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Aquaponics systems as an educational tool: effects on students' achievement and teachers' views

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Abstract

Aquaponics systems model aquaculture and hydroponics systems for food production. Aquponics allow cycle of nutrients as well as wastes and offers a sustainable option to the use of environmental resources. Aquaponics systems are also considered in education as a teaching tool which can be implemented into different grade levels. . It's possible to talk about different science concepts around a real world problem with aquaponics and they present a good opportunity for STEM education. In addition, problem solving, systems thinking and science process skills can easily be adapted to aquaponics activities as they are considered effective teaching tools. With this in mind the aquaponics system activity was designed targeting the "Ecosystems Ecology and Contemporary Environmental Issues" unit of the 10th grade biology curricula using the STEM framework. The aquaponics systems activity was implemented as an afterschool activity with the participation of 10th grade students and as a workshop with science and biology teachers. This study explores; a) how effectively aquaponics systems activity can be used in the classroom, b) what is the impact on students' achievement and c) what are students' and teachers' perception of it. Teachers identified aquaponics systems activity as interesting and motivational for student learning. They all were able to identify scientific concepts of the activity in relation to the biology curriculum however making the connection with STEM disciplines was found to be more difficult. Participating students' academic achievement scores were found to be statistically higher in post-test analysis. Students were able to practice science process skills, problem solving, and design processes in addition to learning scientific concepts.

Keywords: Aquaponic system, academic success, ecosystem ecology, science teacher, high school students

1. Introduction

Creating the best learning environment for students has been a major goal of education with an ultimate goal of development of individuals who are capable of functioning productively in society. Especially with the declining interest in STEM related careers among youth and the observed gender gap, a global effort started to increase students' interests in such career choices. STEM education has been getting a

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lot of attention lately with the hope that it will lead to individuals who are capable and willing to work in the STEM related jobs. The promise of STEM education is to allow individuals to be able to make connections between disciplines of mathematics, science, technology and education. To do so they should be problem solvers, critical thinkers, innovative, and successful using 21st century skills. This global expectation is also valid for Türkiye as well. STEM education is promoted for K-12 grade levels but like other countries there is a significant need for STEM activities for these grade levels as well. However, in K-12 science curricula the number of attainments that address STEM disciplines are limited and the same applies to available activities as well.

With this need in mind an aquaponics systems activity (ASA) was developed aligned with biology curriculum. Aquaponics are farming systems that integrate fish, bacteria and plant production technology (Ravindranath, 2017). They are also great teaching materials to teach about ecosystems and environmental issues (Genello at al., 2015; Hart, 2013; Junge at al., 2014; Viktor, 2018) as well as systems understanding (Junge et al., 2014). Considering that earth we live in is a system with many interconnected elements, a system understanding among individuals becomes vital for a sustainable life. As Junge at al., (2014) points out, aquaponics systems addresses all four dimensions of systems thinking; "(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 (Ossimitz, 2000 p.). Therefore, aquaponics systems as a teaching tool presents a great opportunity to foster systems understanding with a STEM framework in science education.

In the United States aquaponics has had a wide and successful use in the classrooms since the 1990's (Hart, Webb, Danylchuk, 2013). Aquaponics presents a valuable opportunity to promote systems thinking, science process skills (data collection, observation), problem solving, critical thinking and STEM integration in classrooms. However, in Türkiye there hasn't been any examples of using aquaponic systems as a part of science or biology education in any grade levels regardless of its potential. Therefore, this study aims to investigate implementation of aquaponics systems activity (ASA) in 10th grade biology curriculum. The 10th grade biology curriculum includes a unit on "Ecosystems and ecosystem ecology", which presents a good opportunity for implementation and was considered a good fit to test the impact of ASA.

The research questions of the study were;

1- How do students and teachers perceive aquaponics activity?
2- What is the impact of aquaponics activity on students' academic achievement?
3- Is there a difference between male and female students' academic achievement?

1.1. Systems Thinking and STEM in Science Education

Systems understanding by definition means to understand a system by its components and their interactions as well as problem solving in relation to the system. Thus the term “systems understanding” has a use in different fields such as science, economics, and psychology and includes biological systems, economic systems and social systems (Momsen et al., 2022). However, in recent years system understanding has been used mostly in association with complex biological processes and systems. And the value of systems thinking in science education is widely accepted and emphasized in the Next Generation Science Standards as well (Verhoef et al., 2018). Research suggests introducing students to systems thinking in early years such as elementary education (Ben-Zvi Assaraf & Orion 2005). Verhoef et al (2018) states the vagueness of “what is system thinking?” and argues that it is a learning strategy. This study takes a similar approach to Verhoef et al., (2018) and the ASA was designed as a learning strategy to help students learn about ecosystems and its components.

