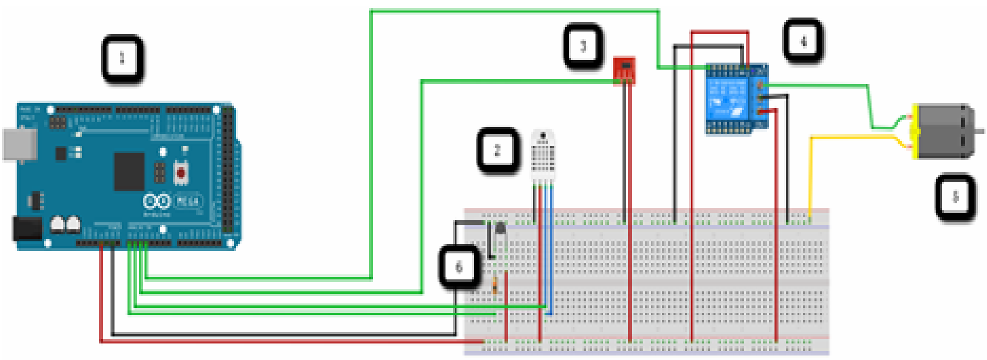


Fig. 6 – Electric scheme of monitoring system: 1 – Arduino Mega 2560, 2 – temperature and humidity sensor DHT11, 3 – light sensor, 4 – 5V relay, 5 – DC motor (water pump simulation), 6 – analogue temperature sensor. The colored versions can be accessed at http://www.infim.ro/rrp/.

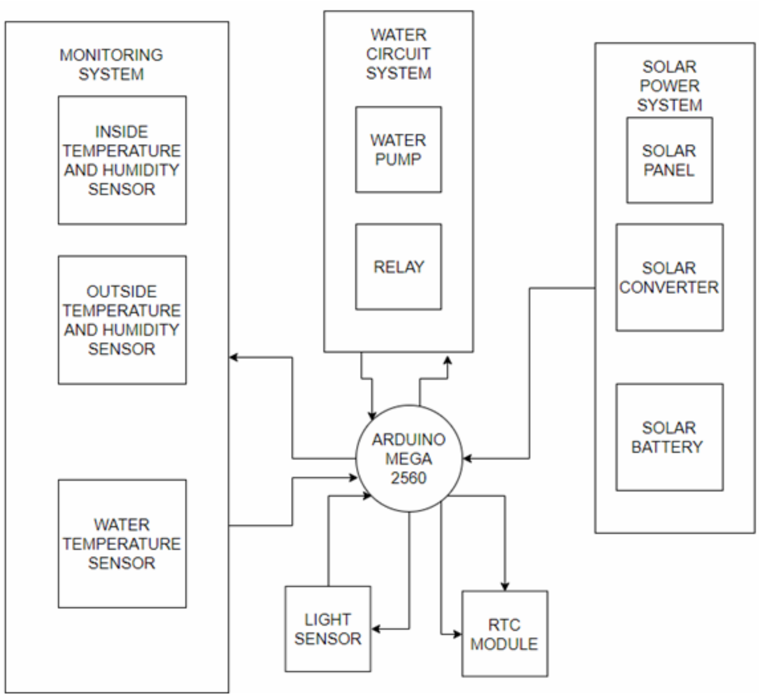
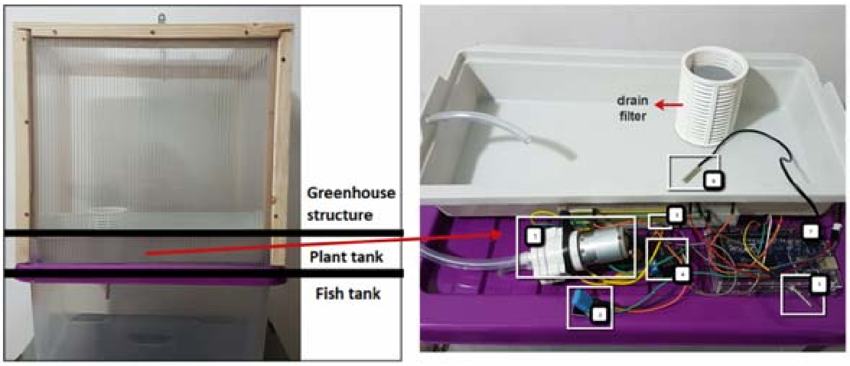


Fig. 7 – Assembly scheme of aquaponics system.

