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Automated Multiparameter Water Monitoring System as an Experiential Learning Platform for Undergraduate STEM Majors

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Abstract

Continued concerns over the effects of fossil fuels have made renewable and sustainable fuels a priority. Algal fuels, like bioethanol derived from the seaweed *Gracilaria*, are easily produced, and incur fewer environmental impacts than their fossil counterpart. Furthermore, the alga can also produce other valuable products and remediate impacted ecosystems during the production cycle. Typically, algal culture for bioenergy occurs as a separate venture, but studies have shown that there are numerous benefits to integrated approaches. For example, seaweeds grown in tandem with aquaculture (Integrated Mutli-Trophic Aquaculture) have access to nutrient rich effluents while improving water quality and husbandry for fish and other seafood species. However, such integrated systems possess numerous parameters requiring constant monitoring, and therefore the effort required to achieve maximum productivity increases exponentially. In other industries, systems with this level of complexity have greatly benefitted from the injection of automation for fairly mundane routines. In this specific instance, the process of monitoring water quality to ensure that the parameters remain within the optimal and safe ranges, meets these criteria, freeing up time to deal with other operational challenges.

Kolb's cycle of experiential learning formed the basis for the student-led activities for the duration of the project. The cycle is a well-known and effective model in education which outlines the process where knowledge is gained through transformative experiences. As students immersed themselves in an active learning framework, acquisition of knowledge resulted from the combination of participation, assimilation, comprehension, and conceptualization of experiential processes in the affective, psychomotor, and cognitive domains.

In an effort to support the grant-funded research for bioenergy systems and also provide experiential learning opportunities, undergraduate student researchers in STEM disciplines were recruited to develop a tool to improve daily algaculture operations. Once the project objectives and requirements had been defined in consultation with the lead graduate student on the research project, eight undergraduate engineering and computer science students set out to design and fabricate the monitoring and data acquisition system. The undergraduate students followed the system development procedure, where they proposed project objectives, identified design requirements, characterized system specifications, sourced all required components, and were involved in system fabrication. Throughout the project, the students were exposed to a multi-disciplinary team of researchers and faculty members from engineering, environmental sciences, and the aviation programs at the university. The students based their design around the Arduino MEGA, and the system has the capability to measure, log, and display seven environmental parameters on an LCD screen. The parameters included temperature, conductivity, color, dissolved oxygen, oxidation reduction potential (ORP), pH, flow rate, and nitrate levels. The final system was originally to be packaged in a 3D printed case; however, the team opted for an alternate arrangement that was robust for the operating environment. An assessment was conducted following the activities, and students reported high levels of enthusiasm for the opportunity to participate in this cutting-edge research, and also displayed improvement in their content and team-building skills.

1.0 Introduction

Concerns over ever increasing fossil fuel combustion rates and dwindling reserves have brought energy issues to the center stage. It has been reported that as much as 80% of global energy usage is derived from fossil fuels (FF) while in the United States, 9 million barrels of petroleum are consumed per day [1-2]. At this rate of consumption, plus projected population growths in key world economies, it becomes very apparent that current practices will soon become unsustainable [3-5]. At the same time, it is impossible to ignore the deleterious effects of our traditional energy practices. Significant alterations to global biogeochemistry have occurred as a consequence of FF utilization and the true extent of the damage is still not yet known. What is certain is that persistent fluxes of FF combustion products to the atmosphere continue to increase concentrations of greenhouse gases (GHG). These GHGs have been implicated in major perturbations to global climate [3, 5-7]. Furthermore, atmospheric concentrations of these compounds have increased so significantly over the last century that noticeable changes to atmospheric chemistry, deposition, and eutrophication of surface waters have been observed [6, 8 and 9]. This fact alone speaks to the significance of research pertaining to carbon neutral fuels.

Algal biofuels are investigated as a viable alternative to FF. As previously stated, the main drawback of FF combustion is the release of GHGs like CO_2 and NO_x to the atmosphere. The production of algae for biofuels requires large amounts of these same compounds (C and N both are integral to algal metabolism) and may be useful in reducing the levels of these compounds in the environment [10 & 11]. Furthermore, efflux from algal biofuels has also been shown to contain lower levels of harmful gases [12]. The red seaweed genus, *Gracilaria* is one such example of a suitable candidate for bioethanol production. This seaweed exhibits high growth rate and dense stores of fermentable sugars while also possessing established culture and processing methods [13 & 14]. Even after processing to bioethanol, *Gracilaria* residue can be utilized in agriculture as a fertilizer or soil amendment or even as a source of forage for a variety of livestock [15].