STEM education refers to Science, Technology, Engineering and Mathematics and emphasizes the interconnectedness between these disciplines (Hiğde, 2018), thus, the STEM approach utilizes system thinking within itself. STEM education focuses on real life problems and aims to find a solution from an interdisciplinary perspective. The expected outcomes can be either products or students’ achievement or acquired skills (Bolat, 2020). STEM activities are reported to motivate students’ learning (Schaefer, Sullivan and Yowell, 2003). STEM education promotes problem based learning, inquiry, design based learning and collaboration (Thibaut et al., 2018) therefore students are actively engaged in their learning process. Since STEM education promotes collaboration, learning is socially constructed as well (Thibaut et al., 2018). In this study, problem based learning and collaboration to teach concepts of ecosystems and sustainability were also used during the development of ASA.

1.2. Aquaponics Systems as a Teaching Tool

Aquaponics systems are a combination of aquaculture and hydroponic systems for food production (Bernstein, 2011) and they are sustainable plant and fish production models. (Kargın and Bilgüven, 2018). Aquaculture is the cultivation method of aquatic plants and animals (Nash, 2011) while hydroponics is the method of farming without soil (Smith, 2000). Aquaponic systems allow both plant production and fisheries. It’s a symbiotic system and the water cycle continues between fish and plant production areas. Figure 1 shows a schematic of an aquaponics system.

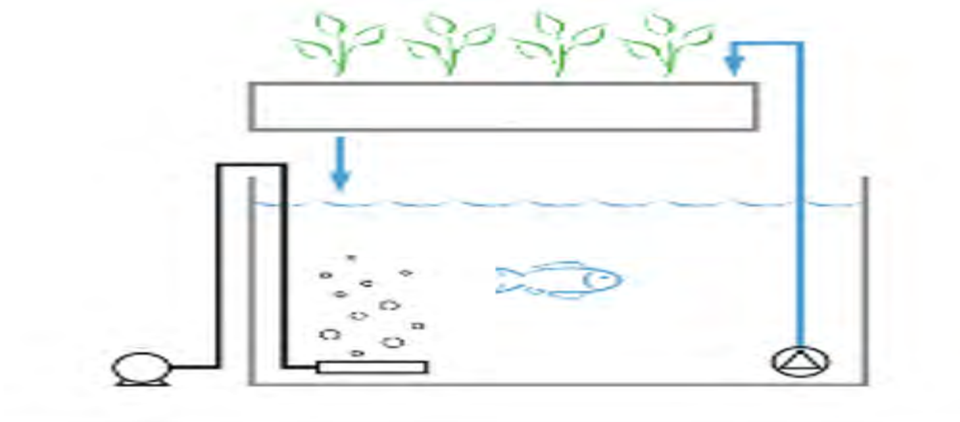

Figure 1: Schematics of an aquaponics system (Adapted from Palm et al., 2019)

Although the main purpose of the aquaponics systems is to have a sustainable food manufacturing system, aquaponics systems also serve as a great teaching tool for various grade and age levels to promote scientific and ecological literacy. An aquaponics system provides a good opportunity to improve and practice 21st century skills as well as systems thinking (Hofstetter, 2008; Junge et al., 2014) and in class use is promoted by many educators since it provides a good opportunity to promote scientific communication between teachers and students as well (Hofstetter, 2008; Hart et al., 2013; Junge et al., 2014; Junge et al., 2019; Viktor, 2018). Aquaponics systems can be used to address different disciplines including; economy, sustainable development, environmental sciences, health agriculture and food systems.

Aquaponics systems still have a limited use in schools due to reasons including teachers' lack of knowledge and experience, technical issues, cost, and requirement of long term maintenance which is difficult during holidays. Hardt et al., (2013) states that due to such limitations teachers should have necessary knowledge and motivation for implementation of aquaponics systems in schools. In terms of time frames several approaches are recommended for the implementation; a semester long implementation, 1-2 hours of classroom time per week for a period of 8-12 weeks, a half day workshop, 2-5 days long science project or semester long after school project (Junge et al., 2019). Depending on the grade level, purpose, time and availability, length of the activity can be determined. Aquaponics have the potential to develop an understanding among students on how to make healthy and sustainable food choices for themselves as well as the environment.

1.2.3. *Aquaponics Systems Activity*

The aquaponics systems activity was developed by the researcher and her advisor targeting 10th grade curriculum as an after school activity. The activity addresses the concepts of biotic and abiotic components of the ecosystems, nutritional relationships, matter cycles and energy flow and environmental issues and sustainability which are covered in the Ministry of National Education's (MoNE) 10th grade biology curriculum "Ecosystems Ecology and Contemporary Environmental Issues" unit. The designed activity consists of a 6 weeks period and has the potential to address all four dimensions of the STEM education. The aquaponics system activity is designed around an everyday problem with science content of biology, chemistry and physics as well science process skills and mathematics content of data analysis, drawing and interpreting graphs, ratio, volume and content related calculations. Both technology and engineering dimensions are utilized with an emphasis on problem solving, systems thinking and design. Although the aquaponics system activity is designed to address all STEM dimensions it can be modified to address some of the STEM dimensions rather than all depending on the grade level, student readiness, time, related concepts and other factors. During the study while conducting ASA students got the opportunity to discuss and learn the following concepts: ecosystems, environmental preservation, water cycle, N Cycle, water conservation, water pollution and preservation, sustainable agriculture. ASA allows group dynamics and promotes peer learning, collaboration, problem solving, science process skills, data collection, data analysis, and design.

