

## Chapter 22

# Aquaponics as an Educational Tool



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**Abstract** This chapter provides an overview of possible strategies for implementing aquaponics in curricula at different levels of education, illustrated by case studies from different countries. Aquaponics can promote scientific literacy and provide a useful tool for teaching the natural sciences at all levels, from primary through to tertiary education. An aquaponics classroom model system can provide multiple ways of enriching classes in Science, Technology, Engineering and Mathematics (STEM), and the day-to-day maintenance of an aquaponics can also enable experiential learning. Aquaponics can thus become an enjoyable and effective way for learners to study STEM content, and can also be used for teaching subjects such as business and economics, and for addressing issues like sustainable development, environmental science, agriculture, food systems, and health. Using learner and teacher evaluations of the use of aquaponics at different educational levels, we attempt to answer the question of whether aquaponics fulfils its promise as an educational tool.

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## 22.1 Introduction

Aquaponics is not only a forward-looking food production technology; it also promotes scientific literacy and provides a very good tool for teaching the natural sciences (life and physical sciences) at all levels of education, from primary school (Hofstetter 2007, 2008; Bamert and Albin 2005; Bollmann-Zuberbuehler et al. 2010; Junge et al. 2014) to vocational education (Baumann 2014; Peroci 2016) and at university level (Graber et al. 2014).

An aquaponic classroom model system provides multiple ways of enriching classes in Science, Technology, Engineering, and Mathematics (STEM). The “hands-on” approach also enables experiential learning, which is the process of learning through physical experience, and more precisely the “meaning-making” process of an individual’s direct experience (Kolb 1984). Aquaponics can thus become an enjoyable and effective way for learners to study STEM content. It can also be used for teaching subjects such as business and economics, addressing issues such as sustainable development, environmental science, agriculture, food systems, and health (Hart et al. 2013).

A basic aquaponics can be built easily and inexpensively. The World Wide Web is a repository of many examples of videos and instructions on how to build aquaponics from a variety of components, resulting in a range of different sizes and set-ups. Recent investigations of one such prototype micro-aquaponics showed that despite being small, it can mimic a full-scale unit and it is an effective teaching tool with a relatively low environmental impact (Maucieri et al. 2018). However, implementing aquaponics in classrooms is not without its challenges. Hart et al. (2013) report that technical difficulties, lack of experience and knowledge, and maintenance over holiday periods can all pose significant barriers to teachers using aquaponics in education, and that disinterest on the teacher’s part may also be a crucial factor (Graham et al. 2005; Hart et al. 2014). Clayborn et al. (2017), on the other hand, showed that many educators are willing to incorporate aquaponics in the classroom, particularly when an additional incentive, such as hands-on experience, is provided.

Wardlow et al. (2002) investigated teachers’ perceptions of the aquaponic unit as a classroom system and also illustrated a prototype unit that can easily be constructed. All teachers strongly agreed that bringing an aquaponics unit into the classroom is inspiring for the students and led to greater interaction between students and teachers, thereby contributing to a dialogue about science. On the other hand, it is unclear exactly how the teachers and students made use of the aquaponics and the instructional materials offered. Hence, the information needed to evaluate the impact of aquaponics classes on meeting the objectives of the students’ curricula is still missing. In a survey on the use of aquaponics in education in the USA (Genello et al.

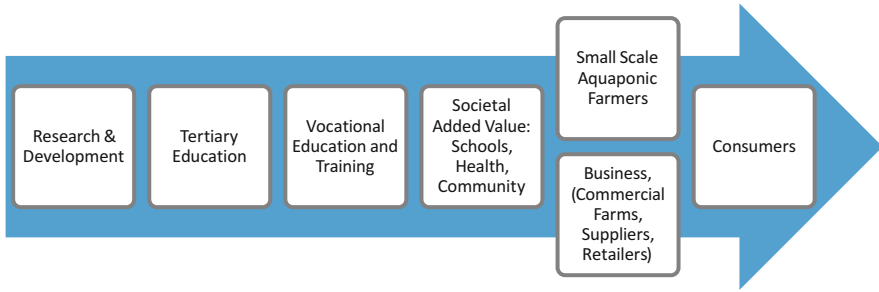
2015), respondents indicated that aquaponics were often used to teach subjects, which are more exclusively focused on STEM topics. Aquaponics education in primary and secondary schools is science-focused, project-oriented, and geared primarily toward older students, while college and university aquaponics were generally larger and less integrated into the curriculum. Interdisciplinary subjects such as food systems and environmental science were taught using an aquaponics more frequently at colleges and universities than they were at schools, where the focus was more often on single discipline subjects such as chemistry or biology. Interestingly, only a few vocational and technical schools used aquaponics to teach subjects other than aquaponics. This indicates that for these educators, aquaponics is a stand-alone subject and not a vehicle to address STEM or food system topics (Genello et al. 2015).

While the studies mentioned above reported aquaponics as having the potential to encourage the use of experimentation and hands-on learning, they did not evaluate the impact of aquaponics on learning outcomes. Junge et al. (2014) evaluated aquaponics as a tool to promote systems thinking in the classroom. The authors reported that 13–14 year old students (seventh grade in Switzerland) displayed a statistically significant increase from pre- to post-test for all the indices measured to assess their systems thinking capacities. However, since the pupils did not have any prior knowledge of systems thinking, and since there was no control group, the authors concluded that supplementary tests are needed to evaluate whether aquaponics has additional benefits compared to other teaching tools. This issue was addressed in the study by Schneller et al. (2015) who found significant advances in environmental knowledge scores in 10–11 year old students compared to a control group of 17 year olds. Moreover, when asked for their teaching preferences, the majority of students indicated that they preferred hands-on experiential pedagogy such as aquaponics or hydroponics. The majority of the students also discussed the curriculum with their families, explaining how hydroponic and aquaponics work. This observation extends the belief that hands-on learning using aquaponics (and hydroponics) not only has a stimulating impact on teachers and students, but also leads to intergenerational learning.

The objective of this chapter is to provide an overview of possible strategies for implementing aquaponics in curricula at different levels of education, illustrated by case studies from different countries. Based on evaluations conducted with some of these case studies, we attempt to answer the question of whether aquaponics fulfils its promise as an educational tool.

## **22.2 General Scenarios for Implementing Aquaponics in Curricula**

The introduction of aquaponics into schools may be an aspiration, but in many countries, primary and secondary schools have rigid curricula with learning objectives that must be met by the end of each school year. Commonly, these objectives,



**Fig. 22.1** An aquaponics can address various goals or stakeholders by offering to develop key competences in appropriate educational and training processes. (Modified after Graber et al. 2014)

called attainment terms or outcome competencies, are course-specific and defined by the education authorities. Thus, this calls for a well-thought-out strategy to successfully introduce an aquaponics in school classes. In comparison, colleges and universities have more freedom to map out their own curricula.

### ***22.2.1 Which Types of Aquaponics Are Suitable for Education?***

There are, as stated above, many aquaponics described and illustrated on the web. It is also possible to purchase a kit, or have a complete system delivered and installed. However, building an aquaponics is in itself a valuable educational experience, and the fact that it is not delivered to the classroom ready-made adds to its instructional value.

An aquaponics can address various goals or stakeholders (Fig. 22.1). To attain all of these, the components of a system have to fulfill various requirements (Table 22.1). The choice of what kind of aquaponics is suitable for a particular institution should result from a realistic assessment of its facilities and the educational objectives.

Maucieri et al. (2018) proposed a general classification of aquaponics according to different design principles. While a system can simultaneously fulfill several objectives, including greening and decoration, social interaction, and food production, here we assume that the main objective is education. If we follow the classification of Maucieri et al. (2018), which categorizes the aquaponics according to several categories (stakeholder, size), several distinct options for choosing a suitable aquaponics emerge (Table 22.2). Any decision has to be made within the limits of the available budget, though it is possible to construct a system at very low cost.

**Table 22.1** General requirements for three types of educational aquaponics

Aspect	Research (basic and applied)	Tertiary education (BSc, MSc, PhD)	Societal added value: Education (primary and secondary), vocational training, communication, health benefits
Access	Good access for daily work and monitoring,	Good access for daily work and monitoring; Good access for groups	Good access for groups
Size	Reasonable size for scaling-up for potential commercial farms (depending on the crop)	Reasonable size for a good overview of different cultivation options	Reasonable size for a good overview
Construction	Easy remodeling <sup>a</sup>	Easy remodeling	Mostly commercial off-the-shelf elements
Climate control	Advanced	Basic	Basic
Diversity of production methods	Variable according to current research projects <sup>b</sup>	Variable to high: from basic (demonstration of system) to cutting edge (research)	High: from basic (demonstration of system) to cutting edge (demonstration of potential)
Recycling, closed-loop systems	Quantitative importance: improving the ecological footprint and thus reducing costs	Quantitative and qualitative importance	Qualitative importance: demonstration of ecological principles
Provision of energy from renewable sources	Quantitative importance: improving the ecological footprint and thus reducing costs	Quantitative and qualitative importance	Qualitative importance: demonstration of ecological principles
Rainwater harvesting, treatment, and use	Quantitative importance: improving the ecological footprint and thus reducing costs	Quantitative and qualitative importance	Qualitative importance: demonstration of ecological principles

Modified after Graber et al. (2014)