In spite of the many advantages for using *Gracilaria* to produce bioethanol, sourcing enough feedstock for conversion still poses many challenges. Typically, this seaweed is produced as a monocrop under benthic, line, and cage cultures in coastal locations around the globe [16-18]. Under these conditions, production is constrained by the availability of nutrients and prevailing environmental conditions [15]. Research has subsequently demonstrated that *Gracilaria* is uniquely suited to mixed aquaculture systems, which is known as integrated multi-trophic aquaculture (IMTA). Here, the seaweed can make use of the nutrient-rich effluent produced from the culture of other finfish, crustaceans, or mollusks, thereby improving the water quality, husbandry, and yields [16-18]. However, as the number of cultured species in a system increases, so does the complexity and workload required to maintain stable and safe operations [16, 18-20]. Multiple environmental and water quality parameters must be closely and routinely monitored to ensure optimum conditions for all species within the system [18-20]. Salinity, pH, temperature, and dissolved oxygen are just a few of the most critical parameters that if left to fluctuate widely could lead to disastrous results. To remain abreast of these changes, operators typically conduct frequent, and often times, time consuming in-situ measurements and wet-lab procedures. Thus, there is an intrinsic benefit to be able to quickly determine culture state, and become more responsive to potentially adverse conditions. The development and use of automated multiparameter samplers could make this possible.

To understand these specific challenges, a collaborative effort was undertaken to support the IMTA research and operations on the campus of University of Maryland Eastern Shore (UMES). Once the decision was made to move forward on this project, the idea was taken to the weekly multidisciplinary project meeting attended by students in various STEM fields as well as faculty and staff collaborators. It was explained to the group that the project objective was for students to design and fabricate an automated, multiparameter water quality monitoring system for use in a *Gracilaria* IMTA system for bioethanol production. The activities were driven largely by the participating students (with limited supervision by a team of faculty and graduate students from various relevant disciplines). The activities were also designed using the Kolb's cycle of experiential learning. Kolb's theoretical framework posits that knowledge is gained through transformative experiences and is cyclical through the duration of the experience (Figure 1) [21 & 22]. The model suggests that students will immerse themselves in an active learning framework, and the acquisition of knowledge will result from the combination of participation, assimilation, comprehension, and conceptualization of experiential processes in the affective, psychomotor, and cognitive domains [21 & 22].