3. LABORATORY ACTIVITY

This laboratory conducts students to use the implemented experimental model (Fig. 8), to develop their own supposition for exploration and then design and accomplish their own experiments. To test and explore, they could acquire data for 28 days under different conditions of temperature, humidity and water flow rate. The values for water temperature, water flow rate and pH level are constantly acquired. In addition, manual measurements of the plant height and fish weight may be performed. A statistical analysis of these kinds of data could describe the relationships between the plant growth and the fish growth [24]. More species of plants and fish may be tested and analyzed in this aquaponics system. The students could also try to establish the best hydraulic loading rate to minimize the environmental impacts [25–26].

It is also feasible to drive students to calculate the energy needed to power the monitoring system, the water pump and heat the system until the optimal temperature determined after the previous analysis. Another task for the students is to evaluate the quantity of the gases within the greenhouse that is reduced by powering these components of the system with green energy (solar panel). The challenge of improving the monitoring system will become an important activity for the students in this laboratory.



a) b)

Fig. 8 – The experimental aquaponics system: a) structure of aquaponics system; b) monitoring system 1 – water pump, 2 – temperature and humidity sensor, 3 – resistance 10 kΩ, 4 – relay, 5 – light sensor, 6 – analog temperature sensor, 7 – Arduino Mega 2560. The colored versions can be accessed at http://www.infim.ro/rrp/.

In the test phase, each sensor was independently verified by a test program in Arduino. A program was used in order to test the analogue temperature sensor. A program that transforms the received values from bits into temperature values in Celsius degrees was absolutely necessary. The temperature reading range is from –20 to 120ºC. Analogue sensor DHT-11 has a specific Arduino library, so the values obtained in the binary system have been converted to Celsius degrees and relative humidity was converted in percent. The sensor can read values between 0–50ºC and 20–90% relative humidity. The light sensor transmits bits values from 0 to 1024 and for the test were used "if" functions, where a given value returns a specific message, low brightness for values between 0–500, good brightness for values between 500–800 and bright light for values between 800–1024. The water pump was tested by means of a relay to start and stop the pump on demand by switching off the power supply, where the relay was connected to a 12 V source and was controlled by an analogue A0 pin of the board purchase.

In order to test the aquaponics system, we analyzed lettuce and basil cultures. In the fish tank we placed Xiphophorus helleri fishes (Fig. 9). During four weeks we have recorded the temperature and relative humidity values (Fig. 10) and also, we measured the plants' height.

We started the set of experiments with lettuce culture analyses. After 7 days three of the lettuce plants were died and the forth plant increased with 10%. Hourly variation of humidity and temperature into the greenhouse, in case of lettuce culture is shown in Fig. 10 a. The higher values of temperature recorded in the sunny days explain the short life of lettuce plants, as the aquaponics system was placed near a window oriented to south. For the analyses of the basil culture (Fig. 9) we have changed the system position relative to direct solar radiation. The maintained temperature and humidity inside of the greenhouse (Figs. 10 b, c) allow a good development of plants (Table 1). In order to maintain the accurate humidity inside the greenhouse, the water flow rate for each type of plant was been established.

Fig. 9 – The experimental aquaponics system with fishes and plants (basil 1, 2, 3). The colored versions can be accessed at http://www.infim.ro/rrp/.