<sup>a</sup>allows testing of different set-ups

<sup>b</sup>from state of the art (aligned with current practices of professional vegetable growers and fish farmers) to cutting edge (testing innovative production methods)

Additional questions to be asked before installing an aquaponics are

- What size of system to choose? The size of the system will most probably increase in relation to the age of the students: smaller systems in kindergarten and larger systems in high school.
- Where is the system to be placed? Micro-systems (Table 22.2) can be placed in a classroom. However, very small and small systems (Table 22.2) require more space and perhaps a greenhouse will need to be constructed to house these.
- Is the system going to be a temporary or a permanent feature? If it is going to be a permanent feature, who will take care of the system during the holidays? If it is going to be a temporary feature, the institution might consider borrowing an

**Table 22.2** Suitability of different design options for an educational aquaponics. The green color denotes the most suitable options, yellow options are less suitable, while red options are not suitable for the majority of cases

Size	Operational mode of the aquaculture compartment	Water cycle management	Water type	Type of implemented hydroponic system	Use of space
XXS micro systems (<5 m <sup>2</sup> )	Extensive <sup>a</sup>	Closed loop systems <sup>c</sup>	Freshwater (Tap or Well)	Grow beds with different media	Horizontal
XS very small (5-50 m <sup>2</sup> )	Intensive <sup>b</sup>	Open loop systems <sup>d</sup>	Rainwater	Ebb-and-flow system	Vertical
S small (51-200 m <sup>2</sup> )			Salt / Brackish water	Grow bags	
M medium (201-1000 m <sup>2</sup> )				Drip irrigation	
L large (>1000 m <sup>2</sup> )				Deep water cultivation (rafts)	
				Nutrient film technique (NFT)	

<sup>a</sup>Extensive (fish density is mostly under 10 kg/m<sup>3</sup> and allows for integrated sludge usage in grow beds).

<sup>b</sup>Intensive (fish density requires additional sludge separation; however, the sludge has to be treated separately).

<sup>c</sup>Closed loop (“coupled” systems): after the hydroponic component, the water is recycled to the aquaculture component.

<sup>d</sup>Open loop or end-of pipe (“decoupled” systems): after the hydroponic component, the water is either not or only partially recycled to the aquaculture component.

aquarium from an aquarist among the staff or the students, who would also be able to give advice on fish care.

- Are the fish going to be harvested? Animal welfare should always be observed and killing the fish should be done according to animal protection laws (Council of the European Union 1998). Children might have problems in killing and eating a living animal, which resembles Dory (from the movie finding Nemo). If the fish are not going to be harvested, then goldfish or Koi are a good option.
- Are the plants going to be harvested and eaten? If yes, then suggestions for using the produce need to be prepared. If not, then consider using ornamental plants instead.

### 22.2.2 How to Embed Aquaponics as a Didactic Tool?

An aquaponics with living fish and plants obviously provides the potential for long-term engagement compared to conventional single discipline scientific experiments. While this is a manifest asset for progressive and continuous experiential learning, it has been indicated that safeguarding the teacher’s interest in the long run and the provision of learning material are key challenges to successfully incorporating aquaponics in school classes (Hart et al. 2013; Clayborn et al. 2017).

Ideally, the model aquaponics should be embedded in different classes in a way that it facilitates attaining course-specific educational goals. Subjects, which promote an understanding of natural cycles, waste recycling, and environmental protection, are the most obvious. However, aquaponics can also be used in other subjects, such as art, social sciences, and economics. The examples discussed in Examples 22.1, 22.2, 22.3, 22.4, 22.5, 22.6 and 22.7 below provide an insight into the versatility of aquaponics in education.

Active aquaponics can be used for teaching over different time periods, and accordingly there are distinct scenarios:

- (a) Over one term, 1–2 classes per week (8–12 weeks) (see Examples 22.1 and 22.3)
- (b) As a half- to one-day educational activity (see Example 22.4)
- (c) As a Science Week or Project Week on 2–5 consecutive days (see Example 22.2)
- (d) As an extracurricular activity, during one term of 10–15 weeks
- (e) As a permanent feature for the whole school, thus providing a focal “conversation piece” and study/research facility for several classes (see Examples 22.5 and 22.6, Graber et al. 2014)

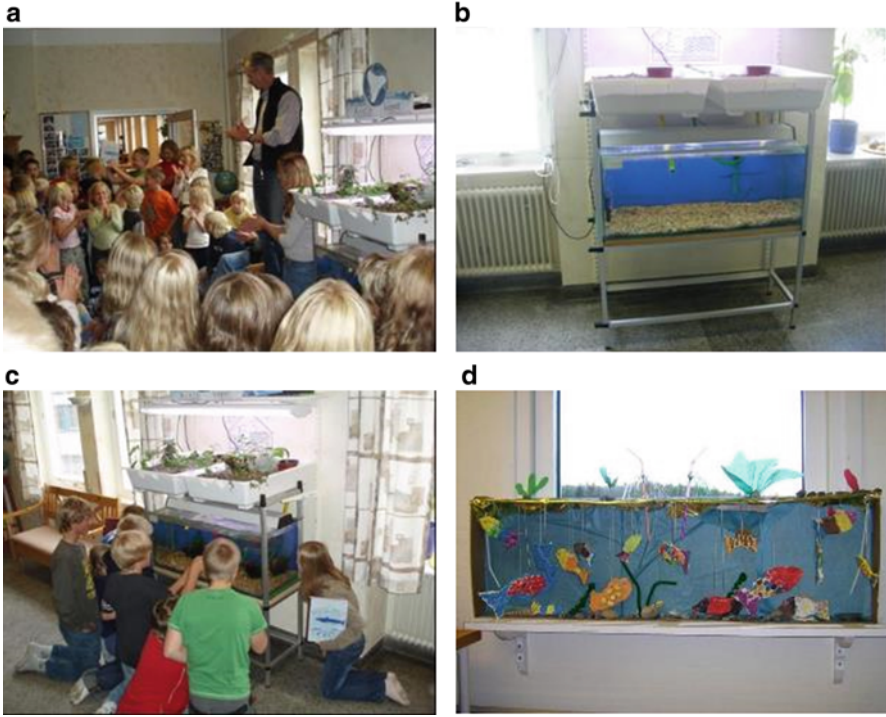
### 22.3 Aquaponics in Primary Schools

According to the International Standard Classification of Education (UNESCO-UIS 2012), primary education (or elementary education in American English) at ISCED level 1 (first 6 years) is typically the first stage of formal education. It provides children from the age of about 5–12 with a basic understanding of various subjects, such as maths, science, biology, literacy, history, geography, arts, and music. It is therefore designed to provide a solid foundation for learning and understanding core areas of knowledge, as well as personal and social development. It focuses on learning at a basic level of complexity with little, if any, specialization. Educational activities are often organized with an integrated approach rather than providing instruction in specific subjects.

The educational aim at ISCED level 2 (further 3 years) is to lay the foundation for lifelong learning and human development upon which education systems may then expand further educational opportunities. Programs at this level are usually organized around a more subject-oriented curriculum.

According to the United Nations Children’s Fund (UNICEF 2018), providing children with primary education has many positive effects, including increasing environmental awareness.

At primary school age, children’s rich but naïve understandings of the natural world can be built on to develop their understanding of scientific concepts. At the same time, children need carefully structured experiences, taking into account their prior knowledge, instructional support from teachers, and opportunities for sustained engagement with the same set of ideas over longer periods (Duschl et al. 2007). One



**Fig. 22.2** (a) Opening ceremony in the school of Älandsbro, (b) The simple aquaponics at Älandsbro, (c) Older students making observations for the “Recirculation Book,” (d) Model built by the younger students during an arts class

way of providing sustained and continuous engagement can be through the building, management, and maintenance of an aquaponics.

Key advice for introducing aquaponics to primary school students is as follows:

- Low-tech and robust classroom systems favor the engagement of both the teacher and the students and are most effective for this stage of education (Example 22.1, Fig. 22.2b).
- Productivity is not a central issue but demonstrating the laws of nature (cycling of nutrients, energy flow, population dynamics, and interactions within the ecosystem) is. Therefore, sufficient effort needs to be put into developing learning materials to meet the goals of the curriculum.
- From an educational point of view, understanding the chemical, physical, and natural processes in an aquaponics, albeit through trial and error, is more important than achieving a perfectly run system.



- Include a wide range of activities: drawing the plants and animals, keeping a class journal, measuring the water quality, monitoring the fish (size, weight, and well-being), feeding the fish, cooking the produce, role playing, writing, prose, poetry, and song.

**Example 22.1 Aquaponics at Älandsbro skola, Primary School (Sweden)**

The 10-month project, which was a part of the FP6 project “Play with Water,” started with an opening ceremony in September (Fig. 22.2a) and ended before the summer holidays. Several teachers and about 90–100 students aged between 9 and 12 years were involved and were very enthusiastic about the project. The school used readily available materials to create two simple tabletop systems with an aquarium, fish and plants (Fig. 22.2b). Before the start of the learning activities, the students filled in a questionnaire (see the section on Assessment), which was then repeated at the end of term. After an introduction to aquaponics, the students planted the system and populated it with fish.

A diary, called a “Recirculation Book,” was kept for each aquarium. Students made daily notes about the systems (Fig. 22.2c). They recorded the pH, temperature, nitrate and nitrite concentrations, the length of the plants, the activity of the fish, and when they added food and water into the system. They also made drawings and described any significant events, which occurred.