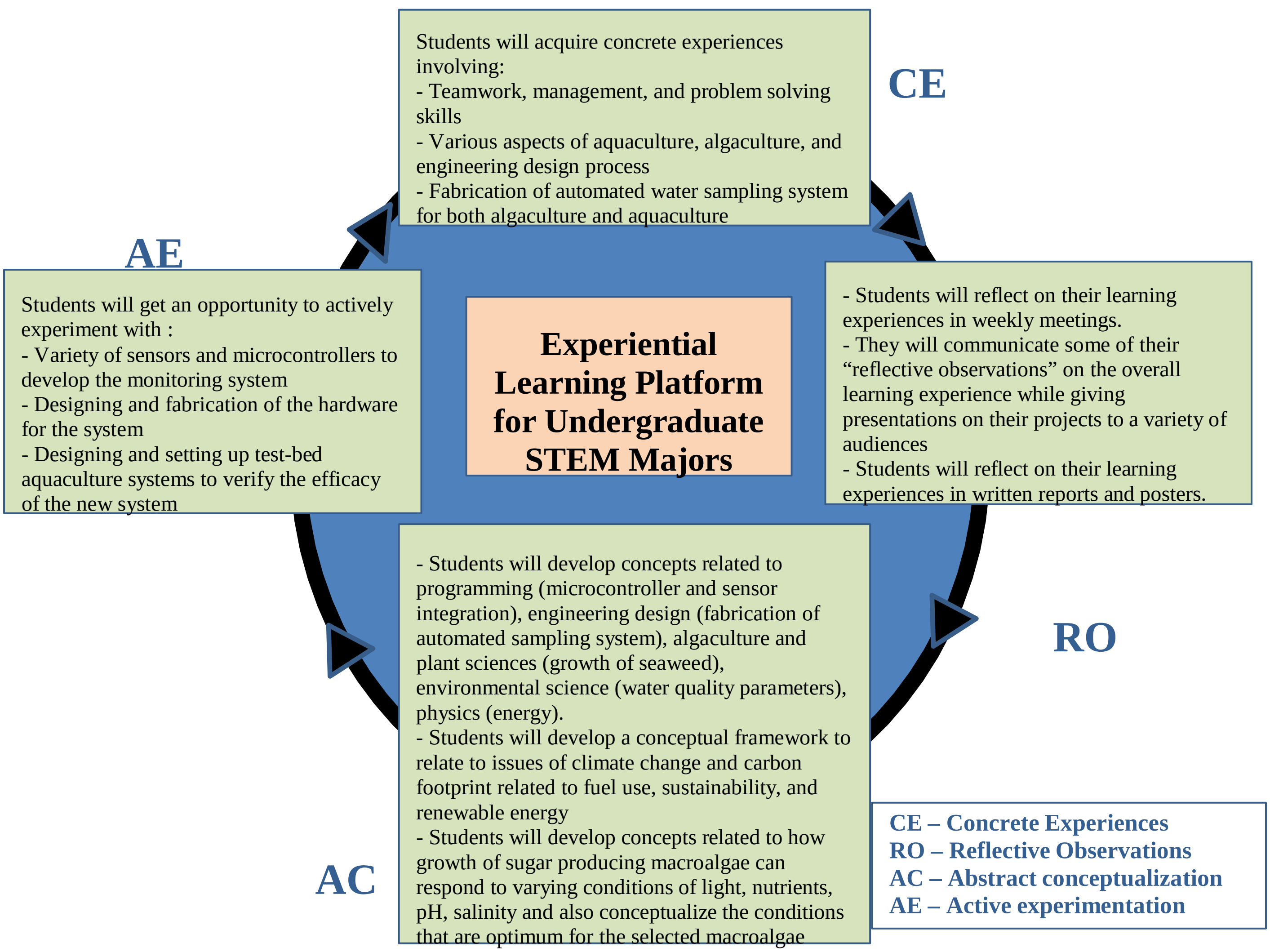

Figure 1. Implementation of Kolb's Cycle of Experiential Learning to a Water Quality Monitoring Project.

2. Methodology; System Definition; and Design

Six undergraduate engineering and two computer science students volunteered to participate in the project. Subsequently, these students were supported for the duration of the project through a grant funded by the United States Department of Agriculture (USDA). An initial meeting was held with the graduate student leading the IMTA efforts to gain a perspective of the theories encompassing the research and also to determine the scope, mission, and final deliverables. The outcome of the meeting generated the following design specifications for the Water Quality Monitoring System. The design must be:

a) Compact and portable;
b) Robust with corrosion protection;
c) Comprised of a handheld unit with integrated graphical user interface and separate but connected apparatus with probes for deployment;
d) Capable of measuring temperature, conductivity, color, dissolved oxygen, oxidation reduction potential (ORP), pH, flow rate, and nitrate levels in situ; and
e) Capable of instantaneous review and logging of sensed parameters.

Using the above specifications, the team followed the system development procedures where they outlined their own set of objectives, design requirements, and specifications. These ideas were then shared with the graduate student and a team of faculty and researchers from various disciplines, including engineering, environmental sciences, aviation sciences, to garner their feedback. Once all stakeholders were satisfied, the students worked on the sourcing and pricing the required components and developing an initial design. The student team then decided to meet weekly, independent of the faculty and graduate student, to brainstorm the potential solutions and updated their progress. Their findings were then shared with the graduate student for confirmation that their solutions would be feasible in the working environment.

Eventually, it was decided that the system would be based upon the Arduino MEGA. The Arduino was selected since a few of the students had prior knowledge of this suite of microprocessors from previous research projects and class activities. The MEGA was specifically chosen because of its expanded capabilities and ability to support the eight instruments needed for the required water quality parameters. To power the system, a NiMH Onyx battery was used in conjunction with a BEC (Battery Eliminating Circuit) to regulate the voltage and comply with the power specifications of the microcontroller. Atlas Scientific probes were selected mainly because they offered research grade instruments and probes that could be integrated relatively easily with the Arduino MEGA. Finally a generic LCD and 12 button keypad were chosen and a general schematic of the monitoring system was made (Figure 2).

