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Aquaponic in classrooms as a tool to promote system thinking

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Abstract

System thinking with Aquaponic“ is an educational concept that aims to train students in system thinking by using a connected fish and plant culture system. System thinking is seen as a central skill in education for sustainability. Between October 2007 and January 2008, a teaching sequence took place with three classes of 7th grade students in the Zuerich agglomeration, Switzerland. Several themes were introduced in the lessons by means of a classroom model: what is a system, relationship between system components, feedback loops and self-regulation and finally planning and construction of an Aquaponic classroom system. The students then also operated and monitored the system. The effect of the teaching sequence on system thinking competences was assessed at the beginning and at the end of the sequence. The ability of students to think in a systemic way instead of linear succession improved significantly in the posttest compared to the pretest. In addition, gender specific differences in relation to learning systemic thinking were compared. Female students showed slightly better results than male students; the reasons for this could not be pinpointed.

Key words: Aquaponic, system thinking, ecotechnology, paedagogical work

1 Introduction

1.1 Aquaponics for schools

Aquaponics is an innovative, sustainable food production system combining AQUAculture of fish with hydroPONIC cultivation of plants, in a closed water cycle (Graber & Junge-Berberovic, 2009). Aquaponics technology contributes significantly toward sustainable aquaculture and food provision: it is one of the most water saving and pollution preventing technologies, uses no antibiotics and/or pesticides, greatly reduces nutrient emissions from fish husbandry and is thus a high-level strategy in the fight against eutrophication, and last but not least, fish in aquaponic are farmed according to the best standards. While it is a widely discussed technology today (about 1.3m hits on Google in May 2014), there are only a handful of research papers on system efficiency and performance published yet.

The most cited ones include Diver (2000), Rakocy et al. (2006) and Graber & Junge-Berberovic (2009).

However, Aquaponic is not only a forward-looking technology, it also provides an excellent tool to teach about natural sciences at all school levels, from primary school to university, and it promotes scientific literacy. The basics for the implementation of Aquaponics in teaching were elaborated during the EU Framework 6 Project "WASTE WATER RESOURCE" (www.play-with-water.ch). Aquaponic is a possible answer to many challenges in sustainable development. Such intricate problems require thinking in complex contexts. For this, system thinking promotes the relevant competencies. Due to its systemic, interlinked design Aquaponic is a suitable subject matter to train such systemic competencies.

1.2 Sytem thinking

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

System thinking includes four central dimensions (Ossimitz, 2000): (i) thinking in models, (ii) interconnected thinking, (iii) dynamic thinking, (thinking about dynamic processes, such as delays, feedback loops, oscillations), and (iv) steering of systems, which implies the ability for practical system management and system control. Classroom aquaponic systems mostly concern the interconnected thinking and thinking in models. Interrelated thinking contains identification and appraisal of direct and indirect effects, particularly with regard to identifying feedback loops, construction and understanding of entire nets of cause and effect. The key for interrelated thinking is the identification of feedback circles. Ossimitz (2000) states that dynamic thinking in interconnected structures is always connected to thinking in models. The models should be realized as simplifications and abstractions of natural circumstances. Students should therefore learn how to design, analyse, and optimize models.

The main goal of the teaching sequence "Classroom aquaponic" was to qualify students to adopt tools which can help them to examine complex problems. They should know how to analyse systems, name the system variables and get a general idea of a systems inner structure. The hypothesis tested was that incorporating Aquaponic into teaching units has a positive influence on system thinking abilities of the pupils.

2 Methods

2.1 Profile of the students

The school (Bezirksschule) was situated in Mutschellen, within the the Zurich agglomeration, Switzerland. Three classes of 7th grade (age 12-14 years) were involved, a total of 68 students, 32 female, 36 male, all native German speakers. The general level of these students was high: they concluded 5th grade with an average mark of 5 (from 1-6) in German, mathematics and natural sciences, were used to autonomous work, showed consistent ability and general interest. Each class was divided into six groups (Table 1), three groups were responsible for one (of totally six) classroom Aquaponic system.

