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ORIGINAL RESEARCH

Nutrition Bulletin

Aquaponics in schools: Hands-on learning about healthy eating and a healthy planet

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Abstract

Our food system is giving rise to a growing social, health and environmental crisis. Much of the food consumed in the United Kingdom is cheap, nutrient-poor and highly processed, leading to under-consumption of essential foods such as grains, beans, vegetables and fruit. This has contributed to a rise in diet-related diseases, with approximately 22% of primary school leavers being overweight or obese. Food production is unsustainable with agriculture responsible for 10% of the UK's greenhouse gas emissions and intensive farming practices have led to a significant loss of soil carbon and a decline in biodiversity. COVID-19 increased inequalities in our food system. Therefore, there is an urgent need for interventions to counteract these adverse social, health and environmental impacts. Education can play a crucial role as an intervention to address challenges in the food system. We tested an innovative school initiative using portable aquaponic pods and aligned to the national curriculum, to engage pupils in food production and foster learning about sustainability, climate change and healthy eating. The evaluation, based on teacher surveys, aquapod chart data, student blogs and postcards and feedback from the development team, revealed positive impacts on students' environmental awareness, as well as sustainability and practical food production knowledge. However, the programme encountered logistical challenges and we therefore highlight future improvements to produce a curriculum programme that can be delivered at scale to enhance food education and empower pupils to drive the agenda on tackling food sustainability and climate change.

KEYWORDS
aquapod, educational resources, food system education, primary school, STEM, sustainability

INTRODUCTION

Our food system is contributing to a multifaceted crisis with significant social, health and environmental implications. In the United Kingdom, a substantial portion of the food available is both low in nutrients and highly processed, often leaving people with inadequate consumption of essential grains, beans, vegetables and fruits (Global Nutrition Report, 2021). As a result, diet-related diseases are on the rise (Health Survey for England, 2017; Hofmarcher et al., 2020) and approximately 22% of children are already classified as being overweight or obese by the time they start primary school (Department for Health, Improvement and Disparities, 2023). Notably, COVID-19 exacerbated existing inequalities within our food system, particularly in relation to families experiencing food insecurity (Brown et al., 2022; Kakaei et al., 2022; Loopstra, 2020; Power

et al., 2020). The sustainability of food production is another pressing societal challenge (Mikkelsen & Bosire, 2019). Agriculture alone is responsible for 10% of the UK's greenhouse gas emissions and intensive farming practices have contributed to a staggering 60% loss of soil carbon and a decline in biodiversity (Agriclimate report, 2022; Dasgupta, 2021; Eurostat, 2021; Climate Change Committee, 2020; Woodland Trust Report, 2000; Hayhow et al., 2019).

The school system offers an opportunity to communicate these interlinked issues and raise awareness about the impact of our food system on climate change (Kluczkovski et al., 2021). Initiating food system education from an early age not only cultivates lifelong habits but also equips children with a profound awareness of the world, preparing them for the future (Carreira & Pessanha, 2021). These educational strategies empower students to organise research, apply effective problem-solving strategies and develop critical thinking skills, laying a foundation for their ability to identify and confront real-world challenges (Bell, 2010). This holistic approach prepares children for future careers and imparts invaluable skills that will serve them well in future scientific endeavours. While school gardens have been established as a common hands-on approach for experimental learning by growing food (Clayborn et al., 2017), the rise of science, technology, engineering and math (STEM) has meant that the emphasis on scientific and technological solutions is now education's main way of addressing sustainability (Davies, 2012; Gavari-Starkie et al., 2022; Gülhan, 2023). Furthermore, the UK Department for Education strategy for education on sustainability includes preparing children for a world impacted by climate change through learning and practical experience (Department for Education, 2023).

Modern aquaponics is a cultivation method that facilitates the growth of plants, particularly leafy greens (Smith & Watson, 2018), by combining fish farming (aquaculture) with hydroponic crop production. It enables the cultivation of fish and plants concurrently within a balanced system that effectively closes the loop on aquaculture waste, while also growing plants. Fish waste, rich in nutrients, fertilises plants and the plants, in turn, purify the water by removing these nutrients (Kyaw & Ng, 2017). Integrating fish farming and hydroponic crop production, the closed loop system not only exemplifies sustainable agricultural practices but also the context of a self-sustaining ecosystem. Aquaponics education within school settings therefore provides a practical, hands-on route to engage students with science, technology, engineering, arts and mathematics (STEAM) concepts due to its interdisciplinary nature (Baykir et al., 2023; Hart et al., 2013), while providing a context to start learning about business and economics, when addressing issues such as sustainable development, environmental science, agriculture, food systems and health (Junge et al., 2019).