Different classes in the school then had different weeks where they took over daily responsibility for the systems. The younger students took care of one system, while the second system was used by the older children.

The aquaponic units were used for teaching different subjects. The younger students worked with the concept of recirculation by building cardboard models of an aquaponics, with tubes, pumps, fish, and plants (Fig. 22.2d). They also worked with paintings, drama, and music in order to increase their understanding of the relationship between the plants and the fish.

The older students collected information about pH, temperature, nitrate, nitrite, and other changes in the “Recirculation Book.” They were pursuing different themes, for example: (i) the water cycle in a global perspective; (ii) the everyday use of water in a house; (iii) the different appearances, smells, and tastes of water; (iv) fish biology and ecology; (v) other ecological recirculation systems; and (vi) the importance of water on a global scale. They also taught the younger pupils, for example, by explaining recirculation systems, or demonstrating small experiments.

For the evaluation, see Sect. 22.8.1.2.

### **Example 22.2 Two-day Aquaponic-Centered Course in Waedenswil, Switzerland**

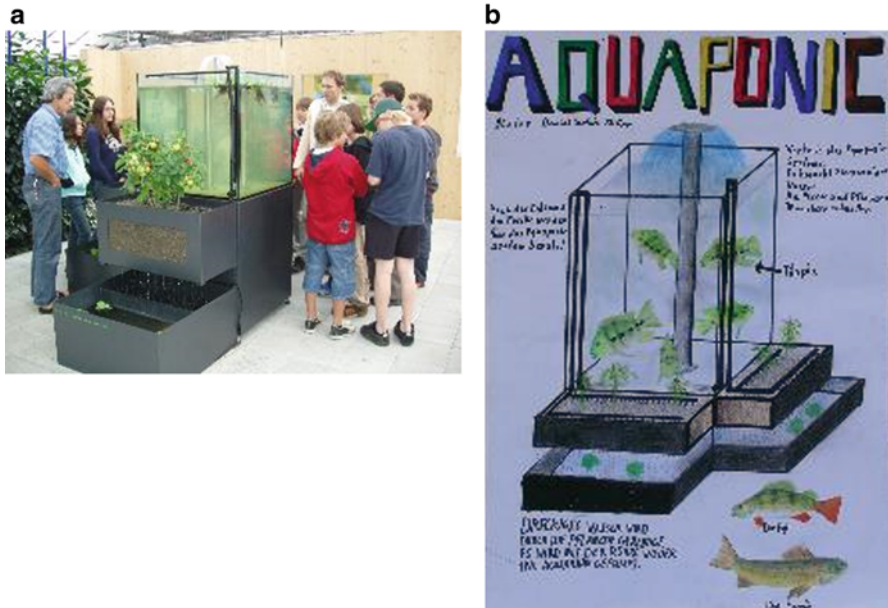
Over 2 days, 16 students (aged 13–14 years) and their teacher from the Gerberacher School visited the Zurich University of Applied Sciences (ZHAW) campus in Waedenswil, where an undergraduate student had prepared a two-day program about the importance of water using aquaponics as a focus (Fig. 22.6). Learning progression was assessed by means of a questionnaire (pre-activity and post-activity).

#### Day 1:

- Welcome address, explanation of the course schedule.
- Knowledge test (what do students know about aquaculture, recycling, plant nutrition, ecosystems, etc.)
- The concept of “systems” explained through simple analogy with hammer as an example of a system (The hammer is made of two parts: the handle and the head. If the parts are separated, the hammer cannot function. So, the hammer is more than just the sum of its parts, it is a system.)
- Assessment of the understanding of systems before the teaching unit: What is a system? Fill in the gap text.
- Introduction to aquaponics and ecosystems. The students learn what an ecosystem is and understand that individual systems are integrated into it.
- Visit to the demonstration aquaponics (Fig. 22.3a).
- Expanding the knowledge: The importance of proteins in food. Discuss and fill in the gap text.
- Expanding the knowledge: The benefits of a closed water cycle (Discuss and fill in the Worksheet).
- Practical work: Construction of two simple aquaponics, adding plants (basil), measuring nitrite and pH.
- Basics of tilapia (*Oreochromis niloticus*) and basil, *Ocimum basilicum* biology.
- Global importance of water (Role-playing game, Worksheets).
- Time for questions.

#### Day 2:

- Why is water conservation necessary? How many people perish due to lack of drinking water? (Mathematics Task).
- Measure the pH and nitrite content in the aquaria. Students learn how to carry out an Aqua-Test and what the values indicate.
- Answer repetition questions (Card game with rewards, Worksheets).
- Practical work: Transfer tilapia from the aquarium to the aquaponics. Feed the fish. Fill in the fish observation sheet.
- Draw a poster of Aquaponics, explaining the important terms (Fig. 22.3b).
- Final knowledge test and evaluation of the learning unit (see also Sect. 22.8.1.3).



**Fig. 22.3** (a) Students from the sixth grade of Gerberacher School visiting the demonstration aquaponics at Zurich University of Applied Sciences (Waedenswil, Switzerland). (b) A poster designed by the same students, explaining the basics of aquaponics

## 22.4 Aquaponics in Secondary Schools

According to the ISCED classification (UNESCO-UIS 2012), secondary education provides learning and educational activities building on primary education and preparing for both first labor market entry as well as post-secondary non-tertiary and tertiary education. Broadly speaking, secondary education aims to deliver learning at an intermediate level of complexity.

While at primary education level, students are mainly directed toward observational and descriptive exercises on organisms and processes in an aquaponics, students from secondary schools can be educated in understanding dynamic processes. Aquaponics enables this increased complexity and fosters system thinking (Junge et al. 2014).

### Example 22.3 One Semester Course in a Grammar School in Switzerland

Hofstetter (Hofstetter 2008) implemented aquaponic teaching units in a Grammar School (German: Gymnasium) in Zurich and tested the hypothesis that incorporating aquaponics into teaching has a positive influence on systems thinking (Ossimitz 2000) among the students. Gymnasium students in

(continued)

**Example 22.3** (continued)

Switzerland belong to an above-average section of the student population: they have very good grades, are used to autonomous work, and show consistent ability and general interests in different issues. Three seventh grade classes were involved, with a total of 68 students (32 female, 36 male), aged between 12 and 14 years old.

Six simple, small aquaponics were constructed according to the general description in Bamert and Albin (2005) (Fig. 22.4). The students were responsible for the construction, operation, and monitoring of the systems. They were provided with the necessary materials and built the aquaculture and hydroponic units. Tomato (*Solanum lycopersicum*) and basil (*Ocimum basilicum*) seedlings were planted in expanded clay beds. Each aquarium was stocked with two common rudd (*Scardinius erythrophthalmus*) caught in a nearby pond and returned there after the experiment.

Each system was monitored daily, and the following operations were carried out: measuring plant height, observing plant health, measuring fish feed and feeding the fish, monitoring fish behavior, measuring water temperature, and topping up the aquarium with water. All the measurements and observations were documented in a diary, which also served to transfer information between the three groups that worked on the same system.

The teaching sequence (Table 22.3) took place between October 2007 and January 2008. Several themes were introduced in the lessons basic system concepts (relationship between system components, concepts of feedback, and self-regulation), and basic knowledge about aquaponics. All the teaching units are described in detail in Bollmann-Zuberbuehler et al. (2010). The effect of the teaching sequence on systems thinking competences was assessed at the beginning and at the end of the sequence (See Sect. 22.8.1.4) and was described in detail in Junge et al. (2014).

**Example 22.4 EXPLORLabor: Science Day at Zurich University of Applied Sciences for the Students of Secondary Schools, Switzerland**

Twenty students aged 18–19 (11th school year, majoring in Biology & Chemistry) from the Cantonal School at Menzingen visit the Zurich University of Applied Sciences (ZHAW) every year for an Aquaponics Workshop. The program varies slightly from year to year, depending on the current experiments in the Aquaponics Lab.

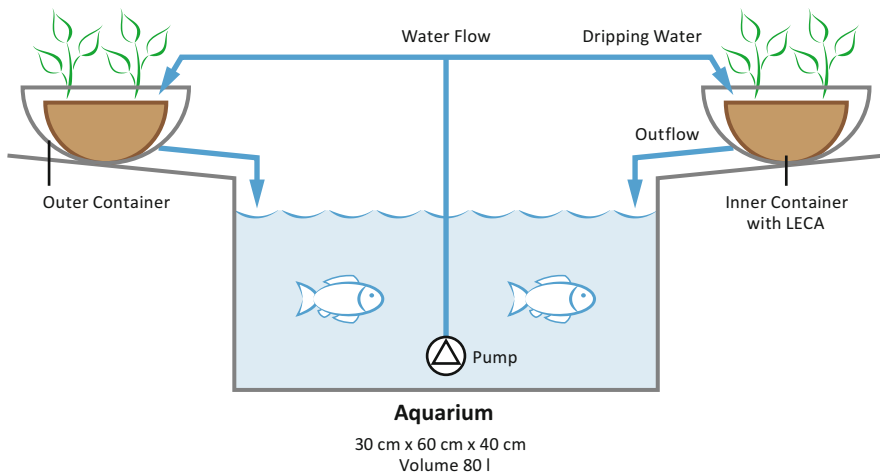
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**Example 22.4** (continued)Program:

- Greetings: Introduction to the workshop.
- E-learning video: Introduction to aquaponics.
- Tour of the aquaponic demo facility; discussion of appropriate behavior in the experimental facility.
- Learning measurement methods. Division into 4 teams.
- Tour of the Aquaponics Lab, consisting of 4 systems (three aquaponic and one hydroponic). Each team gathered data from one system.