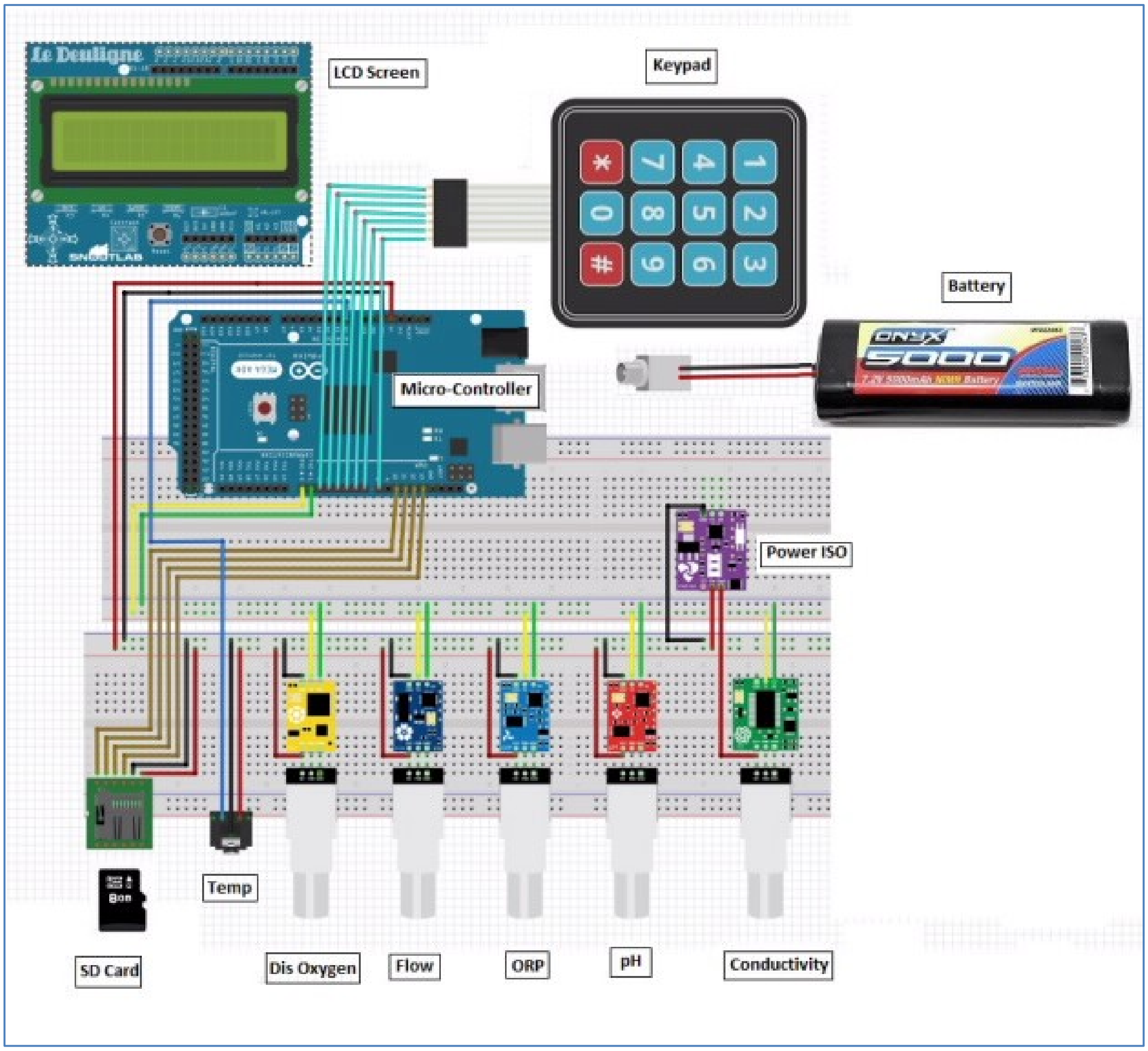

Figure 2. Automated Multiparameter Water Quality Monitoring System

Once the design had been completed and shared with all stakeholders, the students integrated sensors, microcontroller, and other peripherals. Originally, it was decided that a universal asynchronous receiver/transmitter (UART) protocol with multiplexing would be used to integrate the eight sensors. After several attempts, it was realized that there would be difficulties in attempting to parse data in this way; certain sensors simultaneously returned all their results while others failed to respond completely or in a timely fashion. One potential solution was to include an additional multiplexor, but it was quickly realized that this would increase system complexity unnecessarily. Eventually, after much frustration and research, the students identified an alternate protocol, Inter-Integrated Circuit (I^2C). I^2C utilization gave the team the ability to assign unique addresses to each sensor and then call upon them when required. This was also helped by the fact that Arduino already maintained built-in libraries simplifying the process of communicating with multiple devices. The only downside to this new approach was that I^2C is slower than the original UART. Fortunately this proved of little consequence to the application for which the system was being designed and therefore allowed the components to be subsequently integrated for testing and calibration (Figure 3). Once these phases were completed, the students continued with the finishing aspects; development of suitable protective cases for the various system components.