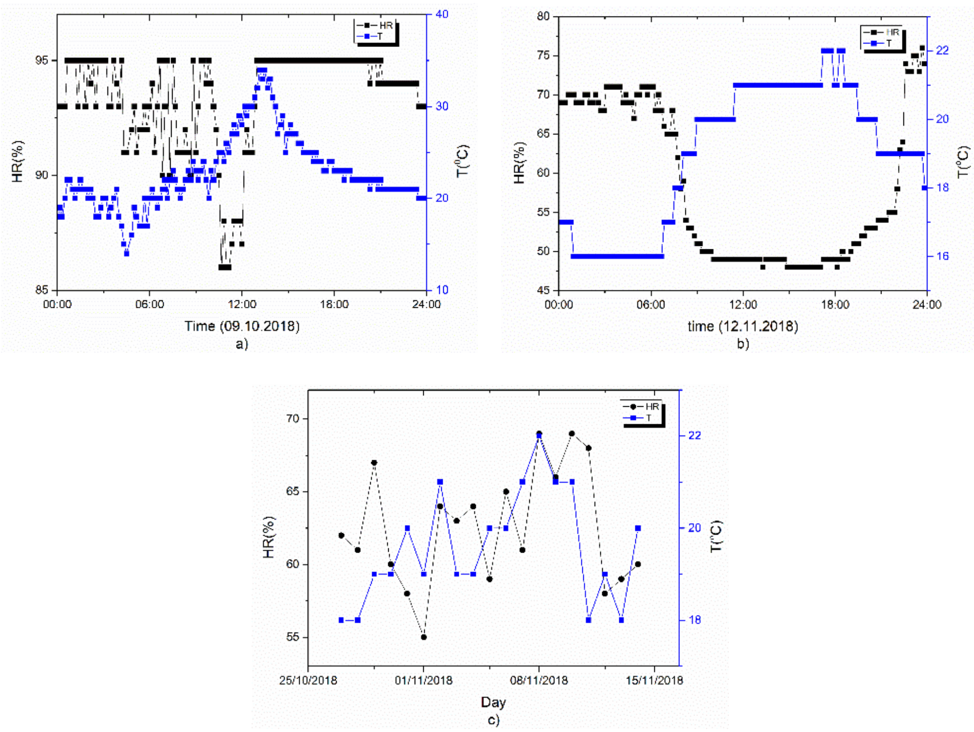


Fig. 10 – Variation of temperature and relative humidity in greenhouse: a) recording values in case of lettuce culture; b) recording values in case of basil culture; c) averages daily values in case of basil culture. The colored versions can be accessed at http://www.infim.ro/rrp/.

Table 1

Experimental data regarding the progress of basil plants

Height/Time	Basil 1 (cm)	Basil 2 (cm)	Basil 3 (cm)
1 day	3.1	6.9	4.9
7 day	3.4	7	6
14 day	3.5	7	6.2
21 day	3.6	7.1	6.3

4. CONCLUSIONS

A smart aquaponics system was designed and developed as an interdisciplinary laboratory for students use. The proposed system can continuously monitor water temperature and pH, air temperature and, additionally, control the water debit. Furthermore, this aquaponics greenhouse is powered by renewable energy in order to reduce environmental pollution. By working in this type of laboratory the students may integrate knowledge from multiple domains. Future work will include automatically sending of early warnings, correction of system anomalies using the mobile application and addition of supplementary sensors, in order to detect the oxygen and nitrate concentration level in the water. The low-cost technology that consists in Arduino microcontrollers and associated sensors opens the direction to implement applied interdisciplinary topic science to student labs. This paper describes a practical framework for such laboratories, where students can carry out pertinent physical, chemical and biological phenomena studies at the level of high school and university programs, even with this inexpensive equipment. The knowledge acquired by students will be less conceptual than in a classic lab and more centered on the autonomy and to team work. Beyond this particular structure, the possibility of doing physical experiments with low-cost hardware opens up some interesting possibilities. It could also be used to allow students to perform homework with "do-it-yourself" experiments, using Arduino plates and simple electronic sensors.

REFERENCES

1. D. Stoica, C. Miron, Al. Jipa and M.V. Popescu, Rom. Rep. Phys. **68**(1), 425–439 (2016).
2. D. Stoica, C. Miron and Al. Jipa, Rom. Rep. Phys. **66**(4), 1285–1300 (2014).
3. M. Oprea and C. Miron, Rom. Rep. Phys. **68**(4), 1621–1639 (2016).
4. L. Dan, M. Dan, C. Miron and S. Antohe, Arduino Yun photovoltaic system for solar energy study in school, *Proceedings of the 12th International Conference on Virtual Learning (ICVL)*, 478–485 (2017).
5. N. Korganci, C. Miron, A. Dafinei and S. Antohe, Inquiry-Based approach to teaching photovoltaics, *Proceedings of Conference 11th International Scientific Conference on eLearning and Software for Education (eLSE)*, 491–496 (2015).
6. F. Bouquet, J. Bobroff, M. Fuchs-Gallezot and L. Maurines, Am. J. Phys. **85**, 216–222 (2017).

