



Communication

# Aqu@teach—The First Aquaponics Curriculum to Be Developed Specifically for University Students

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**Abstract:** Aquaponic food production requires a broad spectrum of knowledge in order to understand and manage the processes involved, and for commercial aquaponics to develop its full potential, it will require an appropriately trained workforce. Devised in collaboration as an Erasmus+ Strategic Partnership for Higher Education, Aqu@teach covers the basics of aquaponics with a focus on transferable and entrepreneurial skills. The aquaponics curriculum can either be taught using blended learning—combining digital media and the internet with classroom formats that require the physical co-presence of the teacher and students—or as an e-learning course. The supplementary entrepreneurial skills module was devised on the basis of two surveys: of aquaponics companies around the world, in order to get a broad overview of the skills that are important in the early years of a business; and of European higher education institutions that teach subjects where aquaponics could be incorporated as an optional module. The entrepreneurial skills curriculum introduces the main processes involved in developing a business idea into a start-up company. All of the Aqu@teach resources—the e-learning modules, textbooks, module guides for students, curriculum guides for teachers, best practice guide for teaching aquaponics, and toolbox of innovative didactic practices—are open access.

**Keywords:** open access curriculum; aquaponics; higher education; e-learning; transferable skills; entrepreneurial skills



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## 1. Introduction

The policies affecting food systems in Europe—agriculture, trade, food safety, environment, research and development, education, fiscal and social policies, market regulation, competition, and many others—have developed in an ad hoc fashion over decades [1]. However, in recent years, there has been a common agenda to strive towards improving the economic, social, and environmental sustainability of both the methods by which food is produced, and the supply chains by which it is distributed. In the European Parliamentary Research Service report on ‘Ten technologies which could change our lives’, aquaponics was singled out as a solution for developing innovative and sustainable food sources for Europe [2]. Combining two technologies—recirculating aquaculture systems (RAS) and hydroponics—in a closed-loop system, aquaponics requires a low level of resource input, since the plants receive their nutrients from the fish water [3–5]. Over-fishing in the sea, water scarcity and soil/water degradation caused by intensive farming, the use of antibiotics in aquaculture, and pesticides and herbicides in field production, should all favour

this soil-less food production technology that neither contributes to nor exacerbates these problems. Controlled-environment agricultural technologies such as aquaponics are likely to become more important in the future due to climate change, while the phenomenon of ‘food kilometres’—the carbon footprint of food production and distribution—plays to the strengths of local production of food, especially within cities, by shortening food supply chains and improving the security and resilience of food systems. A synergy can be created between a farm and its host building by coupling the flows of the agricultural process—heat, water, and CO<sub>2</sub>—with those of the building, in order to close the waste, resource, and energy loops [6].

Aquaponics also clearly has a role to play in the agendas of both Agriculture 4.0 and Aquaculture 4.0, which embrace the application of innovative and disruptive technologies in order to increase efficiency, productivity, and sustainability. Agriculture 4.0, also called ‘the fourth agricultural revolution’, embraces the adoption of technologies such as hydroponics and vertical farming to ensure food security in the face of growing population size, increased urbanization, scarcity of natural resources, and climate change [7], while ‘Aquaculture 4.0’ advocates the application of Industry 4.0 technologies, such as the Internet of Things and artificial intelligence, in fishery management strategies that require real time monitoring of water quality, such as RAS and multi-trophic aquaculture [8].

Governments have the power to foster a full ecosystem of technology companies, research centres, universities, and innovative start-ups working together to drive forward these agendas, and can enable the environment by offering financial incentives, regulatory flexibility, and providing infrastructure at an affordable price. However, aquaponics requires explicit political support in Europe regarding legislation, because, as a hybrid technology, it falls between the two stools of agriculture and aquaculture. At the EU level, policy is dictated by two separate Directorates-General of the European Commission—Agriculture and Rural Development (DG AGRI) and Maritime Affairs and Fisheries (DG MARE)—and by separate European Parliament Committees (AGRI and PECH). In the absence of an umbrella strategy cutting across these different policy areas, a number of synergies are missed, including aquaponics. This silo approach to the governance of food production is also found in the national ministries of many countries in Europe [9,10].