Assignment:

1. Measuring water quality in different parts of the aquaponic and hydroponic systems (fish tank, biofilter, and sump) using the handheld multi-electrode meter (Hach Lange GmbH, Rheineck, CH) to measure the temperature (T), pH, oxygen content, and electric conductivity (EC).
2. Using the Dualex-Clip to measure Nitrogen Balance Index (NBI), Chlorophyll Content (CHL), Flavonoid Content (FLV), and Anthocyanin Content (ANTH) of leaves of three lettuces.
3. Filling in the data in the pre-prepared Excel spreadsheet.
4. Back to the classroom: Calculating if there are differences between the lettuce plants that grow in aquaponic and hydroponic systems, comparison of the data, and discussions.



**Fig. 22.4** Simple classroom aquaponics. (Adapted after Bamert and Albin 2005). The plants grow in the containers filled with light expanded clay aggregate (LECA) that is usually used in hydrocultures

**Table 22.3** Sequence of teaching units in three classes of seventh grade students during one semester course in a Grammar School in Switzerland

Teaching unit	Number of lessons	Methods	Content
TU1	1	Survey of existing knowledge	Pre-activity Test
TU2	4	Lecture by teacher, research, & presentations by students	System basics
TU3	2	Lecture by teacher, student assignment	“Connection circle” tool allows the students to draw a diagram of a system (adopted from Quaden and Ticotsky 2004)
TU4	2	Discovery learning Presentations by students	Planning an aquaponics: sub-units, connections
TU5	2	Problem-based learning (PBL)	Defining the main indicators of the system: Fish and plants and their interactions
TU6	3	Discovery learning	Monitoring the aquaponics
TU7	3	Presentations by students	Drawing a diagram of the interconnections in the aquaponics
TU8	1	Survey of knowledge	Post-activity test
TU9	2	Aquaponic party	Harvest, preparation of salad, eating

Modified after Junge et al. (2014)

## 22.5 Aquaponics in Vocational Education and Training

UNESCO-UIS/OECD/EUROSTAT (2017) defines vocational education programs as “*designed for learners to acquire the knowledge, skills and competencies specific to a particular occupation, trade, or class of occupations or trades. Successful completion of such programs leads to labour market relevant, vocational qualifications acknowledged as occupationally-oriented by the relevant national authorities and/or the labour market*” (UNESCO, 2017).

In order to educate future aquaponic farmers and aquaponic technicians, the training has to include the professional operation of aquaponics. Therefore, the training environment needs to be state-of-art. However, the setting does not have to be large: 30 m<sup>2</sup> should suffice (Podgrajsek et al. 2014, Examples 22.5 and 22.6). Such systems should be planned and built by professionals as they require complex monitoring and operation.

Students can be involved in: (i) installation (under professional guidance); (ii) general maintenance and operation (including daily checks and cleaning); (iii) operation of the hydroponic subsystem (planting, harvesting, integrated pest management, climate control, adjustment of pH and nutrient levels, etc.); (iv) operation of the aquaculture sub-system (fish feeding, fish weight determinations, adjustment of pH levels, etc.); (v) monitoring of parameters (water quality, fish growth and health, plant growth, and quality); and (vi) harvesting and post-harvest operations.

The European Union invested in the development of vocational education via the Leonardo Program, and more recently ERASMUS+. These programs have funded several projects that included the implementation of aquaponics, including the Leonardo da Vinci Transfer of Innovation Project (Lifelong Learning Programme) “Introducing Aquaponics in VET: Tools, Teaching Units and Teacher Training” (AQUA-VET)<sup>7</sup>. The project prepared a curriculum for vocational education in aquaponics and the results are available at [www.zhaw.ch/iunr/aquavet](http://www.zhaw.ch/iunr/aquavet). The teaching units were tested at three vocational schools in Italy, Switzerland (Baumann 2014), and Slovenia (Peroci 2016). As part of this project an aquaponics unit was constructed at the Biotechnical Centre Naklo vocational school in Slovenia (Example 22.5). Another example is the aquaponic unit built at the Provinciaal Technisch Insituut, a horticulture school in Belgium (Example 22.6).

### **Example 22.5 Aquaponics at Biotechnical Centre Naklo in Slovenia**

The aquaponics (Fig. 22.5a) was constructed in 2013 within the framework of the Leonardo da Vinci project “AQUA-VET” (Krivograd Klemenčič et al. 2013; Podgrajšek et al. 2014). An aquaponics course module was developed and taught to a class of 30 students in the second year of their Environmental Technician program (Peroci 2016). The aim was to investigate the possibility of including aquaponics in the regular program of secondary vocational education in biotechnical sciences, and in the standard curriculum of professional skills needed for the national vocational qualification of an “Aquaponic farmer.” The course consisted of six lessons (45 min each), of which four were dedicated to the theory of aquaponics and two to practical training (Fig. 22.5b).

*Lesson 1* Aquaponics: definition, introduction to aquaculture and hydroponics, operation of an aquaponics.

*Lesson 2* Microorganisms: (i) the role of microorganisms: useful microorganisms, the nitrogen cycle, and the importance of biofilters in aquaponics; (ii) monitoring of selected parameters, monitoring plan, protocols, and evaluation of the results.

*Lesson 3* Fish: structure and functioning of the fish body, selection of fish species suitable for growing in aquaponics, feeding methods, fish diseases and injuries, and fish breeding.

*Lesson 4* Plant anatomy, selection of plant species suitable for growing in aquaponics, the role of plants in aquaponics, identification of plant diseases, and appropriate plant protection strategies.

*Practical work (2 h)* Students worked in two groups (observation, monitoring, discussion, presentation) at the aquaponic unit at the Biotechnical Centre Naklo.

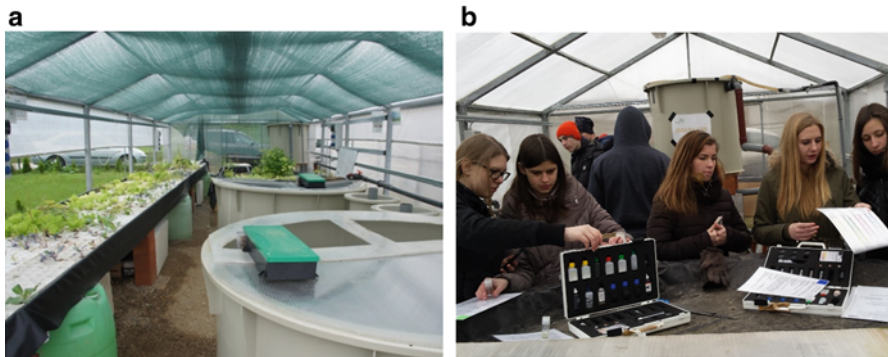
The learning activities covered various skill levels, providing well-designed lessons for both the theoretical and practical parts. Learning progression was assessed by means of several questionnaires (see Sect. 22.7.2).

### Example 22.6 Aquaponics at Provinciaal Technisch Instituut, a Horticulture School in Belgium

The Provinciaal Technisch Instituut (PTI) in Kortrijk pioneered classroom aquaponics in Belgium at the vocational education level. The project started in 2008, when fish tanks were introduced into the greenhouse that is used for teaching practical courses to students in agronomy and biotechnology (Fig. 22.6).

Initially, the aquaponics was used on an ad hoc basis in a number of classes, for example, to teach plant and fish biology, water chemistry, etc., but it was only after a couple of years that aquaponics became structurally embedded in a number of course modules. The main challenge was to find the time to translate the governmental attainment goals into the aquaponics course modules. This challenge illustrates the importance of providing sufficient support both in terms of meeting the needs of the curriculum, and in tackling operational and organizational obstacles for new aquaponic initiatives in schools.

From the beginning, the aquaponics at PTI also acted as a pilot in applied research projects with universities (Ghent University, KU Leuven, ULG Gembloux), university colleges (HoWest, HoGent, Odisee), research institutes (Inagro, PCG), and private companies (aqua4C, Agriton, Lambers-Seeghers, Vanraes automation). In effect, the school has become a valuable partner in multiple national and international projects. Pupils at PTI are involved not only in the day-to-day operational work but also in data collection for experiments coordinated by the academic researchers. This collaboration creates a unique opportunity for the students to familiarize themselves with the activities of university colleges and universities, and may stimulate the students to progress to higher education.



**Fig. 22.5** (a) Aquaponics at the Biotechnical Centre Naklo in Slovenia. (Photo: Jarni 2014). (b) Practical work at the aquaponic unit of the Biotechnical Centre Naklo. (Photo Peroci 2016)



**Fig. 22.6** A view into the greenhouse of Provinciaal Technisch Insituut (PTI). Fish tanks (containing *Scortum barcoo*) are located below the drip-irrigated tomato gullies. In the middle of the greenhouse, Australian crayfish (*Cherax quadricarinatus*) are grown in a series of aquaria



## 22.6 Aquaponics in Higher Education

Higher education programs need to be adapted to meet the expectations of the new millennium, such as long-term food security and sovereignty, sustainable agriculture/food production, rural development, zero hunger, and urban agriculture. These important drivers mean that higher education institutions involved in the areas of food production can play a key role in the teaching of aquaponics through both capacity development and knowledge creation and sharing. Additionally, it is clear that the interest in teaching and learning aquaponics is increasing (Junge et al. 2017).