Table 1: Subdivision of each class into 6 groups. Each Aquaponic system was operated and monitored by three groups from three classes.

Aquaponic System No	**Class (Grade 7)**		
	K 7.1	**K 7.2**	**K 7.3**
1	Gr. 1, only girls	Gr. 1, only girls	Gr. 1, only girls
2	Gr. 2, mixed	Gr. 2, mixed	Gr. 2, mixed
3	Gr. 3, mixed	Gr. 3, mixed	Gr. 3, mixed
4	Gr. 4, mixed	Gr. 4, mixed	Gr. 4, mixed
5	Gr. 5, mixed	Gr. 5, mixed	Gr. 5, mixed
6	Gr. 6, only boys	Gr. 6, only boys	Gr. 6, only boys

2.2 Construction of classroom aquaponic

Six simple aquaponic systems (Figure 1) were constructed according to the general description in Albin & Bamert (2005). The students were responsible for construction, operation and monitoring of the aquaponic classroom model. They were provided with the required material (Table 2), and established the aquaculture and hydroponic. Tomato and basil seedlings were planted in expanded clay beds. The Aquarium was stocked with two common rudds (*Scardinius erythrophthalmus*) caught from the nearby pond and returned after the experiment. Students figured out themselves how to connect plant culture with fish farming, and outlined a scheme of the proposed arrangement.

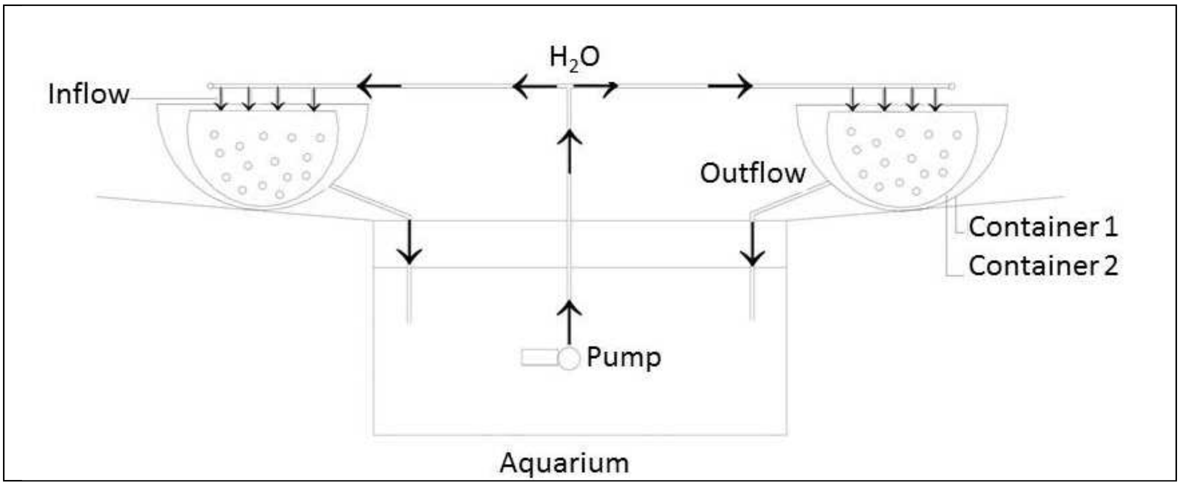

Figure 1: General sheme of classroom aquaponic (modified after Albin and Bamert, 2005)

Each Aquaponic system was monitored daily, and following operations were executed: measurement of the plant height, observations of the plant health, portioning of the fish feed and feeding of the fish, monitoring of the fish behaviour, measurement of the water temperature, refilling of the aquarium with water. All the measurements and observations were documented in the "Aquarium journal", which also served to transfer information between the three groups which worked on the same Aquaponic model.

Table 2: List of consumables for one classroom aquaponic. All can be purchased either from a pet store or from a DIY store. The cost for one unit was about 250 EUR in 2008 in Switzerland.