However, there are signs that things at EU level are starting to change or, at least, that efforts are being made to break down the institutional silos in order to foster innovation. In 2012, the European Commission launched five European Innovation Partnerships, one of which—EIP-AGRI—is dedicated to agricultural productivity and sustainability. Their mandate is to help to pool expertise and resources by bringing together public and private sectors at EU, national, and regional levels, and to support cooperation between research and innovation partners. Their recent report on circular horticulture acknowledged the contribution that aquaponics could make, although it also flagged up the bottlenecks, including the lack of experience in and tradition of aquaponic farming in Europe [11].

In order for aquaponics to develop its potential in Europe, it needs an appropriately trained workforce. The Aqu@teach project aimed to address that need, by developing the first ever aquaponics curriculum specifically for higher education students. Aquaponic food production requires a broad spectrum of knowledge—aquaculture, horticulture, chemistry, biology, food safety, and engineering—in order to understand and manage the processes involved. The Aqu@teach curriculum was designed to equip students with expert knowledge and skills, as well as digital, entrepreneurial, and transferable skills that will provide them with a competitive advantage in the labour market. The curriculum was developed by an Erasmus+ Strategic Partnership for Higher Education between the University of Greenwich (UK), the Zurich University of Applied Sciences (CH), the Technical University of Madrid (ES), the University of Ljubljana, and the Biotechnical Center Naklo (SI). Given the multi-disciplinary nature of aquaponics, the curriculum can be taught as an optional module in a wide variety of degree courses, including agriculture, agronomy, horticulture, aquaculture, and ecological engineering. Indeed, catering for the variety of backgrounds of the potential

students was one of the greatest challenges that the partnership faced when developing the curriculum.

## 2. Materials and Methods

Aqu@teach was developed in accordance with the recommendations of the Standards and Guidelines for Quality Assurance in the European Higher Education Area [12] and the Considerations for Quality Assurance of E-learning Provision issued by the European Association for Quality Assurance in Higher Education [13]. According to these recommendations, higher education e-learning courses should be delivered in a way that encourages students to take an active role in creating the learning process, and this should be reflected in the way that they are assessed. Student-centered learning, teaching, and assessment should involve the use of flexible learning paths, different modes of delivery, and a variety of pedagogical methods, and students should be given a sense of autonomy. An online course needs to be designed in such a way that it stimulates and engages students in the learning process, and to reflect best practices and research in teaching and learning. In accordance with these recommendations, Aqu@teach is hosted by the open source Moodle virtual learning environment, which facilitates student-centered learning by incorporating a variety of different activities—wikis, workshops, glossaries, discussion forums, etc.—designed to encourage students to use different ways to engage with the teaching materials and different ways to interact and express themselves.

The fifteen module Aquaponics Curriculum and the supplementary Entrepreneurial Skills module were designed using a ‘Toolbox of Innovative Didactic Practices’ intended to encourage a mixture of student dialogue and collaboration, autonomy, critical thinking, and creativity. The open source Learning Designer software (<https://www.ucl.ac.uk/learning-designer/>) was used, which helps teachers to design learning experiences as sequences of teaching and learning activities that will help students move towards their learning goals. Learning Designer is based on the six types of learning as defined by the Conversational Framework [14]: Acquisition—reading, listening, watching; Inquiry—researching; Practice—performing a task; Production—producing something for teacher or peer evaluation; Discussion—asking questions; and Collaboration—shared student activities resulting in a shared output. Laurillard argues that effective learning requires cycles of communication to take place between teachers and learners and between learners and their peers, and that these are promoted by the combination of the six learning types. In principle, a good learning design will therefore contain a mixture of all of these types of learning [15,16].

### 2.1. The Aquaponics Curriculum

The Aquaponics Curriculum was pilot tested as an instructor-led, cohort-based e-learning course at each of the five partner institutions, with students studying very different disciplines: landscape architecture (Greenwich), agricultural engineering (Madrid), natural resource sciences (Zurich), sanitary engineering (Ljubljana), and horticulture (Naklo). Each of the 15 modules involved a range of different activities, some of which are inherent in Moodle, such as workshops, wikis, and discussion forums, while others involved external platforms, such as the Flickr image sharing service and the Diigo social bookmarking website that enables users to bookmark and jointly annotate web pages.