At universities and colleges, aquaponics is usually taught as part of agriculture, horticulture, or aquaculture courses and the context for course content development in higher education is specific to each institution's internal and external dynamics. The main challenge in designing courses at higher education level is the interdisciplinary nature of aquaponics, as prior knowledge of both aquaculture and horticulture is essential. While some studies investigated the use of aquaponics in education (Hart et al. 2013; Hart et al. 2014; Junge et al. 2014; Genello et al. 2015) and a number of on-line courses are available, a course outline for aquaponics at the tertiary level at a main-stream does not yet exist, or at least hasn't been published. For tertiary level aquaponics courses to be implemented in the EU, the Bologna Process, which underlines the need for meaningful implementation of learning outcomes in order to consolidate the European Higher Education Area (EHEA),

needs to be followed. Learning outcomes are (i) statements that specify what a learner will know or be able to do as a result of a learning activity; (ii) statements of what a learner is expected to know, understand, and/or be able to demonstrate after completing a process of learning; and (iii) are usually expressed as knowledge, skills, or attitudes (Kennedy 2008).

Table 22.4 and Example 22.7 introduce two conceptual frameworks for teaching aquaponics. Both courses are considered to be worth 5 ECTS credits (European Credit Transfer System), which correspond to a study load of approximately 150 h.

### **Example 22.7 Project Aqu@teach, an Erasmus+ Strategic Partnership in Higher Education (2017–2020)**

The core task of the project is to devise an aquaponics curriculum (150 h of student's workload corresponding to 5 ECTS credits and a supplementary entrepreneurial skills module (60 h), which will be taught by means of blended learning. Blended learning (combining digital media and the Internet with classroom formats that require the physical co-presence of teacher and students) offers alternative pathways to gain knowledge and involve students in creating content. This also improves the preparation of students for their lessons, and fosters their motivation, so that interactions with the teacher can be devoted to in-depth learning and the development of practical skills. Information and Communication Technologies (ICTs) are particularly valuable for teaching aquaponics as they enable effective presentation of systems and processes, such as simulation modeling (graphic, numerical) of the parameters (weight of fish/feeds input/surface area of aquaponic beds, etc.). Students taking the Aqu@teach course will use e-portfolios (Mahara programme) to document their progress in learning. The curriculum will include the following modules:

	Module	No. of hours
1	Aquaponic technology	8
2	Aquaculture	12
3	Fish anatomy, health and welfare	8
4	Fish feeding and growth	10
5	Nutrient water balance	5
6	Hydroponics	13
7	Plant varieties	10
10	Integrated pest management	8
9	Monitoring of parameters	8
10	Food safety	12
11	Scientific research methods	10
12	Design and build	16
13	Urban agriculture	10
14	Vertical aquaponics	8
15	Social aspects of aquaponics	12

(continued)

**Example 22.7** (continued)

The use of blended learning to teach a unique multidisciplinary curriculum will enable HE students from a variety of different academic disciplines to join together physically and virtually to gain professional and transversal skills desired by employers. They will gain advanced skills in the circular economy, environmental and ecological engineering, and closed-loop production systems (energy, water, waste), using aquaponics as an example of good practice. At the end of the project in 2020, the module guide and curriculum will be made available on the project website (<https://aquateach.wordpress.com/>), along with a toolbox of innovative didactic techniques appropriate for teaching aquaponics, a textbook and teaching materials, and a best practice guide for teaching aquaponics. The aquaponics curriculum and supplementary entrepreneurial skills curriculum will be freely accessible as an interactive online aquaponics course.

**Table 22.4** Proposed aquaponics course outline at university level (5 ECTS). The flexible framework contains two key topics (hydroponics and aquaculture) and is clustered into six learning areas

<b>Course title:</b>	<b>Aquaponics</b>	
<b>Course Description:</b>	Aquaponics is a food production method that combines hydroponics and aquaculture to form a system that re-circulates the water and nutrients and grows terrestrial and aquatic plants including algae and aquatic organisms while minimizing waste discharge. This course allows students to use the technical skills acquired to set up an integrated system. It equips them with the knowledge needed to be able to undertake and be aware of critical aspects of aquaponics.	
<b>Entry Level:</b>	<b>BSc or MSc</b>	
<b>Unit Name</b>	<b>1. Aquaponics</b>	<b>2. Aquaponics Operations</b>
<b>Unit Purpose</b>	To understand system design and management, components, and construction techniques.	To understand water characteristics, the microbiological and biochemical cycles (e.g., the nitrogen cycle) within an aquaponics, and interactions between water and plants.
<b>Recommended prior knowledge and skills:</b>	Basic knowledge of biology and agriculture (horticulture and aquaculture).	Basic knowledge of water quality, aquatic organisms, aquatic microbiology.
<b>Learning outcomes</b>	Students should be able to	Students should be able to
	explain the characteristics of an aquaponics;	explain water quality parameters;
	explain the types of aquaponics;	explain biochemical cycles and microbial transformations;
	explain the construction techniques; and	identify criteria for fish and plant production;
describe the operational components.	calculate all relevant fish growth parameters; and	explain harvesting and processing.

(continued)

**Table 22.4** (continued)

<b>Knowledge and/or skills:</b>	On completion of the unit, students should be able to design an aquaponics.	On completion of the unit, students should be able to
		describe water quality criteria;
		analyze the main water quality; parameters (dissolved oxygen, pH, ammonia, nitrite, nitrate);
		explain the effects of water temperature on fish and plants;
		explain the optimum water conditions for fish;
		explain the interaction between water and plants;
		explain feeding strategies; and
		compute the required feed rations
<b>Evidence requirements:</b>	Students will be required to evaluate the different types of aquaponics in terms of their relative advantages and disadvantages.	Students will be required to Apply a calculation for stocking density and feeding regime using fish size, water volume, and water quality parameters.
<b>Unit Name</b>	<b>3. Plant Production</b>	<b>4. Aquatic Organisms Production</b>
<b>Unit Purpose</b>	To demonstrate the ability to care for plants in order to maintain optimum growth and health while considering pruning, planting, and irrigation.	To understand the growth of aquatic organisms such as fish and crustaceans and their requirements in an aquaponic system.
	To describe the optimal conditions for plant growth.	
<b>Recommended prior knowledge and skills:</b>	Basic knowledge of horticulture.	Basic physiology of aquatic organisms, nutritional concepts, and reproduction of fish and crustaceans in aquaculture.
	Computer/technical literacy.	
<b>Learning outcomes</b>	Students should be able to describe how to plant a plant;	Students should be able to explain the growth of aquatic organisms, nutritional principles in aquaculture, fingerling production, broodstock management, breeding/fry sex reversal; and
	describe plant growth requirements;	explain the principles of aquaculture.

(continued)

**Table 22.4** (continued)

	identify the most suitable plants for the aquaponics;	
	describe seed production techniques;	
	describe transplantation techniques;	
	allocate suitable plants for different seasons;	
	define water pressure; and	
	flow rate and how to calculate these;	
	explain how to control pests; and	
	explain harvesting techniques.	
<b>Knowledge and/or skills:</b>	On completion of the unit, students should be able to explain	On completion of the unit, students should be able to:
	seedling production	describe the functioning of RAS
	plant growth	identify the fish/crustacean species suitable for aquaponics
	disease and insect control harvesting	identify the growth requirements of different aquatic organisms
<b>Evidence requirements:</b>	Students will be required to	Students will be required to
	Compare different plants regarding their suitability for aquaponics	Describe the role of aquaculture within an aquaponics
<b>Unit Name</b>	<b>5. Economics of Aquaponics</b>	<b>6. Risk Management Strategy</b>
<b>Unit Purpose</b>	To understand the processes required to set up an economically viable system	To understand the risk management elements including risk identification, analysis, responses, and control
<b>Recommended prior knowledge and skills:</b>	Basic mathematical and statistical knowledge	Basic mathematical knowledge
<b>Learning outcomes</b>	Students should be able to	Students should be able to
	explain profitability and sustainability;	identify the potential risks;
	estimate the depreciation, capital expenditure, operating expenses, sales, profit and loss statement;	develop a risk management plan;
	explain the calculations used to determine cash flows;	analyze quantitative and qualitative risks; and
	discuss the balance of the budget; and	monitor and control the risks.
	rate the financial indicators.	

(continued)

**Table 22.4** (continued)

<b>Knowledge and/or Skills:</b>	On completion of the unit, students should be able to create an economic feasibility model.	On completion of the unit, students should know how to create a probability impact matrix relating to risks.
<b>Evidence requirements:</b>	Students will be required to	Students will be required to
	Create a feasibility model using different financial indicators based on a case study	Create a probability impact matrix of risk based on a case study
<b>Outcome Assessment Activities:</b>	Oral/computer presentation, written report, classroom quizzes.	