System	**Material**	**Quantity**
Aquaculture	Aquarium (80 l, larger is better)	1
	Water pump	1
	Aquarium hose	0.5 m
	Injection pipe	0.5 m
	Fish feed	1 l
	Aquarium silicone	1 Tube
	Wire mesh (as aquarium cover)	approx. 0.5 m^2
	Cable ties	several
	Plugs for injection pipe	several
Hydroponic	Flower boxes, 60 cm	4
	Expanded clay, 8 – 14 mm	5 l
	Grow lights, 100 Watt	2
	Bulb sockets	2
	Power cable	2 sections à 0.5 m
	Multi-plug	1
	Power extension cord, 10 m	1
	Time switch	1

2.3 Teaching organisation

The Aquaponic teaching sequence (Table 3) took place between October 2007 and January 2008. The teacher introduced the following themes during the lessons: basic system concepts (relationship between system components, feedback and self-regulation), and basic knowledge about aquaponic. A lot of teamwork was used as teaching method. During this time students operated and monitored the Aquaponic, and made several presentations in the classroom in order to show their growth of knowledge and understanding. All teaching units are described in detail in Bollmann-Zuberbuehler et al. (2010).

2.4 Evaluation of the teaching unit

The research process was designed, carried out and reflected by means of action research (Altrichter and Posch, 2007). This approach includes developing the units through self-observation and field notes. Action research method is a comparatively easy method for reflective teaching. Teachers maintain a detailed journal, where all successes, problems and other observations are noted, allowing to draw conclusions for the ongoing teaching process. The teacher (Urs Hofstetter) kept this journal and provided the conclusions about the teaching sequence.

Table 3: Sequence of teaching units in three classes of 7th grade students.

Teaching Unit	**Number of Lessons**	**Methods**	**Content**
TU1	1	Knowledge query through a test	Pre-Test
TU2	4	Teacher lecture, Research, Presentation	System basics
TU3	2	Instruction, Student assignment	Tool "connection circle", 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 aquaponic arrangement
TU5	2	Problem-based learning (PBL)	Define the main indicators of the system fish and plant and their interactions
TU6	3	Discovery learning	Monitoring the aquaponic
TU7	3	Presentations by students	Draw a diagram of the interconnections in aquaponic
TU8	1	Knowledge query through a text	Post-Test
TU9	2	Aquaponic party	Harvest, preparation of caprese salad, eating

2.5 Evaluation of system thinking capabilities

All students performed a test at the beginning and at the end of the teaching sequence. The pre- and posttest were identical and contained a short text about life as a farmer, which animated the students to think about the farmer and his behaviour. 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 pretest was written by all 68 students (32 female, 36 male), the posttest by 64 students (28 female, 36 male, 4 girls were sick). The answers of the students were evaluated according to the method outlined by Bollmann - Zuberbuehler (2005), allowing to use a qualitative method with quantitative results.

In the first step, the drawings were analysed (see Figure 2 for general description, Figure 3 for an example of a drawing). The variables, junctions, arrows, chain(s) of events, and feedback loops were enumerated for each drawing/answer sheet submitted.

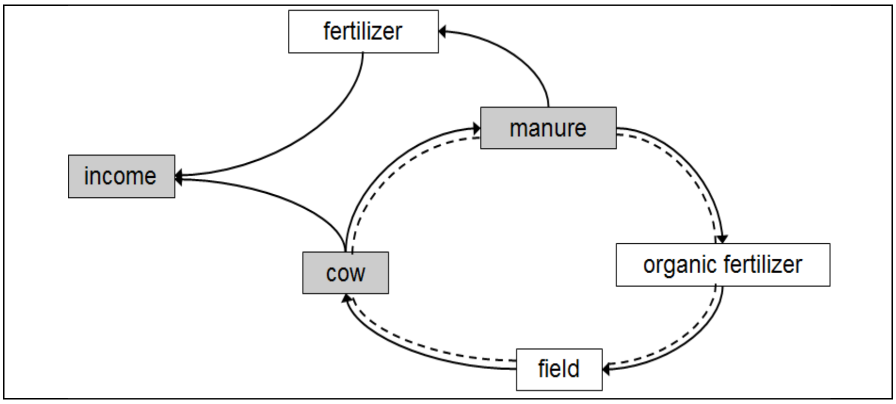

Figure 2: Procedure to assess the elements of a system drawing. A variable (square) is an icon of a subject in the system. The value of a variable can increase or decrease. A junction (shaded square) is a variable that influences at minimum two other variables or two variables that influence at least one variable. An arrow (arrow) shows a directional connection between two variables. A chain of events (-) stretches over at least 4 variables and 3 arrows. If a chain of