The pilot course was taught over a five month period and was evaluated based on comprehensive student feedback on each individual module and on the various teaching and learning methods used, and self-evaluation by the tutors. For each module, the students were asked to provide feedback on the level of content, the textbook chapter, the degree of knowledge gain, the teaching methods used, the balance of activities, the number of hours taken to complete it, and how it could be improved. Regarding the various teaching and learning methods used, the students were asked to evaluate which activities enhanced the learning process, and whether the time and effort needed to complete them was proportionate to the learning benefits. The activities were subsequently modified, and the lessons

learnt were developed into the 'Teaching Aquaponics: Best Practice Guide', which provides instructors with fresh ideas for achieving the best educational results when teaching a multidisciplinary subject that requires high-quality knowledge in diverse fields as well as the specifics of interdisciplinary integration.

## 2.2. The Entrepreneurial Skills Module

The curriculum for the supplementary Entrepreneurial Skills module was developed following two surveys: a survey of aquaponics companies in Europe and further afield, in order to get a broad overview of the skills that are important in the first few years of a business; and a survey of European higher education institutions, which teach subjects where aquaponics could be incorporated into the curriculum—such as aquaculture, horticulture, agriculture, agronomy, landscape architecture, and ecological engineering—in order to ascertain which entrepreneurial skills are pertinent to those disciplines. Questionnaires soliciting anonymous responses were distributed via email.

The questionnaire for aquaponics companies was sent to 250 companies worldwide. The response rate was 16% ( $n = 40$ ). Alongside the questions pertaining to entrepreneurial skills, the opportunity was taken to solicit information on a much broader range of topics, and the correlation between these will be subject to analysis and further investigation at a later date, for example, the relationship between the perceived importance of certain skills and the particular nature of the aquaponics business—production and sales of fresh produce, sales of equipment, or consultancy. There was an overall consensus that all of the skills included in the questionnaire are considered to be more or less important—technical skills, business management skills, and personal skills—but the most important ones are business management skills, and specifically the ability to hire efficient and motivated people and to understand customer needs.

The questionnaire for higher education teachers was sent to 392 people in European higher education institutions. The response rate was 11% ( $n = 44$ ). More than half of the respondents did not include any formal teaching of entrepreneurial skills in their undergraduate curriculum. Those that do mainly teach business plans, business models, and marketing, which reflects their perceived importance for enhancing the employability of their graduates, with less emphasis on financial planning and fundraising. The majority of respondents informally teach entrepreneurial skills through experiential learning, mainly through teamwork and creative thinking, although oral communication skills were considered to be the most important for graduate employability.

The results of the questionnaires were used to design the contents of the Entrepreneurial Skills curriculum. It was taught during a five day summer school in Slovenia attended by students and staff from the five institutions participating in the project, with lectures and group exercises delivered by aquaponics entrepreneurs and experts in marketing, financing and branding. The curriculum was subsequently converted by the staff into an e-learning module.

## 3. Results

The student feedback from the pilot run of the Aquaponics Curriculum revealed that activities involving platforms external to the Moodle environment, such as Flickr and Diigo, were not perceived to have enhanced the learning process, since it took time to register for an account and to learn how to use the web sites. These activities were therefore replaced by Moodle Database which essentially performs the same image and web page sharing functions. The number of internet search activities was also reduced, since these were deemed to be too time-consuming. This section presents the contents of the open access Aqu@teach e-learning course which was released to the public in July 2020, and explains how the various activities have been used and their pedagogical value.

### 3.1. The Aquaponics Curriculum

The Aquaponics Curriculum is intended for tertiary level teachers who want to introduce basic aquaponics to their students. The student workload for the entire curriculum is 150 h, corresponding to five ECTS, and is divided into 15 modules: (1) Aquaponic technology, (2) Aquaculture, (3) Fish anatomy, health and welfare, (4) Fish feeding and growth, (5) Nutrient water balance, (6) Hydroponics, (7) Plant varieties, (8) Integrated pest management, (9) Monitoring of parameters, (10) Food safety, (11) Scientific research methods, (12) Design and build, (13) Urban agriculture, (14) Vertical aquaponics, and (15) Social aspects of aquaponics.