The design elements of ASA included the following plants; parsley (*Petroselinum crispum*), lettuce (*Lactuca sativa* L) and dill (*Anethum graveolens*). They were chosen since they are the most preferred types of plants for aquaponic systems and for the ease of access to the seeds (Kargın ve Bilgüven, 2018; Yeşiltaş, 2021). Goldfish (*Carassius auratus*) was chosen for the system since they are more tolerant to various water conditions such as temperature (Yanar et al, 2022). A total of 15 goldfish were used during this activity. Figure 2a shows the final version of the aquaponics system designed and figure 2b shows students working in collaboration during the design of the system.

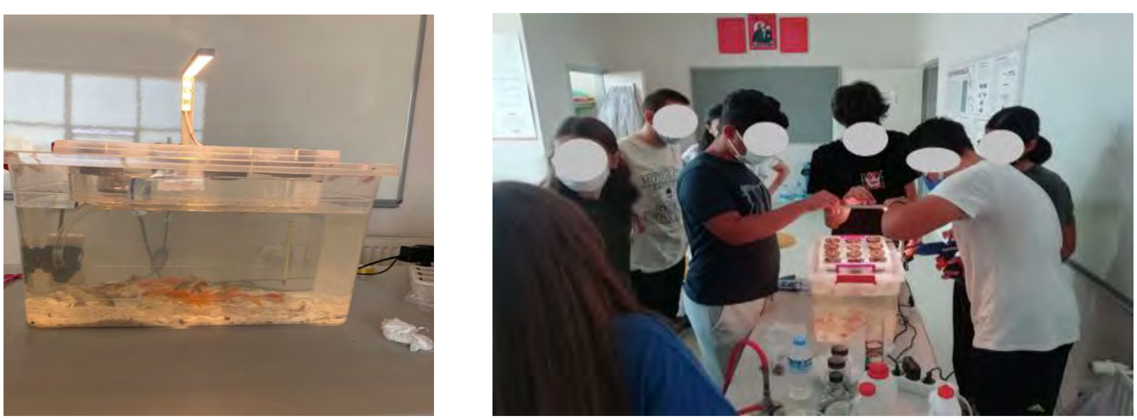

Figure 2. a) Aquaponics design and b) Students designing aquaponics.

This activity was used with two different participant groups in two phases. Phase one was with the 10th grade high school students. ASA took place as an after school activity prior to the related unit "Ecosystems Ecology and Environmental Issues" was covered at the school. First day of the activity was dedicated to investigate students' understanding and pre-existing knowledge on the concepts such as aquatic pollution, water preservation, sustainability, technology, agriculture and possible solutions to environmental issues. Second day was dedicated to designing a system based on the first day's discussions. Due to time limitations an initial aquaponics system design was suggested by the researcher to the students and discussions were held based on the system and its components. Following weeks and sessions were dedicated to the observations and maintenance of the aquaponic system. During the activity students' responsibilities included maintaining the aquaponics system, data collection (such as water quality), data analysis, problem solving, taking part in the discussions. As time progressed problems /issues arose and students were required to come up with solutions; such as fish getting stuck to the filter or position of the plants. Students were required to present their rationale for their solutions, work on different design parameters and modifications to solve the issues which served as the Engineering component of the STEM activity.

Aquaponic systems require certain parameters to be maintained such as water quality to assure health of the system and its components including fish and plants. Table 1 presents water quality parameters that need to be maintained. Students were required to take samples from the aquaponic system and test water quality on regular bases. They used commercially available aquarium test kits. With these kits it's possible to test for parameters such as Ph, CO_2, nitrite, nitrate. Students used a mobile app to complete the analysis and compared them to optimal values presented in Table 1.

Table 1. *Water quality parameters in aquaponics systems (Mol, 2019)*

Organism	**Temperature**	**pH**	**Ammonium**	**Nitrite**	**Nitrate**	**Oxygen**
warm water fish	22-32	6-8,5	<3	<1	<400	4-6
cold water fish	10-18	6-8,5	<1	<0,1	<400	6-8
Plants	16-30	5,5-7,5	<30	<1		>3
Bacteria	14-34	6-8,5	<3	<1		4-8

Based on the tests conducted with water samples students were expected to determine if the values were in the accepted range and if not why such diversion in the values may be occurring and how to resolve the observed issues. Some screenshots of the weekly test values are presented in Figure 3.