Figure 3. Testing and Calibration of Automated Multiparameter Water Quality Monitoring System

3.0 Experiential Survey Assessment

At the completion of the fabrication and testing phases of the project, student participants were administered a short survey which sought to evaluate their experiences. The survey assessed each participant using a 5-point Likert scale in four key domains (Figure 4):

Academic Outcomes

Life Skills

Civic Responsibility

Mentor Relations

The students' responses were then scored, recorded, and used to determine how the activities were internalized, benefitted their development, and could possibly be improved to maximize impact on subsequent cohorts.

A. Academic outcomes from the project

C.1 The objectives of this project were consistent with my research interests
C.2 This experiential learning project had an impact on my hands-on/laboratory skills and data collecting skills Which one(s) in particular?
C.3 This project had an impact on my presentation skills Which ones(s) in particular?
C.4 This project developed my technical skills
C.5 This activity enhanced my content knowledge?
C.6 I was able to integrate knowledge from many different sources and disciplines (example, chemistry, biology, engineering, technology, computer science, environmental sciences, etc)

B. Life Skills Outcomes

C.1 This project had an impact on my critical thinking skills?
C.2 This project improved my ability to work in teams and resolve conflicts?

C. Civic Responsibility Outcomes

C.1 This experiential learning project provided benefits to the community? In what capacity?
C.2 My appreciation for integrated STEM (Science, Technology, Engineering, and Mathematics) research grown?

Q.1 What did you like best about the experiential learning project?

Q.2 What did you like least about the experiential learning project?

D. Interpersonal: Mentor Relation Outcomes

C.1 The mentor relationship with my graduate supervisor-mentor met my work objectives, needs and expectations? Please explain:
C.2 I met regularly with my supervisor-mentor
C.3 My supervisor-mentor understood what I was saying.
C.4 My supervisor-mentor and I had meaningful conversations
C.5 My supervisor- mentor offered me guidance and knowledge.
C.6 I expect to remain in contact with my supervisor-mentor
C.7 As a result of my work experience with my supervisor-mentor I feel more assured about my career path Please explain:

Q.1 Did you experience any difficulties or challenges in your relationship with your supervisor-mentor?

Figure 4. Student Participation Assessment survey and survey questions.

4.0 Results and Discussion

The final automated multiparameter water quality monitoring system is shown below (Figure 5)

Figure 5. Final Version of Automated Multiparameter Water Quality Monitoring System

The students decided to utilize a small toolbox, which they modified, to serve as the case for the microcontroller and associated accessories. This decision came after realizing that their initial 3D custom-printed case may not be robust enough to withstand the rigors of the rough conditions inside the research greenhouse. The choice of the toolbox did have the added benefit of providing additional stowage for a spare battery pack, DC adapter and charger, in addition to any other small instruments that an operator may find useful while in the field surveying operations. All the sensors were eventually housed in a custom PVC casing with appropriate cut-outs to allow water to flow freely to the critical portions of each. The flow meter, due to its unique requirements, was placed below the main sensor bay and has an additional vent tube that can be attached to "vane" the meter to the main direction of flow.

The assessment found that students were very enthusiastic about the opportunity to participate in the hands-on research and product design and development (Figure 6). Feedback showed that content was improved through participation in the experiential learning. The students found that their learning was enhanced by having the opportunity to work closely with mentors, including graduate students and faculty members, throughout the duration of the project. The benefit of working in multidisciplinary teams also became apparent especially when problems arose; the inclusion of participants with a variety of skill sets and perspectives allowed for more organic pathways to solutions for project-related problems and conflicts.

Figure 6. Outcomes across the 4 Experiential Learning Domains

5.0 Conclusions and Future Work

Through involvement with this activity, undergraduate students in engineering and computer science were given an opportunity to participate in tangible and timely research, an occurrence that unfortunately is not too common with many STEM programs today. The tool these students have developed could eliminate the repetitive tasks of measuring and processing a multitude of water samples from the *Gracilaria* tanks at UMES. Additionally, due to the portability of the monitoring system, its use in Marine Botany and Marine and Estuarine Ecology classes is being strongly considered. Moreover, their efforts have the potential to vastly improve the productivity of deployed IMTA's seeking to solve the three dilemmas of the modern society: the production of energy, food, and preservation of the environment. This project facilitated opportunities for experiential learning along with positively impacting the students' academic development during their perusal of their undergraduate studies.