events is interrupted by a junction, the count re-starts. A feedback loop is a closed circle of arrows, and consists of at least 2 elements and 2 arrows (dashed line).

In the next step, the following indices were determined: Delineation of the system, Complexity index, Interconnection index, and Structure index

The delineation of the system was identified according to criteria in Table 4. The delineations of the first group lack complexity, and their corresponding structure index is 0. The delineations of the second group are more complex. In the posttest the majority of the students should draw a delineation of the group 2, as an effect of the instruction.

Table 4. Identification of the delineation of the system

Group	Delineation	Description	Level
1	No drawing	No representation at all	1
	Scenic representation	Scenes without logic connection	2
	Figure with stages	Logic sequence of minimum 3 scenes	3
	Other representation types	All other representations which could not be clearly allocated	4
2	Linear Graph	Contains at least 1 chain of events	5
	Effect diagram	Contains in addition at least 1 junction	6
	Net diagram	Contains in addition at least 1 feedback loop and/or cycle	7

The complexity index (German: „Komplexitätsindex“, KI) shows how many system concepts the student implemented, and was calculated as follows:

$$KI = variables + arrows + chain\ of\ events + junction + feedback\ loops \qquad \text{(Eq. 1)}$$

The interconnection index („Vernetzungsindex“, VI) shows the frequency of the connections between the variables, and was calculated as follows:

$$VI = 2 \times arrows / variables \qquad \text{(Eq. 2)}$$

The structure index („Strukturindex“, SI) shows how many complex system concepts the student implemented in the representation, and was calculated as follows:

$$SI = (chains\ of\ events + junctions + feedback\ loops) / variables \qquad \text{(Eq. 3)}$$

3 Results

3.1 Teacher’s Evaluation of the Aquaponic Unit

This section summarizes the comments of Urs Hofstetter, mentioned within process of self-observation according to the action research method outlined by Altrichter & Posch (2007).

Advantages of the Classroom Aquaponic system

The main goal was to train the pupils in system thinking. They learned this skill during the teaching sequence, as well as the ability to deal with complexity. Through the adoption of this understanding, the knowledge in system thinking can be transferred to other school topics. Since they were divided into smaller groups, they had to develop teamwork skills. In addition, intense social learning took place in the working groups and a clear increase of the pupils' self-esteem could be observed. Their ability for teamwork was tested while they were working in groups. They had to interact among each other and organize and divide the work. A discussion of the variables of the system took place in the group.

Disadvantages of the Classroom Aquaponic

Naturally there were also disadvantages to introducing Aquaponic as a teaching tool. For one thing, costs are an important factor to consider. Most materials for aquaponic are not readily available at schools, and teachers have to buy it at extra costs. One complete classroom aquaponic system like it was built for this study costs about 250 EUR. For a Swiss elementary school that is a lot of money, since teachers only have approximately 300 EUR per year at their free disposal. It is different at high school level, where this sum could easily be raised. Another disadvantage is the time that goes into preparation, construction and maintenance of the system. Although the pupils are responsible for the arrangement, the teacher has to keep an eye on the system. This implies a lot of responsibility and additional work, which elementary school teachers might try to avoid.

3.2 Evaluation of system thinking

Generally, the delineation of systems became more complex in the post-test (Figure 4). In particular it showed the shift from a qualitative description to a more schematic description of the system (Figure 3).