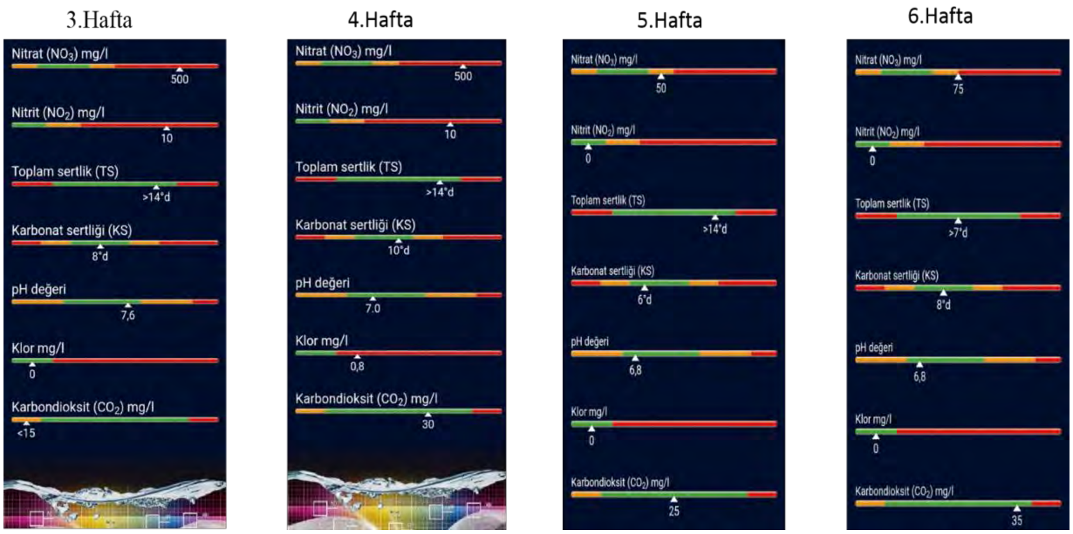

Figure 3. Weekly water quality test results

The second phase of the study was with biology and science teachers who were the second group of participants that ASA was used. A half day workshop was designed for this group of participants to explain how aquaponics systems are built and can be used in the classroom as a part of science and biology instruction. Participants were able to investigate and analyze each component of the system and a brainstorming session was completed to answer possible questions regarding the aquaponics system during the workshop.

2. Method

This study is exploratory in nature and employs a mixed method design to investigate the effectiveness of ASA designed for the purpose of this study. A pre -and post-test approach was used to collect quantitative data. For this purpose the Ecological Concept Test developed by Çetin (2003) was used. Qualitative data were collected with triangulation through semi-structured student interviews, semi-structured teacher interviews, meeting notes, WhatsApp communications and field notes.

2.1. Participants

Participants of this study were 14 students, 8 science and biology teachers and 1 administrator. Administrator was responsible for overseeing students for the duration of the activity. Selection of students was based on a convenience sampling and data collection was conducted during 2021 -2022 academic year. Students were 10th grade students (7 female and 7 male). Participation in the study was on voluntary bases and participants had the right to leave the study at any time. No grading was associated in relation to the study. Necessary permissions from students, parents, teachers and Ministry of Education were received prior to the study. Necessary ethical permissions were also received from the ethical board prior to the study.

Throughout the study participants were identified with code names such as S1 (student 1), T1 (teacher 1) or A (administer). Teachers' years of experience are listed in Table 2.

Table 2. *Participant teacher's specialties and years of experience*

Teachers	Gender	Specialty	Years of Experience
T1, T2, T3	Female	Biology Education	0-5
T7, T8	Female	Science Education	0-5
T4	Female	Science Education	5-10
A	Male	Administrator	10-15
T6, T5, T1	Female	Biology Education	>25

2.2. *Instruments*

The instruments and procedures used during data collection were 1-Ecological Concept Test 2- Semi-structured student interviews, 3- semi-structured teacher interviews, 4- meeting notes, 5- WhatsApp communications and 6- field notes.

2.3. *Ecological Concept Test*

Ecological Concept Test (ECT) was developed by Çetin (2003) and includes items related to ecosystems ecology and environmental issues units and each item targets a standard from the 10th grade biology curriculum. The test consists of two sections; multiple choice questions with reasoning (10 items) and open ended questions (7 items). Each question has 3 levels of scoring; a completely correct answer is 3 points, a partial correct explanation is 2 points, a partial understanding with a misconception is 1 point and a wrong explanation is 0 points. A maximum score of 51 is possible for the Ecological Concept Test. Cronbach alpha values for the subscales were calculated as .51 and .69.

During this study ECT was used as a pre-test prior to aquaponics activity to determine participant students' pre-existing knowledge and as a post-test after the activity.

2.4. Semi-structured interviews

An interview protocol was developed by the researchers to investigate students and teachers' views on the aquaponics system activity. Protocol was developed after an extensive literature review and draft version of the interview was reviewed by content experts. A two stage expert review process was used to receive feedback on the draft version of the interview protocol. Based on the feedbacks, the interview protocol was finalized. Final version of the student interview protocol included 11 questions and the teacher interview protocol consisted of 8 questions. Participants were interviewed face to face by the researcher and out of 14 students 11 of them were available to take part in the interview process. All interviews were voice recorded with the participants' consent. Interviews were transcribed by the researcher prior to the analysis.