7. C. Berlic and V. Barna, Dig. J. Nanomater. Biostruct. **11**(1), 159–165 (2016).
8. C. Berlic and C. Miron, Rom. Rep. Phys. **69**(4), 120 (2017).
9. N. Micescu, M.V. Rusu and C. Berlic, Rom. Rep. Phys. **65**(2), 563–577 (2013).
10. N. Micescu, E.S. Barna, C. Berlic and M.V. Rusu, Rom. Rep. Phys. **65**(2), 563–577 (2013).
11. B. Mihalache and C.Berlic, Rom. Rep. Phys. **70**(2), 901 (2018).
12. C.W. Pratt and K. Cornely, *Essential Biochemistry*, 3rd ed. John Wiley and Sons, Inc., MA. 2014.
13. M.B. Timmons, J.M. Ebeling, F.W. Wheaton, S.T. Summerfelt, B.J. Vinci, *Recirculating Aquaculture Systems*, 2nd. ed. Cayuga Aqua Ventures, Ithaca, NY, 2002.
14. A. Graberand R. Junge, Desalination **246**, 147–156 (2009).
15. Y. Zou, Z. Hu, J. Zhang, H. Xie, C. Guimbaud and Y. Fang, Bioresour. Technol. **210**, 81–87 (2016).
16. S. Wongkiewa, Z.Hub, K. Chandran, J.W. Lee and S. K. Khanal, Aquacult. Eng. **76**, 9–19 (2017).
17. D.C. Love, J.P. Fry, L. Genello, E.S. Hill, J.A. Frederick, X. Li and K. Semmens., Plos One **9**(7), e102662 (2014).
18. J. Boutvelluc, *Aztecs' Aquaponics Revamped,* 2007. Available online: http://napavalleyregister.com/lifestyles/home-and-garden/columnists/mastergardener/aztecs-aquaponics-revamped/article_b67bd13c-fd17-562f-a3a1-3862010ce144.html. (Accessed 15 December 2017)
19. J.E. Rakocy and R. Allison, *Evaluation of a Closed Recirculating System for the Culture of tilapia and Aquatic Macrophytes*. In: L.J. Allen, E.C. Kinney (Eds), Proc.of the Bio-engineering Symposium for Fish Culture. Publ. No. 1, American Fisheries Society, Bethesda, MD, 296–307, 1981.
20. A.Graber and R. Junge, Desalination **246** (1–3), 147–156 (2007).
21. A. Cohen, S. Malonea, Z. Morrisa, M. Weissburgb and B. Brasa, *Combined Fish and Lettuce Cultivation: An Aquaponics Life Cycle Assessment*, 25th CIRP Life Cycle Engineering (LCE) Conference, 30 April – 2 May 2018, Copenhagen, Denmark Procedia CIRP **69**, 551–555 (2018).
22. A.A. Forchino, V. Gennotte, S. Maiolo, D. Brigolin, C. Mélard and R. Pastres, *Eco-designing Aquaponics: a case study of an experimental production system in Belgium*, 25th CIRP Life Cycle Engineering (LCE) Conference, 30 April – 2 May 2018, Copenhagen, Denmark, Procedia CIRP **69**, 546–550 (2018).
23. A.A. Forchino, H. Lourguioui, D. Brigolin and R. Pastres, Aquacult. Eng. **77**, 80–88 (2017).
24. T.Y. Kyaw, A.K. Ng, Smart Aquaponics System for Urban Farming, *World Engineers Summit – Applied Energy Symposium & Forum: Low Carbon Cities & Urban Energy Joint Conference*, Energy Procedia **143**, 342–347 (2017).
25. A. Endut, A. Jusoh, N. Ali, W.B. Wan Nik and A. Hassan, Bioresour. Technol. **101**, 1511–1517 (2010).
26. O. Schneider, V. Sereti, E.H. Eding and J.A.J. Verreth, Aquacult. Eng. **32**, 379–401 (2005).