Previous studies evaluating aquaponic teaching in school classrooms have shown that integrating practical engagement with such systems into classroom activities significantly increased students' knowledge of the aquaponics system (Baykir et al., 2023) and further suggested that aquaponic models have the ability to create authentic science learning environments to positively affect secondary school students' understanding of concepts concerning ecosystems and ecological relationships (Junge et al., 2019; Mikkelsen & Bosire, 2019; Thompson et al., 2023). The limited number of aquaponics in primary school studies (Carreira & Pessanha, 2021; Junge et al., 2019; Mikkelsen & Bosire, 2019) suggests use is low and it is usually regarded as a stand-alone subject, rather than a vehicle to address food system topics (Genello et al., 2016). From a nutrition perspective, hands-on approaches such as aquaponics, teach students about sustainable food production and its nutritional value. By interdisciplinary learning, these methods equip students with the skills to make informed dietary choices and address real-world challenges in nutrition and sustainability.

To address this gap in evidence, we developed and tested an innovative school initiative in which portable aquaponic pods were provided to primary school pupils for hands-on experience in food production; the 'Future Food Heroes' programme. The programme was designed in alignment with the UK school national curriculum for Key Stage Two and emphasised sustainability, food systems and healthy eating. The evaluation explored the feasibility and acceptability of the initiative in primary schools whereby trained teachers are equipped to deliver lessons without the involvement of external providers.

MATERIALS AND METHODS

We aimed to design a programme of school-based activities using portable aquaponic pods with school children that could be delivered across UK primary schools to show how food production can be climate-friendly and community-based. We sought to test the feasibility, acceptability and sustainability of the programme in a sample of primary schools within Yorkshire, located in areas with differing levels of deprivation.

The background and developmental steps of the 'Future Food Heroes – The Aquapod Programme' (hereafter the aquapod programme), are provided below, followed by an account of the methods used for data collection and evaluation throughout and after running the programme.

Future food heroes: Background and development

The programme is built upon an existing educational initiative by 'Farm Urban', a social enterprise that creates and implements urban farming systems. Based in Liverpool, United Kingdom, Farm Urban engages with communities through various learning, outreach and engagement activities to enhance skills and provide education. The original programme, rooted in project development literacy, engaged students in a project to improve their local food system, crafting a compelling pitch, creating presentations, developing a product and refining literacy skills and was, as such, aligned with the national school curriculum. It utilised portable aquaponic pods to enable pupils to experience food production and learn about sustainability, climate change and healthy eating.

The research discussed in this paper was a collaborative effort between Farm Urban and FixOurFood, the latter of which is a food system transformation research programme based at the University of York (Doherty et al., 2022). We built upon the original aquapod programme but with a significant shift in focus towards integrating food systems learning that could be delivered by teachers in schools. The core idea was to go beyond project development literacy and incorporate essential elements related to food systems: health concerns, food production, regenerative farming, vertical farming, climate change and nutrition. This integration aimed to make the programme more relevant to teachers and students by addressing subjects crucial to their learning objectives while fostering a comprehensive understanding of the broader implications of food systems and sustainable practices. The aim was to build a programme that not only complemented the national curriculum, but also provided students with valuable insights into the interconnectedness of food, health and the environment.

Programme outreach and participation

The programme was made available for schools from across Yorkshire who were part of a network of schools within the FixOurFood programme (Doherty et al., 2022) via an invitation sent to headteachers. Those who were interested nominated a Year Five teacher to take responsibility for the collaboration and run the programme. The funding allowed five schools to participate.

The researchers made it clear to teachers that the programme, originally designed for primary school pupils in Year Five (ages 9 to 10 years), was adaptable to different ages. They were provided with the flexibility to adjust based on school-specific factors like curriculum capacity, time constraints, staff availability or focus topic areas and were encouraged to choose alternative paths, reporting changes back to the team for evaluation and potential consideration at the programme's conclusion.