2.5. Meeting notes, WhatsApp communications and field notes

Throughout the study field notes were kept by the researcher during the face to face student meetings. Researcher recorded field notes during and immediately after the meetings to prevent data loss. Following face to face meetings the second form of communication was through WhatsApp. This form of communication allowed students and researchers to communicate, share data and images outside of the classroom environment. This way students were involved in the activity longer than the time they spent in the classroom during observations, maintenance and activity related tasks. Through WhatsApp communications students were able to share their thoughts, ask any questions they had related to activity, collect water quality data, identify issues that were raised during the activity and propose possible solutions to observed problems. All communication data was included as a form of data in the study. In addition to these forms of communications, zoom meetings were held twice for a minimum of 30 minutes to talk about the content, discuss students' progress and evaluate the ongoing activity.

2.6. Data Analysis

Quantitative data collected through the study with the Ecological Concept Test was analyzed using the Statistical Package for the Social Sciences (SPSS) 25. Normality assumption was tested using Kolmogorov Smirnov/Shapiro Wilks test. Analysis revealed that normality assumption was violated and since the number of participants were less than 30 non-parametric analysis was used to analyze the data.

Qualitative data collected from semi-structured interviews, meeting notes, WhatsApp communications and field notes were first transcribes then analyzed with document analysis to be able to identify emerging categories and codes. To be able to maintain trustworthiness and avoid bias an outside content specialist also analyzed all of the qualitative data. Findings were finalized after a consensus reached between the researchers and specialists and presented below.

3. Findings

Descriptive analysis of the ECT scores of the students revealed that students pre-test scores ranged between 16- 35 and mean score was ($\bar{X}$=23, 86). Post-test scores ranged between 21- 45 and mean score was ($\bar{X}$ =28, 29). As seen from the data in Table 3 all of the students' scores increased in the post-test.

Table 3. *Participant pre and post test scores on ECT*

Number of Student	**Total Score (Pre - Test)**	**Total Score (Post - Test)**
1	20	23
2	34	45
3	20	25
4	16	21
5	26	27
6	22	23
7	35	45
8	21	26
9	20	23
10	27	33
11	25	29
12	29	31
13	18	21

Number of Student	Total Score (Pre - Test)	Total Score (Post - Test)
14	21	24

Students' pre and post-test results were also analyzed based on gender as well. Descriptive analysis revealed that for both pre-test and post-test female students' mean scores were higher than male students. Minimum and maximum scores were also higher for female students in pre-test scores and maximum scores calculated for post-test were also higher for females.

Table 4. Female and male students' pre and post-test mean and minimum and maximum scores

	Female		Male	
	Mean±SS	Min-Max	Mean±SS	Min-Max
Pre-test	25,00±7,071	18-35	22,71±4,309	16-29
Post -test	31,14±10,172	21-45	25,43±3,645	21-31

Ecological Concept Test items were also analyzed individually to identify students' preexisting knowledge. Maximum possible score for each question in the Ecological Concept Test is 3. When pre-test scores were analyzed items 1, 3, 5, 7, 8, 9, 12 were found to have a score of less than 1. These items correspond to the following concepts; 1- biotic and abiotic components of an ecosystem, 3- food chain, 5- energy pyramid, 7- O_2 and CO_2 cycle, 8- N cycle, 9- Phosphorus cycle, and 12- dominant species in an environment. Having a score of 1 or less means either students do not know the concept or have misconceptions about it. Following the aquaponics activity post-test data was collected. And item based analysis was repeated to explore the changes in students' scores. Mean scores for items 1, 5, 8, and 12 increased while decreased for item 3 and 9. Mean pre- and post-test scores for each item is presented in Table 7. Wilcoxon Signed Rank Test was used to analyze item based pre- and post-test scores. A statistically significant difference was identified for items 1, 6, 8, 10 although except two all item based scores increased in the post-test. Concepts corresponding to these items are; 1- biotic and abiotic components of an ecosystem, 6- cycle of matter and energy flow, 8- cycle of matter and sustainability, and 10- population, community, ecosystem and biosphere interactions.

Table 5. ECT item based mean, minimum and maximum pre and post test scores

Questions	Pre - test		Post -test		p^a
	Mean±SS	Min-Max	Mean±SS	Min-Max	
Q 1	0,86±0,770	0-3	1,50±0,855	1-3	0,014
Q 2	1,71±0,994	1-3	1,71±0,994	1-3	1,000
Q 3	0,86±1,231	0-3	0,79±1,051	0-3	1,000
Q 4	1,07±1,141	0-3	1,21±1,051	0-3	0,157
Q 5	0,79±0,893	0-3	1,14±1,027	0-3	0,059
Q 6	1,07±0,917	0-3	1,50±0,760	1-3	0,014
Q 7	0,43±0,938	0-3	0,71±1,139	0-3	0,180
Q 8	0,79±0,579	0-2	1,29±0,914	0-3	0,020
Q 9	0,71±0,726	0-2	0,50±0,519	0-1	0,334
Q 10	2,14±1,027	0-3	3,00±0,000	3-3	0,008
Q 11	1,71±0,914	0-3	1,79±0,975	0-3	0,317
Q 12	0,93±0,917	0-2	1,21±1,122	0-3	0,180
Q 13	2,07±0,829	0-3	2,36±0,842	0-3	0,102
Q 14	2,36±0,497	2-3	2,50±0,519	2-3	0,157