The Aquaponics Curriculum takes full advantage of the various activity tools in Moodle, which are designed to encourage a mixture of student dialogue and collaboration, autonomy, critical thinking, and creativity, and provides instructional scaffolding to support the students as they progress through each module.

#### 3.1.1. Moodle Database

The Database activity enables the students to build, display, and search a bank of entries about a particular topic. In so doing, they create a communal resource for the benefit of themselves and their peers. The format and structure of these entries can be almost unlimited, and they can include images, files, URLs, and text. Image sharing activities are particularly useful for topics such as plant pests and diseases and nutrient deficiencies, where different databases can be used to store a handy reference source of photos for each topic. The webpage sharing activities ('social bookmarking') are mainly geared towards finding and storing pages relating to equipment and consumables, so that the students can obtain a broad overview of what is available, and what it costs. The communal building of a database reduces the amount of time that each student needs to spend searching the internet for images or webpages, and it is a useful tool for sharing resources. The ability to search the database makes it a handy reference tool, and it is also a good revision tool.

#### 3.1.2. Moodle Wiki

A wiki is a report on a single topic that contains enough complexity to allow individual students to contribute, review, and edit a section of an entry. It encourages collaboration, is easy to use, and provides a useful forum for sharing the results of a research exercise. In the Aquaponics Curriculum, the Wiki activity is used for topics such as the range of hydroponic fertilizers that are commercially available and how they differ in terms of their constituent elements and price, abnormalities in the external anatomy of fish, and the five stages of an integrated pest management programme.

#### 3.1.3. Moodle Glossary

The Glossary activity encourages students to create and maintain a communal alphabetical list of specialised or technical terms and their definitions. Since aquaponic production requires a broad spectrum of knowledge in order to understand and manage the processes involved, this means that there will be many terms with which the students will be unfamiliar. The glossary helps students get used to new terminology, which in turn helps them to acquire a better understanding of the related concepts. When students are responsible for creating the definitions, they are more likely to remember the word and the correct definition. It also ensures that students have a handy source for the definitions of terms, and it is a good revision tool.

#### 3.1.4. Moodle Forum

The Forum activity enables students and teachers to engage in asynchronous discussion by posting comments as part of a 'thread'. Asynchronous discussion forums allow learners to participate without the limits of time and space, and give the participants more time to reflect, and to interact with each other, which provides potential for more in-depth discussion. It also promotes collaborative learning, higher order thinking, and

critical thinking. In the Aquaponics Curriculum, the Forum activity is used to enable students to critically evaluate the knowledge that they have acquired from their reading, watching, or searching activities, for example: suitable plant varieties for growing as a polyculture in a small commercial greenhouse, whether fish feel pain, and the microbiological, chemical, and physical hazards and allergens most likely to be expected in aquaponic food production.

#### 3.1.5. Moodle Workshop

Workshop is a powerful peer assessment activity. Students submit their own work and then receive one or more submissions from their fellow students, which they must assess according to a predetermined list of criteria set by the teacher. Predetermined assessment criteria means that there can be little confusion about assignment outcomes and expectations. Moodle Workshop encourages collaborative learning and increases student responsibility. It develops a better understanding of a student's own subjectivity and judgement, as well as critical thinking. It also exposes them to solutions, strategies, and points of view that they would not see otherwise. Students can produce more effective feedback than tutors by providing explanations in terms that their peers understand best, and according to their level of understanding. It therefore shifts the role of the student from passive learner to active learner, which encourages a deeper approach to learning. The Workshop activity is particularly useful for peer assessment of exercises that involve calculations and practical tasks, for example calculating the nutrient balance of an aquaponic system; creating a crop schedule; and calculating fish biomass and feed for a 300 m<sup>2</sup> polyculture of leafy greens, herbs, and flowers.