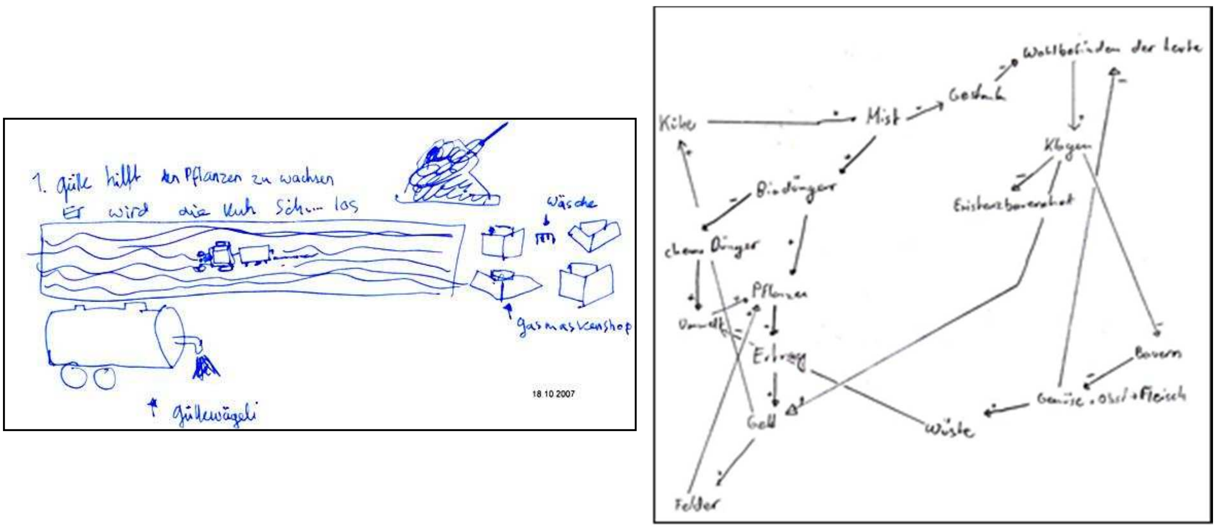

Figure 3: Two examples of students' answer to the question: "Why did the farmer put manure on his field?" Left: scenic representation from the pre-test (Level 2), right: net diagram from the post-test (Level 7).

If numerical values were assigned for each "level" of drawing (Table 4) an interesting pattern emerged (Table 5). While both genders reached the median level of 7 at the end of the teaching sequence, the change was larger for boys, who started at a lower level. This might mean that boys might profit more from hands-on experience than girls.

Table 5. Comparison of the results between the pre- and posttest.