## 22.7 Does Aquaponics Fulfill Its Promise in Teaching? Assessments of Teaching Units by Teachers

### 22.7.1 Teacher Interviews in Play-With-Water

Aquaponic teaching units were assessed in the FP6 project “Play-With-Water” on seven separate occasions in three countries (Sweden, Norway, Switzerland). This involved six schools (1 school in Norway, 1 in Sweden, and 4 in Switzerland) where the age of students ranged between 7 and 14 years. Six teachers were asked to keep a diary, which they then used to answer an online questionnaire complemented with phone interviews, which are summarized in Table 22.5.

Feedback from teachers on their experience with the aquaponics indicated that some issues were too complex for primary schools. The “Play-With-Water” experiments such as those available on the project website ([www.zhaw.ch/iunr/play-with-water/](http://www.zhaw.ch/iunr/play-with-water/)) may be more appropriate for use in secondary education. The learning

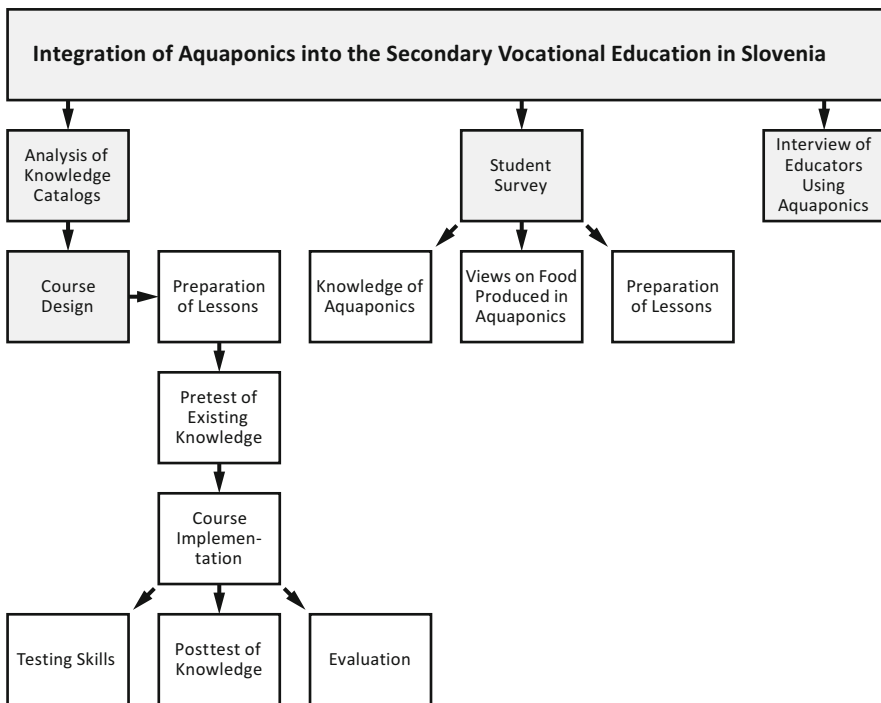
**Table 22.5** Summarized answers of the six interviewed teachers regarding the advantages and disadvantages of using aquaponics as a teaching tool

What are the main advantages?	Number of mentions	What are the main disadvantages?	Number of mentions
Suitable to learn system thinking	3	None.	2
Facilitates teamwork	2	High time requirements.	2
mobilization of students	2	High knowledge requirements.	2
Provides diversity in teaching	2	Difficult concepts & language.	1
Motivating for students	1	Sensitive for pests.	1
Motivating for teachers	1	Students were not always paying attention.	1
Transfer between different subjects possible	1		
Versatile: several possible educational objectives	1		

materials contain descriptions of complex processes and ecological interactions that require a deeper knowledge of natural sciences such as chemistry or biology than can be expected at primary school. If the material is to be used by teachers, it needs to provide the information in a classroom-ready format. Explanations of chemical and biological processes such as nitrification ought to be greatly simplified.

### 22.7.2 *Comprehensive Study of the Potential for Including Aquaponics in Secondary Vocational Education in Slovenia*

Peroci (2016) investigated a series of aspects related to the potential for including aquaponics in the educational process of secondary vocational education in Slovenia (Fig. 22.7). This included



**Fig. 22.7** The general structure of the study of Peroci (2016) about the potential for including aquaponics in the educational process of secondary vocational education in Slovenia

- (i) Analysis of catalogs of vocational secondary education in biotechnical fields in order to assess the compatibility of these educational programs with learning objectives related to aquaponics.
- (ii) Design of a short Aquaponic Educational Course including the definition of learning outcomes (knowledge and skills). The didactic material for experiential learning was tested and evaluated by a class of students at the Biotechnical Centre Naklo (Precedent 5, Sect. 22.8.2).
- (iii) Survey of the knowledge of, and attitudes toward, aquaponics in biotechnical schools in Slovenia by students attending the programs for land managers, horticultural technicians, technicians in agriculture and management, and environmental technicians, in order to evaluate students' attitudes toward this type of food production (see Sect. 22.8.2.) The list of potential candidates for participation in the survey was prepared based on a review of secondary schools by the Ministry of Education, Science and Sport of the Republic of Slovenia.
- (iv) Semi-structured interviews with teachers at relevant schools, examining the implementation of aquaponics as a learning tool in Slovenia (Sect. 22.7.2.1).

#### **22.7.2.1 Interview with Teachers and Trainers Using Aquaponics in the Educational Process in Slovenia**

In order to investigate the use of aquaponics as a learning tool in Slovenia, Peroci (2016) conducted semi-structured interviews (45–60 min) with five teachers.

The analysis of interviews revealed the following reasons for using aquaponics: (i) possibility for experiential learning, (ii) flexible installation that can be adapted to the education goal, (iii) a good way of teaching about food production, and for teaching STEM subjects. These were very similar to reasons revealed by interviews in North America conducted by Hart et al. (2013). However, in contrast, in the interviews conducted in Slovenia, two reasons for using aquaponics were absent: fun, and developing responsibility and compassion for living organisms.

Based on the analysis of the interviews related to the three aquaponics units used for education in Slovenia, the future implementation of aquaponics as a learning tool needs to focus on the following steps:

1. Developing a set of learning outcomes that can be achieved using an aquaponic unit
2. Designing the aquaponic teaching unit, which facilitates learning outcomes and competencies that students must gain in order to become an “Aquaponic Farmer”
3. Establishing a link between teachers and trainers (kindergartens, primary schools, secondary schools, universities), local communities, companies, and individuals involved in aquaponics
4. Developing guidelines for integrating aquaponics in the learning process
5. Performing workshops for the design, construction, operation, and maintenance of an aquaponics



## 22.8 Does Aquaponics Fulfill Its Promise in Teaching? Evaluation of Students’ Responses to Aquaponics

### 22.8.1 EU FP6 Project “WasteWaterResource”

The aim of the Waste Water Resource project was to assemble, develop, and assess teaching and demonstration material on ecotechnological research and methods for pupils aged between 10 and 13 years (<http://www.scientix.eu/web/guest/projects/project-detail?articleId=95738>). The teaching units were assessed in order to improve the methods and content and maximize learning outcomes. Based on discussions with educational professionals, the assessment was based on a simple approach using questionnaires and semi-structured interviews. Teachers assessed the units by answering the online questionnaire (see Sect. 22.7.1). The aquaponic units were evaluated in Sweden (in the Technichus Science Center, and in Älandsbro skola in Härnösand), and in Switzerland.

#### 22.8.1.1 Technichus Science Center, Sweden

Between 2006 and 2008, an aquaponic unit was installed at Technichus, a science center in Härnösand, Sweden ([www.technichus.se](http://www.technichus.se)). The questionnaire was placed beside the system so that the visiting students could answer the questions at any time. It consisted of 8 questions (Fig. 22.8).

The answers showed that the students understood how the water in the system was re-circulated. They understood less well how nutrients were transported within the system and the contents of the nutrients and, interestingly, one in four students did not know that the plants growing in the aquaponic unit were edible.

#### 22.8.1.2 Älandsbro skola, Sweden

The questionnaire used in Älandsbro skola was first explained by the teacher in order to ensure that the students would understand the questions. The questions were answered before the project started and at the end of the project.

	I agree (%)	I mostly agree (%)	I mostly disagree (%)	I disagree (%)
I understand that the plants in this aquarium get the nutrients from the fish.	33	21	21	25
I know the content of the nutrient, which comes from the fish.	29	14	24	33
I know that the water recirculates from the aquarium to the plants and back to the aquarium.	43	14	33	10
I know that the plants need light in order to grow.	59	9	5	27
I understand what a circulating system is.	61	11	6	22
I think it is good that you can cultivate plants together with fish.	48	19	19	14
I know that you can eat the plants and fruits which grow above the fish in the aquarium.	50	20	5	25
I know that this aquarium with fish and plants are a recirculating system.	43	10	33	14

Fig. 22.8 Questionnaire and the frequency of answers of the 24 students (aged from 8 to 17 years) visiting the exhibition in Technichus, Sweden

On average, there were 28% more correct answers to the general questions about nutrient requirements of plants and fishes after the teaching unit. As expected, and similar to the findings of Bamert and Albin (2005), the increase in knowledge was evident.

The conclusions of the investigation were that (i) working with aquaponics has a great potential to help pupils attain relevant learning goals in the Swedish curriculum for biology and natural sciences; (ii) the teachers thought that the work gave natural opportunities to talk about cycling of matter and that it attracted the pupils' interest; (iii) the questionnaires showed that a large number of pupils had changed their opinion about the needs of fish and plants before and after they worked with the system; and (iv) the interviews with the older pupils showed that they had acquired good knowledge about the system.