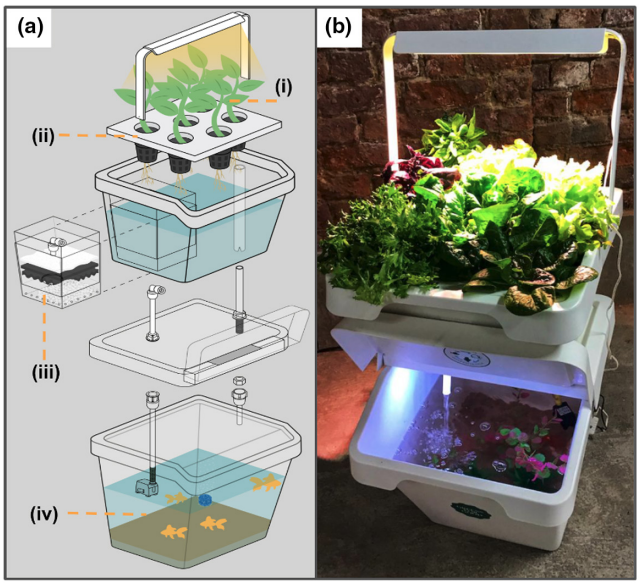


FIGURE 1 Aquapod images. (a) aquapod scheme showing (i) plants – most plants will grow in an aquaponic system but the easiest and quickest are leafy greens, such as basil, parsley, lettuce and kale, (ii) grow bed – is a soilless environment for plants to spread their roots. Plants live in net pots suspended above the water on a raft, making sure they get oxygen, water and nutrients to thrive, (iii) filter box – is where the bacteria live (microorganisms convert fish waste into the perfect plant food and keep water clear), (iv) fish – provide organic fertiliser through fish waste. (b) photo of an actual aquapod with fish and leafy greens being grown.

School training

To implement the programme, the researcher team visited each participating school in person. The aquapod kit was delivered along with a 3-h training session which covered programme details and resources. In addition, a practical and detailed demonstration of the aquapod assembly was provided during this visit. As an illustration of teachers' experiences, Figure 1 presents an image extracted from the assembly instructions guide. This includes a comprehensive view of all the object's components, accompanied by a photograph showcasing a fully assembled aquapod. Each kit was designed to accommodate approximately 30 children. Teachers were given access to the online platform, as well as a teacher's pack comprising printed information and one set of materials for each of the six sessions. Each kit also included five full copies of a linked board game.

For the aquapod, all necessary parts and tools for assembly were included, along with a detailed instruction guide/manual and seeds for the children to plant. However, the responsibility for providing water and fish

fell to the individual schools, with clear instructions provided on suitable choices.

Crucially, the equipment provided to the schools was theirs to keep, eliminating the need for return and providing an incentive for participation. Teachers assumed the responsibility of independently running the programme at their respective schools and upon programme completion, they were invited to visit an indoor vertical farm to connect with what pupils learnt on the programme.

The communication channel was intentionally open to streamline and expedite communication between the FixOurFood team and schools/teachers. Options such as phone calls, WhatsApp messages and direct emails to a designated staff member were recommended, providing teachers with the flexibility to choose the method that suited them best.

The programme

The programme was designed to run over 6 weeks to fit into a school term. Weekly activities were split into two sessions – the weekly core knowledge sessions and practical 'Part b' sessions, which teachers either ran together in a morning/afternoon or split across two slots during the week.

The core knowledge sessions were approximately 60 min long, consisting of an introduction, activities and plenary. Figure 2 shows an overview of a session, highlighting, among others, the resources available to teachers, the key vocabulary needed for that session and the links with the national curriculum.

Teachers conducted the weekly sessions for 6 weeks as part of the programme, focusing on cultivating microgreens/herbs with the aquapod system. Each session included online slides (Figure 3a) and a list of resources, including different activities (Figure 3b).

Participants summarised their learnings and contributed to blog posts at the end of each session as shown in Figure 4.

All resources were accessible through a dedicated online platform and were also distributed in printed form during the induction meeting as part of the teachers' pack. The six sessions were:

All about aquaponics

Students learnt about the aquaponic cycle and the relationship between fish and plants in the same system. The pupils were introduced to how the aquapod functions and how to look after it. They were then