	Pretest	Posttest	Change

	(median)	(median)	
Girls	2.5	7	4.5
Boys	2	7	5

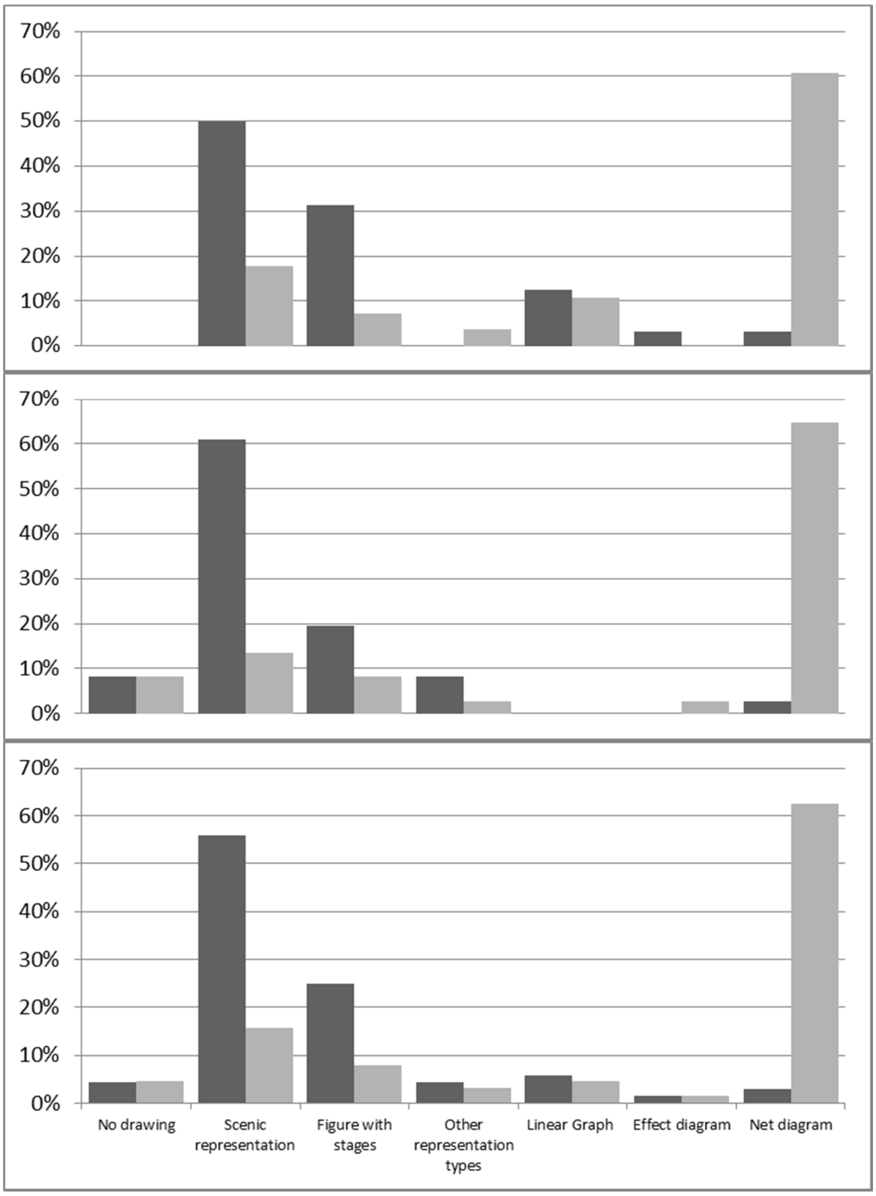

Figure 4. Representations according to delineation level in pretest (dark) and posttest (grey) as outlined in Table 2. Above: girls, center: boys, bottom: all.

The pupils found more system concepts and knew more about system variables at the posttest than in the pretest, a fact reflected by all indices applied (Figure 5). These results seem to support the hypothesis that incorporating Aquaponic into teaching has a positive influence on the system thinking capabilities of the pupils, and that the devised „Classroom Aquaponic sequence“ was able to train pupils in system thinking.

Some of the differences between pre- and posttest results were the appearance of complex system concepts like chains of events, junctions and feedback loops. Due to their gained knowledge, the pupils used more variables to describe their systems, which is a logical consequence of the teaching units. At the pretest, the pupils did not know how to draw a delineation of a system. The results for the Interconnection Index showed that the teaching unit 3 – connection circle – presented them with a possible way to describe a system.