Even more important, all the people involved (teachers and students) found that aquaponics provided the means to expand the horizon of the discipline, in a refreshing and effective way.

### **22.8.1.3 Comparison of the Success of Aquaponics in Classes from Urban and Rural Environments in Switzerland**

Bamert (2007) compared the effects of teaching with classroom aquaponics to students aged 11–13 years in two different environments in Switzerland. The School in Donat, Grisons Canton, is situated in the rural alpine region, where the students mostly live on nearby farms. Many of these farms are organic, so these students knew certain concepts about cycles in nature from their everyday life. There were 16 students, aged 11–13 years, in the joint class of fifth and sixth grade. Their mother tongue is Rhaeto-Romanic, but the aquaponics classes were given in German.

The School in Waedenswil, on the other hand, is situated in the greater Zürich area. The students mostly grew up in an urban environment and had less experience of nature compared with the students from Donat. Because the students from Donat stated that the theoretical part was rather difficult, nitrification was not explained in Waedenswil (Example 22.2). Also, one must consider that the teaching unit was spread over 11 weeks in Donat, while it was performed as a 2-day workshop in Wädenswil.

Answers to questions about what they liked/disliked most about the aquaponics lessons are presented in Fig. 22.9. While the rural students were most fascinated by the system itself, the urban students were mostly fascinated by the fish. Generally, fish were the biggest motivator in both classes. Netting the fish, transporting, feeding, and just observing them were all very popular activities. The thirst for knowledge about fish mainly involved questions about reproduction, growth, etc.

### **22.8.1.4 Promoting Systems Thinking with Aquaponics in Switzerland**

The effect of the teaching sequence described in Example 22.3 on systems thinking competencies was assessed at the beginning and at the end of the sequence. The

<i>Donat</i> (N=16)	everything	nothing	the system	fish	survey	lecture notes	developing countries	puzzles	theory	final party/game
exciting	31	0	38	13	6	6	13	19	6	13
boring	0	50	0	6	13	19	0	0	0	0
difficult	0	13	0	0	19	0	0	0	50	0
fascinating	0	0	94	6	0	0	0	0	0	0
interesting	0	0	13	50	0	0	0	0	0	6

<i>Wädenswil</i> (N=20)	everything	nothing	the system	fish	survey	lecture notes	developing countries	puzzles	theory (simplified)	final party/game
exciting	30	0	5	55	0	0	0	5	0	5
boring	0	40	0	0	15	10	0	0	5	0
difficult	0	40	0	0	15	0	0	0	20	0
fascinating	0	15	30	20	0	0	10	0	0	0
interesting	0	0	15	40	0	0	10	0	10	0

**Fig. 22.9** Answers of students from two different environments (Donat-rural and Waedenswil-urban) about what they liked/disliked most in the aquaponic lessons

ability of students to think in a systemic way instead of linear succession improved significantly in the post-test compared to the pre-test.

Systems thinking is one of the key competencies in the complex world (Nagel and Wilhelm-Hamiti 2008), and is necessary in order to gain an overview of the underlying systems of the real world, because most problems are complex and require a systemic approach to develop a viable solution.

Systems thinking includes four central dimensions (Ossimitz 1996; Ossimitz 2000): (i) thinking in models; (ii) interconnected thinking; (iii) dynamic thinking (thinking about dynamic processes, such as delays, feedback loops, oscillations); and (iv) manipulation of systems, which implies the ability for practical system management and system control. Classroom aquaponics mostly concern interconnected thinking and thinking in models. Interconnected thinking involves identification and appraisal of direct and indirect effects, particularly with regard to identifying feedback loops, construction, and the understanding of networks and of cause and effect.

The main goal of the teaching sequence “Classroom aquaponics” described in Example 22.3 was to enable students to adopt tools, which can help them to examine complex problems. The hypothesis tested was that incorporating aquaponics into teaching units would have a positive influence on the systems thinking abilities of the pupils.

All the 68 students performed a test at the beginning and at the end of the teaching sequence. The pre- and post-test were identical and contained a short text about life as a farmer, which animated the students to think about farmers and their behavior. It ended with the question: “Why did the farmer put manure on his fields?” The pupils answered with a drawing and/or a description of the reasons. The answers of the students were evaluated according to the method outlined by Bollmann-Zuberbuehler et al. (2010), which allows a qualitative method to be used with quantitative results (for more details on this, see also Junge et al. 2014).

Generally, the delineation of systems shifted from a qualitative description to a more schematic description and became more complex in the post-test. When numerical scores were assigned to each level of drawing (Table 22.6), an interesting

**Table 22.6** Identification of the delineation of the system representations

Delineation	Description	Score
No drawing	No representation at all	1
Schematic representation	Schemes without logical connection	2
Figure with stages	Logical sequence with a minimum of 3 stages	3
Other representation types	All other representations, which could not be clearly allocated	4
Linear Graph	Contains at least 1 chain of events	5
Effect diagram	Contains in addition at least 1 junction	6
Network diagram	Contains in addition at least 1 feedback loop and/or cycle	7

**Table 22.7** Comparison of the median delineation scores between the pre- and post-test

	Pre-activity test (median)	Post-activity test (median)	Change
Girls	2.5	7	4.5
Boys	2	7	5

pattern emerged (Table 22.7). While both genders reached the median level of 7, meaning that the majority of drawings contained at least one loop and/or cycle, at the end of the teaching sequence, the change was more marked among the boys, who started at a lower level. This indicated that boys profited more from hands-on experience than girls.

In the next step, the Complexity index, Interconnection index, and the Structure index were calculated (for details, see Junge et al. 2014).

The complexity index (German: Komplexitätsindex, KI) shows how many system concepts the student implemented:

$$KI = \text{variables} + \text{arrows} + \text{chain of events} + \text{junction} + \text{feedback loops} \quad (22.1)$$

The interconnection index (Vernetzungsindex, VI) shows the frequency of the connections between the variables:

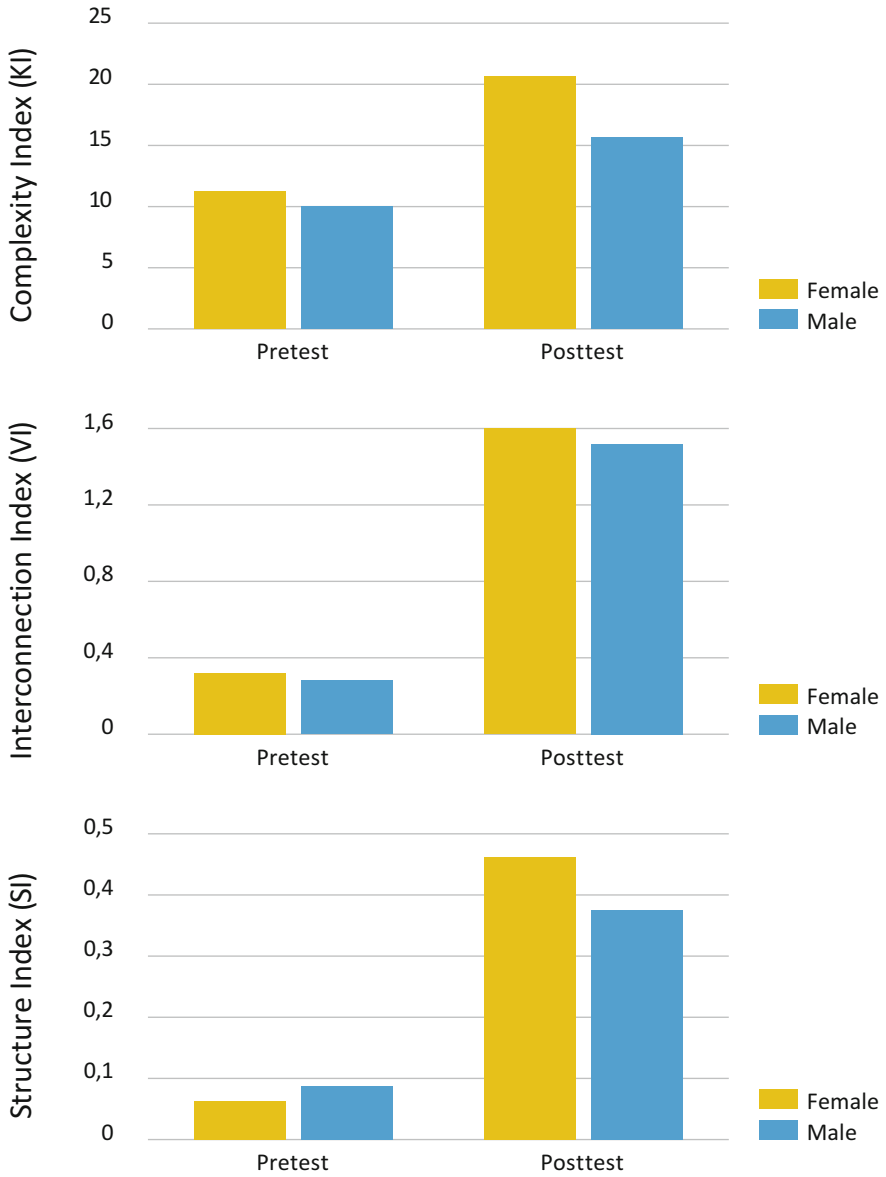
$$VI = 2 \times \text{arrows}/\text{variables} \quad (22.2)$$

The structure index (Strukturindex, SI) shows how many complex system concepts the student implemented in the representation:

$$SI = (\text{chains of events} + \text{junctions} + \text{feedback loops})/\text{variables} \quad (22.3)$$

The students found more system concepts and knew more about system variables at the post-test than in the pre-test, a fact reflected by all indices applied (Fig. 22.10).