Questions	Pre - test		Post -test		p^a
Q 15	2,43±0,852	0-3	2,79±0,426	2-3	0,102
Q 16	1,86±0,949	0-3	2,07±1,072	0-3	0,083
Q 17	2,07±1,072	0-3	2,21±0,975	0-3	0,157
Total score	23,86±5,749	16-35	28,29±7,917	21-45	0,001

Note. p<0, 05

Students' ECT scores were analyzed using the Wilcoxon Signed Rank Test. Students' pre-test mean score was ($\bar{X}$=23, 86) and post-test score was ($\bar{X}$ =28, 29). An increase in the post-test score is observed and this increase is found to be statistically significant (p<0, 05). These scores were also analyzed based on gender using Mann-Whitney U Test. Data is presented in Table 6 below. As seen in Table 6 no statistically significant difference was found between pre and post-test scores based on gender.

Table 6. Students ECT mean pre and post test scores

	Pre Test		Post Test		p^a
	Mean±SS	Min-Max	Mean±SS	Min-Max	
Mean score	23,86±5,749	16-35	28,29±7,917	21-45	0,001

Note. p < 0, 05

Table 7. Pre-test mean scores of female and male students

	Famale	Male	p^a
	Mean ±SS	Mean ±SS	
Pre Test scores	25,00±7,071	22,71±4,309	0,797

	Famale	Male	p^a
Post-test scores	31,14±10,172	25,43±3,645	0,368

Note. p< 0, 05

Student and teacher interviews were transcribed and coded to conduct the content analysis. Coding scheme was initially developed based on literature for student and teacher interviews prior to the analysis. As student interviews were analyzed and coding progressed the data was coded under 3 categories- 1-knowledge of aquaponic systems (know. AS), 2-post activity knowledge of aquaponic systems (p-know. AS), 3- perception on aquaponic systems (per. AS) and 10 codes. Table 8 presents the categories, codes, subcodes and frequencies of the student interviews. Teacher interviews were coded under 3 categories -1- knowledge of aquaponic systems (Know. AS), 2- impact on students and 3- AS as a teaching material)- and 4 codes. Table 9 presents the categories, codes, subcodes and frequencies of the teacher interviews.

Table 8. Student Interview Coding Scheme

Category	Codes	Sub-code	Code description	f
Know. AS	Pre-existing knowledge		Students' preexisting knowledge of the aquaponics system	11
	Post knowledge - qualification		Students' knowledge on aquaponics system after completing the activity and how qualified do they feel to be able to conduct the activity on their own	13
p-know. AS	Knowledge on components and functions.		Students' knowledge and understanding of the Aquaponics systems activity	7
	Curriculum connection	Agriculture	Which concepts of the 10th grade biology curriculum addressed in the aquaponics activity	10
		Ecology		13
		Living organisms		2
		Cycle of matter		13
		Hydrobiology		11
per. AS	Beneficial -pre		How students perceive the aquaponics systems prior to the activity , is it beneficial	3

Category	Codes	Sub-code	Code description	f
	Not beneficial -pre			5
	Beneficial -post		How students perceive the aquaponics systems after the activity , is it beneficial	11
	Interesting feature	Plant grow without soil	What are the interesting features of the aquaponics activity	4
		Building own ecosystem		5
		Fish plant interaction		8
	Difficulties	Design related issues	Difficulties faced during the aquaponics activity	
		Issues related to sustainability of the ecosystem.		3

Data analysis revealed that none of the students had a preexisting knowledge about the aquaponic systems prior to the activity. Although they didn't have prior knowledge, five of the students stated that they do not believe the system will be beneficial and even stated it will be ineffectual. S4 stated this as; "…prior to the activity I didn't think that it would be an effective system…". Following the completion of the activity all of the students stated that aquaponics systems activity is beneficial and showed an interest to do the activity again. S9 states as; "At the beginning of the activity I didn't know how useful it would be (aquaponics activity). Now I think that we can use it in the future".

Students' knowledge of the aquaponics system increased significantly upon the completion of the activity and were able to identify the relationships between the components of the aquaponics systems, such as fish poop being the fertilizer for the plants or role of bacteria during the cycle of matter. When asked to talk about the interesting aspects of the aquaponics systems activity students identified; being able to grow plants without soil, how fish and plants interact and support each other as two interesting aspects of the activity. S2 and S3 were also able to make the connection of building their own ecosystem with AS activity; S2 "it was interesting to grow plants and animals simultaneously, in a way we built our own ecosystem". Students were also asked to identify challenges and issues they faced during the activity. They identified challenges and solutions in two categories; design related issues and issues related to sustainability of the ecosystem. Design related issues included fish dying due to being stuck to the pump and plants not getting enough water due to how they were placed. These problems were resolved by changing the design of the system such as covering the net so that fish do not get stuck. Issues related to the sustainability of the ecosystem were related to the health of the system such as changing nitrate values. Such issues were resolved with changing the water of the ecosystem though students discussed other possibilities such as adding different kinds of plants to the system to level water quality values. In addition, from students' responses it was obvious that problems such as fish dying due to design issues or dill (one of the plants in the AS) not growing were identified as reasons for disappointment.