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Bibliography

1. Nigam, P. and Singh, A. (2011). Production of liquid biofuels from renewable resources. Progress in Energy and Combustion Science, 37: 52-68.
2. Pate, R., Klise, G., and Wu, B. (2011). Resource demand implications for US algae biofuels production scale-up. Applied Energy, 88: 3377-3388
3. Demirbas, A. (2009). Political, economic and environmental impacts of biofuels: A review. Applied Energy, 86: S108-S117.
4. Demirbas, A. (2010). Use of algae as biofuel sources. Energy Conversion and Management, 51: 2738-2749.
5. Demirbas, A. and Demirbas, M. (2011). Importance of algae oil as a source of biodiesel. Energy Conversion and Management, 52: 163-170.
6. Amin, S. (2009). Review on biofuel oil and gas production processes from microalgae. Energy Conversion and Management, 50: 1834-1840.
7. Subhadra, B. (2010). Sustainability of algal biofuel production using integrated renewable energy park (IREP) and algal biorefinery approach. Energy Policy, 38: 5892-5901.
8. US Environmental Protection Agency. (2016). Air Trends. Retrieved from http://www3.epa.gov/air/airpollutants.html
9. Keeling, C., Whorf, T., Wahlen, M., & Van Der Plichtt, J. (2009). Interannual extremes in the rate of rise of atmospheric carbon dioxide since 1980. Nature, 375: 666-670.
10. Kumar, A., Ergas, S., Yuan, X., Sahu, A., Zhang, Q., Dewulf, J., Malcata, F., and Langenhove, H. (2010). Enhanced CO2 fixation and biofuel production via microalgae: recent developments and future directions. Trends in Biotechnology, 28: 371-380.
11. Zidanšek, A., Blinc, R., Jeglič, A., Kabashi, S., Bekteshi, S., and Šlaus, I. (2009). Climate changes, biofuels and the sustainable future. International Journal of Hydrogen Energy, 3: 6980-6983.
12. Timilsina, G. and Shrestha, A. (2011). How much hope should we have for biofuels?. Energy, 36: 2055-2069.
13. Tan, I., Lam, M., and Lee, K. (2013). Hydrolysis of macroalgae using heterogeneous catalyst for bioethanol production. Carbohydrate Polymers, 94: 561-566.
14. Aitken, D., Bulboa, C., Godoy-Faundez, A., Turrion-Gomez, J., and Antizar-Ladislao, B. (2014). Life cycle assessment of macroalgae cultivation and processing for biofuel production. Journal of Cleaner Production, 75: 45-56.
15. McHugh, J. (2003). A guide to the seaweed industry. Food and Agriculture Organization of the United Nations, 91-92.
16. Abreu, M., Pereira, R., Yarish, C., Buschmann, A., & Sousa-Pinto, I. (2011). IMTA with Gracilaria vermiculophylla: Productivity and nutrient removal performance of the seaweed in a land-based pilot scale system. Aquaculture, 312: 77-87.
17. Huo, Y., Wu, H., Chai, Z., Xu, S., Han, F., Dong, L., & He, P. (2012). Bioremediation efficiency of Gracilaria verrucosa for an integrated multi-trophic aquaculture system with Pseudosciaena crocea in Xiangshan harbor, China. Aquaculture, 326-329: 99-105.

18. Abreu, M., Varela, D., Henríquez, L., Villarroel, A., Yarish, C., Sousa-Pinto, I., & Buschmann, A. (2009).Traditional vs. Integrated Multi-Trophic Aquaculture of Gracilaria chilensis C. J. Bird, J. McLachlan & E. C. Oliveira: Productivity and physiological performance. Aquaculture, 293: 211-220.
19. Ren,J., Stenton-Dozey, J., Plew, D., Fang, J., & Gall, M.(2012). An ecosystem model for optimising production in integrated multitrophic aquaculture systems. Ecological Modeling, 246:34-46.
20. Troell, M., Joyce, A., Chopin, T., Neori, A., Buschmann, & A., Fang, J. (2009). Ecological engineering in aquaculture — Potential for integrated multi-trophic aquaculture (IMTA) in marine offshore systems. Aquaculture, 297:1-9.
21. Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development* (Vol. 1). Englewood Cliffs, NJ: Prentice-Hall.
22. Kolb, D. A., & Wolfe, D. (1981). Professional education and career development: A cross-sectional study of adaptive competencies in experiential learning. Final report NIE G-77-0053, ERIC no. ED 209 493 CE 030 519.