These results appear to support the hypothesis that incorporating aquaponics into teaching has a positive influence on the systems thinking capabilities of students, and that the devised “Classroom Aquaponic Sequence” was successful in training students in systems thinking.



**Fig. 22.10** Complexity of answers in pre-activity and post-activity tests. Above: Complexity Index (KI), centre: Interconnection Index (VI), below: Structure Index (SI)

## **22.8.2 *Evaluation of the Aquaponics Teaching Unit in Vocational Education in Slovenia***

### **22.8.2.1 Evaluation of the Aquaponics Course, Biotechnical Centre Naklo, Slovenia**

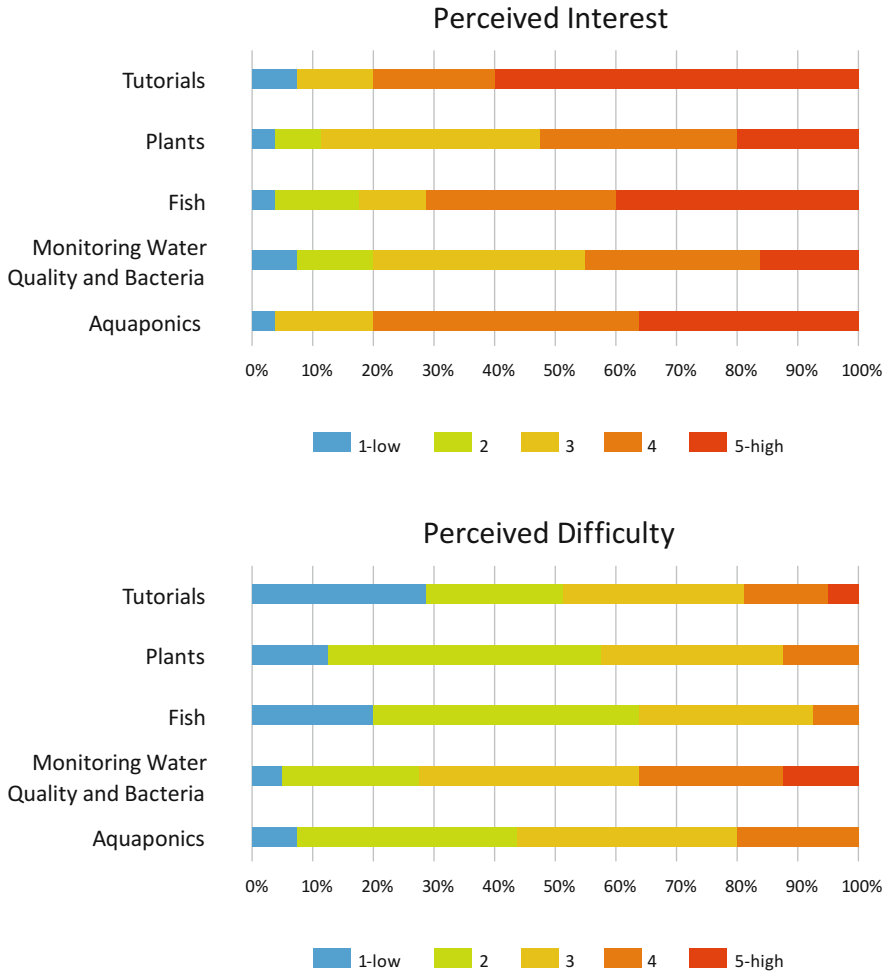
The learning progression of the short aquaponic course within the study of Peroci (2016) (see Precedent 5) was assessed by means of questionnaires: (i) pre-test/post-test; (ii) test of the acquired skill level in connection with food production in aquaponics; and (iii) teaching evaluation.

The influence of various factors on the popularity of the lessons and the practical work was evaluated. Students named several factors as being crucial for their interest in the aquaponics course. The most relevant factors were: more relaxed teachers (80%); entertainment (76%); attractive location of the practical work (72%); contact with nature (68%); active practical work (64%); and use of interesting new methods (56%). Generally, students rated the more interesting lessons as those that were less difficult (e.g., the lesson “Monitoring water quality and bacteria” was less interesting and most difficult) (Fig. 22.11).

### **22.8.2.2 Survey of Knowledge and Attitudes Toward Aquaponics**

Peroci (2016) investigated knowledge, attitudes toward food produced, and interest in the use of aquaponics among students at 8 secondary vocational schools in biotechnical fields within the educational programs for land manager (1st–third year), horticultural technician (1st–fourth year), technician in agriculture and management (1st–fourth year), and environmental technician (1st–fourth year) during 2015 and 2016.

The survey involved a 15-minute questionnaire, with closed-ended answers (yes or no). The survey showed that 42.9% of 1049 students had already heard about aquaponics. They had learnt about it at school (379 students), from the media (79), from peers and acquaintances (42), from advertisements (18), when visiting the aquaponics (12), at agricultural fairs (2), and in aquaristic (1). Most of the positive answers were from students from the Biotechnical Center Naklo where the aquaponics was constructed in 2012 (Podgrajšek et al. 2014) and aquaponics was already integrated in the learning process; 28% of respondents lacked any knowledge about aquaponics and 19.8% of respondents said they would choose the aquaponics course over other modules, mostly because of its interdisciplinary nature and due to its sustainable and creative approach. The students also expected that after attending such a course, they would have better chances of finding a job. Most students liked the practical work, and 10.7% of respondents said they would like to volunteer by maintaining the aquaponics and that they would like to set up their own aquaponics. The analysis regarding the interest of students in producing food using aquaponics showed that they liked this idea. However, they were not sure if they



**Fig. 22.11** Evaluation of the perceived interest (above) and difficulty (below) of aquaponics lessons at the vocational school in Naklo, Slovenia. (Modified after Peroci 2016)

would eat the fish and vegetables produced in this way, mostly because they had no previous experience of eating food produced in an aquaponics. Based on these results, we can assume that the production of food in aquaponics will be well accepted by the students of secondary vocational schools in biotechnical fields. This is important as these students are the next generation of entrepreneurs, farmers, and technicians who will not only generate, make, and evolve aquaponics in the future but also help generate the confidence in aquaponics among stakeholders so that it becomes part of food production in Slovenia in the future.

## 22.9 Discussion and Conclusions

An aquaponics is a perfect example of a system that can bring nature closer to a classroom and can be used as the starting point for a host of educational activities at both primary and secondary school levels. A model system, together with corresponding didactic methods, serves to make natural processes more tangible to pupils. This, in turn, helps to develop the necessary competencies for dealing with the complexity and problems of the environment, and promotes a sense of responsibility toward humanity. Creating the opportunity for hands-on experience with nature and natural elements such as water, fish, and plants also develops environmental consciousness and a greater understanding of the potential for practical solutions and a willingness to act on this knowledge.

In this chapter, we have presented various case studies of the use of aquaponics at different educational levels, and also a number of examples that assess the benefits of introducing aquaponics into schools.

While for each separate study the assessment methods were in themselves logical, and provided interesting insights, clear-cut comparisons across the studies are not practical, because the methods were not, or were only partly, comparable.

During the FP6 Project “WasteWaterResource” the pedagogical specialists in the team voiced some critical comments about using questionnaires to measure impacts on ecological awareness and behavior among students (Scheidegger and Wilhelm 2006):

- In multiple choice questionnaires, students tend to provide the answers that they think the teacher would like to hear.
- Children often have difficulties ranking their answers to questions such as “*how was my motivation in the Aquaponic lectures?*” (1: very low to 5: extremely high).
- The answers are highly influenced by the teacher and the current objectives of education.

Therefore, it is questionable whether quantitative survey methods are appropriate for revealing the potential effects, and whether they provide realistic data on the perceptions of the students.

It seems to be more appropriate to focus on qualitative assessment methods such as semi-structured interviews with the teachers, or the process of self-observation according to the action research method outlined by Altrichter and Posch (2007). Teachers are practitioners who have long-term experience of dealing with students and can therefore provide better and deeper information on a potential impact than a survey can reveal. A deeper interview or dialogue with the teachers will also provide information on critical issues of the learning systems and ideas on its further development. The research question “*how did the teachers perceive the material?*” seems therefore to provide much more useful information than the question “*what was the impact on the students?*”



A key issue for the successful dissemination of new teaching units appears to be a robust integration of the units into the national school frameworks. The feedback from the schools strongly indicates that teachers have very limited time to find and initiate new ideas and teaching materials. They usually use already established information portals that provide the material in a form that corresponds to the national education plan and is ready-made for a particular school level. There is therefore a need to establish cooperation with the key players in the national pedagogical frameworks. In order to better evaluate the impacts of aquaponics on STEM subjects, environmental and other learning outcomes, a comparative study between educational institutions where they used aquaponics as a teaching tool based on the same and well-designed research methods and addressing various teaching goals would be needed.

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