Students were quite interested in the aquaponics systems and were engaged throughout the activity. Except for two students, all students showed an interest to construct a AS in the future. Six students showed an interest to build a bigger system, while one student stated the potential use of the aquaponics systems. All but one student stated that they feel confident that they can build an aquaponics System by themselves and maintain it. Students were asked to identify the content they have learned in relation to the biology curriculum. They identified 5 content areas; agriculture (f 10), ecology (f 13), living organisms (f 2), cycle of matter (f 13) and hydrobiology (f 11). Out of these 5 areas ecology and cycle of matter were the most reported content related to the biology curriculum. Number of connections made by students were between 2 and 4. Two students (S10, and S12) identified 2 connections, 4 students (S1, S4, S6, and S7) identified 3 connections and 7 students identified 4 connections. All students made the connection to the matter cycle.

Students' regular communications were continued on WhatsApp platform to support the activity. Discussions were mainly focusing on problem solving as they faced couple issues during the 6 weeks of the activity. First issue was fish getting stuck to the filter and dying. Students proposed the solution of changing the location of the pump and using a net to prevent fish getting stuck. In addition the location students also proposed to change the location of the feeding to prevent fish being grouped by the pump. Students used three kinds of seeds (lettuce, parsley and dill) for the AS. On the third day of the activity they were able to observe sprouts of the lettuce and parsley. However, dill seeds did not sprout. Discussions were carried out in the classroom to be able to determine the reasons for dill seeds not sprouting. Students were asked to conduct research on the issue and come up with a solution as well evaluate their design for any design flaw that can cause such an outcome. Students identified pot positions as one of the reasons for dill seeds not sprouting. Their solution was to increase the diameter of the holes pots were sitting in. However they failed in their solution and were back to the drawing board to come up with a solution. Students also regularly measured water quality parameters to identify any issues, graphed and discussed their findings. An example of the students' graph is presented in figure 15. In the third week students measured a spike in the nitrite and nitrate levels (500 mg/l and 10 mg/l) as they stated these were above preferred values and they needed to come up with solutions. Students' initial response was "plants not being able to balance the system" and they were thinking that this was due to slow growth rate. Initially they were thinking of supporting the system by adding fast growing plants to the AS but they were concerned that time-wise this solution would not work. Thus their choice of action was to change the AS water partially. This helped to reduce the nitrite and nitrate levels to 75 mg/l and 0 mg/l. As of 5th week the nitrate and nitrite values were within the expected levels since plants were growing students attributed the preserved values to the plants balancing the AS.

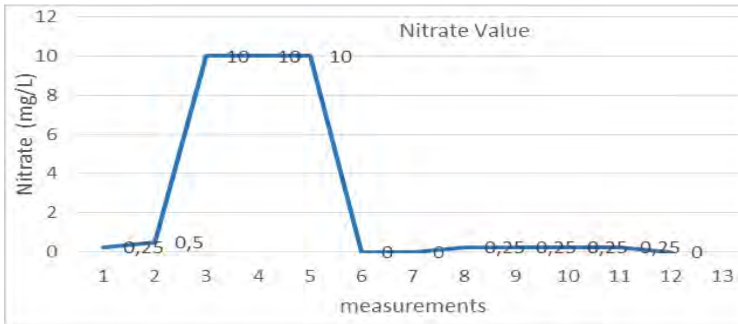

Figure 3. Student graphs showing nitrate values for each week

Analysis of the researcher's field notes indicated a positive attitude from students towards the AS activity as well as the discussions on water pollution and preservation. Being able to conduct an activity that they setted up on their own was reported to be a positive experience since they have not been able to do laboratory work due to Covid 19 pandemic. In terms of collaboration and fulfilling their responsibilities during the setup and maintenance of the AS activity all of the students showed a great enthusiasm and stated an interest for future activities such as AS. Aquaponics are systems for plant and fish growth and during the AS activity students were able to harvest their products and consume them. Thus they were able to experience the agricultural aspect of the whole system and were also motivated by it.

Table 9. Teacher Interview Coding Scheme

Category	Codes	Sub-code	Code description	f
Know. AS	Pre-existing knowledge		Teachers' preexisting knowledge of the aquaponics systems	8
Impact on students	Student motivation	Content related	How effective do they think AS will be for students	6
		Task related/ student responsibility		2
AS as a teaching material	Curriculum connection	Ecology	Teachers' evaluation of AS as a teaching material	11
		Food chain		3

Category	Codes	Sub-code	Code description	f
		Matter cycle		8
		Real World connection		2
		Agriculture		7
		Science process skills		1
		Recycle		1
		Engineering design		1
	Challenges	Management issues /system	What kind if challenges or issues may rise during AS	6
		Time management		3
		Cost		2