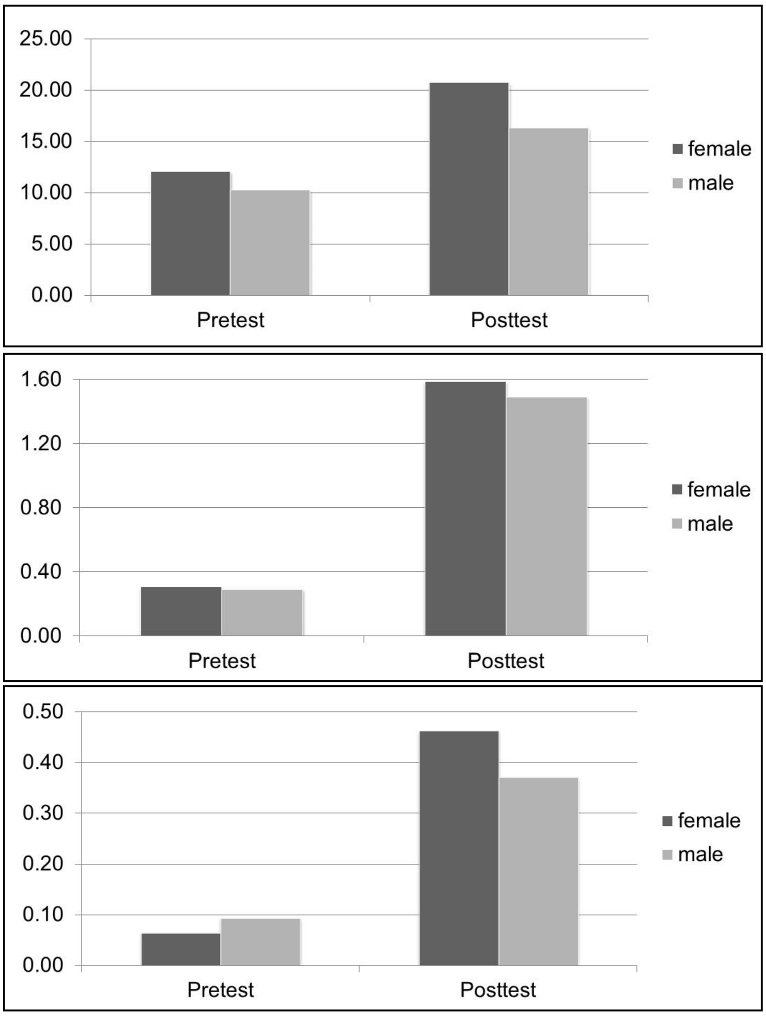

Figure 5. Complexity of answers in pretest and posttest. Above: Complexity Index (KI), center: Interconnection Index (VI), below: Structure Index (SI)

In the posttest also a lot more complex system concepts were drawn than in the pretest (Structure Index). A possible explanation is the fact that during the teaching units they learned that a system needs feedback loops to be able to run. This knowledge was subsequently applied in their drawings.

The analysis also showed female pupils tended to achieve better results than male. Nevertheless, it is not possible to claim a significant gender difference, as the number of students was too small.

4 Conclusion /Discussion

The outcomes of classroom aquaponic were: (i) training in system thinking (aquaponic helps to improve system thinking competences), (ii) training in proper monitoring (contribution to scientific literacy, (iii) training in planning, and implementing the plan (competence to steering of systems, ability for practical system management and system control as Ossimitz (2000) defines), (iv) independent working in groups and increase of self-esteem, (v) contact with fish and plants (i.e. environmental education which is close to everyday life).

The critical points of implementing aquaponic were that this is a long term project with significant costs, which also requires intense teacher involvement. The costs could be offset if aquaponic becomes a regular project for science classes and therefore the required material could be acquired by the school for more than one class. It can also be used for several years. All in all the advantages outweigh the disadvantages, as they are mere resource problems which can be addressed.

The indices introduced by Bollmann-Zuberbuehler (2005) were helpful in testing the hypothesis. There was an increase for all the measured indices from pre- to posttest, especially the Interconnection Index and the Structure Index. Therefore the classroom aquaponic has shown to increase the system thinking of students.

The basis for this lies with the teaching units about system basics and the connection circle tool. But even more important is the actual aquaponic system, where there is planning and monitoring of the arrangement, as well as drawing interconnections in the aquaponic. This hands-on experience is an invaluable addition to increase learning achievements of students. It offers training opportunities in system thinking, planning, implementing and monitoring of systems, as well as learning to work independently and in groups.

On the other hand, the increase in indices might be expected, since the pretest was taken before any teaching on systems took place. So it is not a surprise that the teaching had such an effect. It would be interesting to test whether the classroom aquaponic has additional effects compared to standard teaching that does not include having to build and run a complex system. This would answer whether hands-on teamwork is especially beneficial or whether normal science classes using only theoretic methods can achieve the same results.

Also, the relatively simple set up of the test could reveal if there were other factors involved, like increase of age (maturation) and learning these skills anyway.

System thinking needs a lot of knowledge. If there is no knowledge about the details, no advancement in system thinking can be expected. Still, system thinking includes a shift of thinking: thinking in relations instead of focusing on the single elements.

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