#### 3.1.6. Instructional Scaffolding

By way of example, Figure 1 illustrates the use of instructional scaffolding in Module 7—Plant varieties. Instructional scaffolding is the support provided by the teacher throughout the learning process, and is particularly important when concepts and skills are being introduced to students for the first time. This support is specifically tailored to each student, which enables student-centered learning. In this example, the support from the teacher is provided in the discussion forums and in the formative feedback that is provided after the first two calculation exercises, so that any misunderstandings may be rectified before the final exercise. Sharing definitions in the Glossary and resources in the Database, and the use of Forum and Workshop activities, creates a community of learning, which further supports the students as they progress through the module. In this module, the activities have been designed to develop the students' commercial awareness about the plant cultivars available in their country which might be suitable for commercial production.

### 3.2. *The Entrepreneurial Skills Module*

Aquaponics potentially offers entrepreneurs many possibilities for starting a business, including the commercial production of food and non-food products; consultancy services for the design and build of commercial farms; the supply of specialist equipment; and domestic systems for restaurants, schools, and the general public. The Entrepreneurial Skills module builds on the knowledge that students will have gained through completing the Aquaponics Curriculum and adopts the lean start-up methodology to introduce the main processes involved in developing a business idea into a start-up company—business models, customer segmentation, value proposition, marketing and pricing, and financing. The student workload for the entire curriculum is 60 h, corresponding to 2 ECTS. The curriculum was designed using the same student-centered teaching tools employed in the Aquaponics Curriculum, and the majority of the activities involve student teamwork in order to reflect the reality of setting up a business, since this is rarely a solo endeavour. Each student team is asked to use the Forum activity to agree on an idea for an aquaponics business, and as they progress through the module, they primarily use Forum and Wiki

activities to collaboratively develop their idea, alongside a number of lean start-up methodology tools such as brainstorming canvases. The module culminates with each student recording a 10 min start-up pitch, which is then evaluated by their peers and their teacher in Moodle Workshop.