At the beginning of the study two teachers had a prior knowledge of AS. T3 stated that she/he learned about AS during her masters education and T7 stated that she/he learned about AS from media and journals. Though 6 teachers stated that this is the first time they are hearing about AS after the workshop all of them reported positive thoughts about using the AS in either biology or science classes. They stated that AS activity would be motivational for students "Students will find this activity interesting and motivating….growing fish and plants in a mutualistic relationship is inspiring (T3) and taking responsibility during the task promotes learning "they are taking responsibility during the activity….it is helping them to learn (T6)". All of the teachers were able to make the connection between the Aquaponics activity and the MoNe's 10th grade biology curriculum. They identified topics such as ecology, food chain, mater cycle. They also stated how AS is structured around a real life problem and allows students to use science process skills (T2). However only one of the teachers, (T7), was able to make the connection with the STEM dimension of the activity stating that they can teach engineering and design through this activity. Teachers were also asked about challenges regarding the aquaponics activity and all the challenges identified were related to either students or logistics. Cost was one of the challenges identified and T3 stated that materials should be recycled. T8 also vocalized concerns related to cost while T3 raised issues in terms of time constraints students' may have which could affect the activity. T1 stated concerns on how to manage the system during breaks if there would be any issues regarding the water temperature or light issues.

4. Discussions and Implications

This study was aiming to investigate how aquaponics system activity impacts students' achievement as well as students' and teachers' perception of the activity.

Students' achievement was investigated qualitatively and quantitatively. Ecological Concepts Test items were analyzed based on pre-test and post-test values. In pre-test for items 1, 3, 5, 7, 8, 9, 12 mean score was calculated to be less than 1 mean in student did not know the concepts of 1- biotic and abiotic components of an ecosystem, 3- food chain, 5- energy pyramid, 7- O_2 and CO_2 cycle, 8- N cycle, 9- Phosphorus cycle, and 12- dominant species in an environment. Considering that ASA was implemented in the classroom prior to the aligned unit was covered mean student scores can be accepted since students may not have prior knowledge to these concepts. Except for two items, all items' scores increased in the post-test. The two items with a score decrease were items 3 and 9. Item 3 addresses the food chain and 9 phosphorus cycles as concepts. Although the decrease is not statistically significant the reason for such decrease may be due to the fact that phosphorus cycle was not covered in the aquaponics activity. Therefore the decrease in the mean score of this item is ignored for item 9. ASA had a positive influence on students' academic achievement as post-test results were found to be higher and this increase in scores were found to be statistically significant. In terms of gender difference, analysis revealed a higher score for female students but the difference was not statistically significant. The positive influence of ASA on students' achievement were also supported in other studies conducted by Hart et al., (2013) and Genello et al., (2015).

During ASA students faced issues that needed to be resolved including fish dying due to design issues or dill (one of the plants in ASA) not growing as well as nitrate levels increasing above tolerance values. Students were able to propose different solutions to the problems such as changing the design to prevent fish dying, adding more plants or changing water to help decrease nitrate levels. They were able to come up with various valid solutions related to the sustainability of the ecosystem however, their choice of action was found to be quick fixes as they were concerned that ASA would not survive long enough and fish would die if they choose other possible solutions such as relying on plants to balance nitrate levels of the system. So their choice of action was to change the water of the system to lower the nitrate values which they were successful in the outcome. As the activity was designed for a 6 week period, researchers supported students' decision of action due to time limitations. One approach to such decision conflicts would be having smaller but several aquaponics systems where students can try different solutions and observe their results in a comparative manner. Some of the challenges such as fish dying or dill not growing were reported to be sources of disappointment by the students. We can argue that conducting and completing successful experiments and activities affect students' emotional states but these and similar situations also present great opportunities to practice problem solving skills for students. Therefore, in our view they are valuable learning opportunities. Accordingly, students' discussions on the causes of observed problems and possible solutions allowed them to practice problem solving and critical thinking skills. Students were also showing an understanding of the systems thinking in the process as well. We can conclude that ASA is a valid educational activity as it provides a good opportunity for such practices.

Teachers' perception of the aquaponics activity was also investigated as a part of this study. Teachers identified aquaponics systems as motivational and interesting for students. Aquaponics activity was also identified as a good fit for the 10^{th} grade biology curriculum. All of the teachers were able to make the connections between the activity and the following topics from the curriculum; ecology, food chain, and matter cycle. But how aquaponics activity was related to real life content and how it enables science process skills were pointed out by only two teachers. Additionally, only one teacher identified aquaponics as a STEM activity. Teacher workshop was limited to a half day and this limited time may not be enough for teachers to grasp all the connections they can make with ASA in their classrooms including, science process skills, 21st century skills, problem solving and STEM connection. In this context teachers' background should also be taken into consideration which was not the purpose of this study.

5. Suggestions

This activity can easily be conducted individually by students at their home environments since it's a low cost activity. It's also possible to maintain communication, share data and pictures through environments such as zoom and WhatsApp. Teachers can easily propose questions to their students and supervise their progress outside of the classroom environment through electronic forms of communication. Therefore, aquaponics systems activity can both be used in formal and informal learning settings

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7. Ethics Statement

This study was approved by the Gazi University Ethics Committee (approval number 2022-163) and all data was collected with participants' informed consent.

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