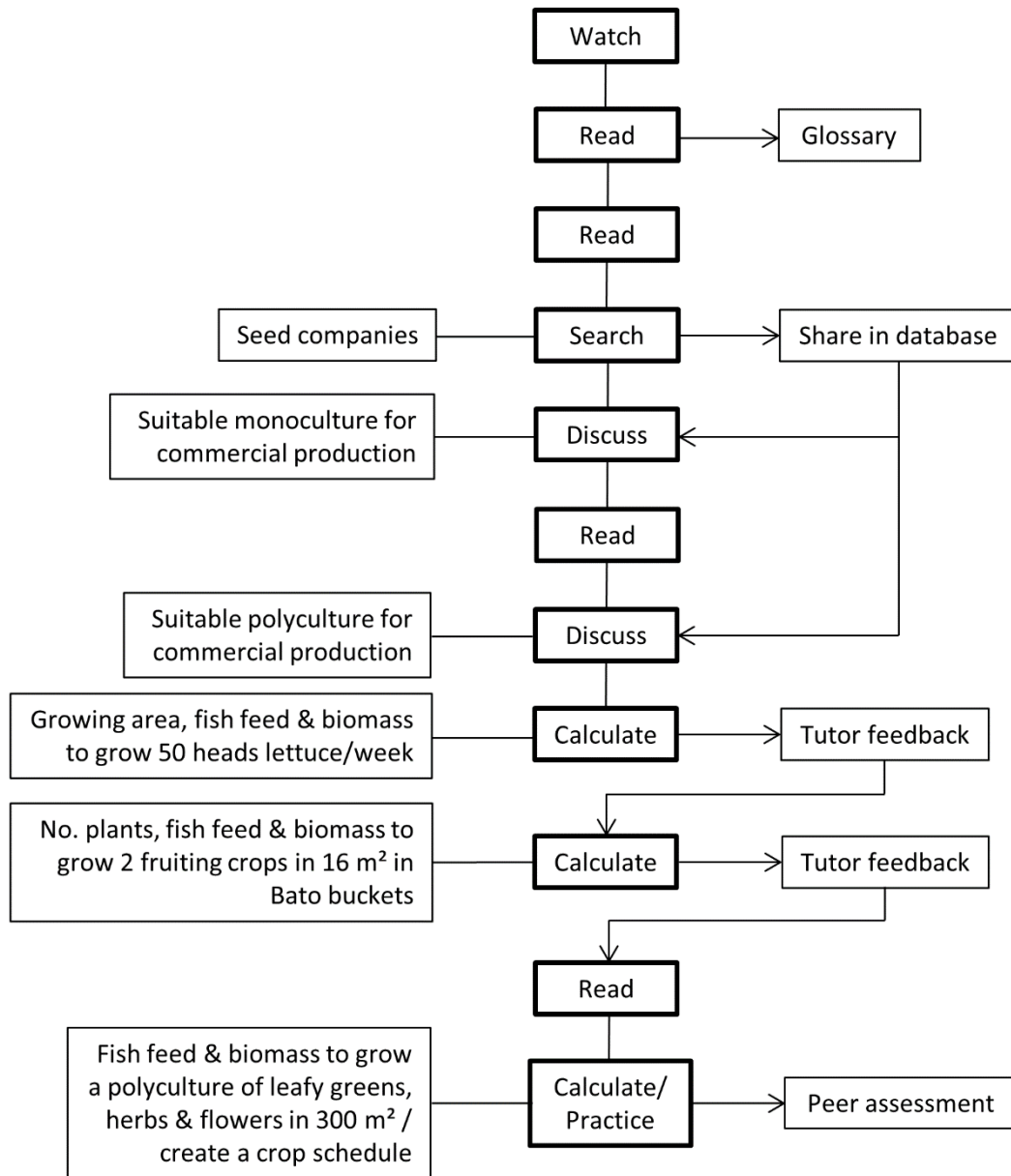


Figure 1. Instructional scaffolding in Module 7—Plant varieties.

#### 4. Discussion

Aqu@teach can be taught either using blended learning—combining digital media and the internet with classroom formats that require the physical co-presence of the teacher and students—or as an instructor-led, cohort-based e-learning course. In education, it is often taken for granted that technologies can ‘enhance learning’, and the term ‘Technology Enhanced Learning’ (TEL) is increasingly being used in Europe and other parts of the world. However, it is important to be aware that adding too many technologies to support teaching and learning, especially where one or two can do a job well, can overwhelm a student [17,18]. Students are efficient technology users, and are interested in getting jobs done, simply and conveniently. Resources are sought quickly, and students rarely look

beyond the first page of results of a Google search [19,20]. The pilot run of the Aquaponics Curriculum confirmed these findings. Based on student feedback, the number of internet search activities was subsequently reduced, and the variety of technologies was simplified.

The development of open access e-learning courses such as Aqu@teach is one of the best possible solutions for democratising higher education, thereby contributing towards achieving Sustainable Development Goal 4—inclusive and equitable quality education and lifelong learning opportunities for all. In contrast to ready-made online courses hosted on private platforms where the curriculum is fixed, Aqu@teach provides educators with a flexible toolbox that they can use to suit their needs. Since the modules are self-contained, educators may choose to teach all or just some of them, either in a blended format—for example by first introducing content online to students at home, with class time then being used to deepen understanding through discussion and problem-solving activities—or entirely online. Indeed, the Moodle files, as well as the accompanying documents—the textbooks, the curriculum guides for teachers, and the module guides for students—have been released with Creative Commons NonCommercial-ShareAlike licenses, which means that educators can alter the contents as they see fit, including translating them into languages other than the ones in which they are currently available: English, Spanish, German, and Slovene. This flexibility was designed in to ensure that the curriculum can be adopted as widely as possible, in order to encourage the development of an appropriately trained workforce and thereby enable aquaponics to develop its full potential as an innovative and sustainable food production technology. All of the Aqu@teach resources are freely available on the project website: <https://www.aquateach.wordpress.com>.

## 5. Conclusions

The development of Aqu@teach involved a consortium of more than twenty individuals with different expertise, including aquaponics, aquaculture, horticulture, agricultural engineering, food safety, marketing, online teaching, and theory and practice of learning. The resulting Aquaponics Curriculum, the first specifically designed for university level students, combines high-quality knowledge in diverse fields and the specifics of interdisciplinary integration, and was co-designed with students in order to ensure that the result meets their needs. The supplementary Entrepreneurial Skills module introduces the process of translating that specialist knowledge into a viable business model. The uptake of Aqu@teach by higher education institutions is being monitored in order to be able to evaluate its impact on the future development of commercial aquaponics.

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