FUTURE FOOD HEROES

Programme Overview

Session 02	Outline Duration (mins)	Core knowledge
All about food systems	**Introduction** (05) Warm up: aquaponics cycle recap* Session outcomes and tasks	*aquaponics cycle: Fish live at the bottom of the produce pod. Fish waste and uneaten food creates a chemical in the water called ammonia. The water is pumped up to the plant basin where bacteria living in the biofilter turns ammonia into nitrates. The nitrate-rich water feeds the plants and drains back into the fish basin through a pipe.
	Knowledge spotlight: Food systems overview (05) **Activity 01:** Food systems quiz (10)	**Our current food system is **unsustainable**, which means it takes **more resources to create** food than it **produces,** relies on **resources** from the Earth that **will not regrow,** creates **waste** and **fumes** that hurt the planet
	Activity 02: Sustainability pairs (30)	
	Plenary (08) Team Review, class blog	

Outcomes and tasks		Resources	Key vocab	Curriculum links
We can . . . • explain why our current food system is unsustainable** • we can explain what makes something "unsustainable" / "sustainable"	**We will . . .** • do a quiz on our current food system • learn about sustainability by playing "sustainability pairs"	Slides Blog sheets Activity 01 Activity 02 Sustainability pairs	Unsustainable Sustainable Environment	Y5E1a, Y5E1b, Y5E1f, Y5E2a, Y5E3b2, Y5E3e, Y5E9J1

FIGURE 2 Overview of programme (detail of a session developed by FixOurFood team).

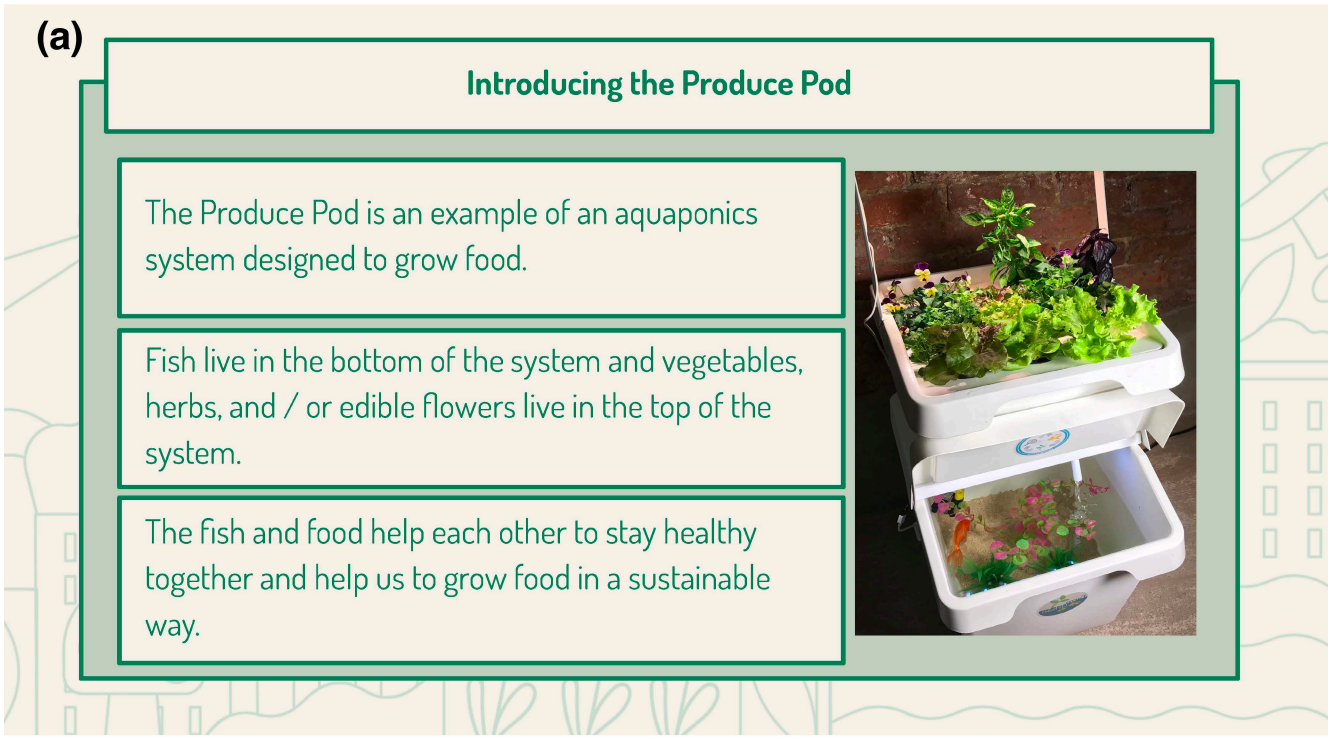
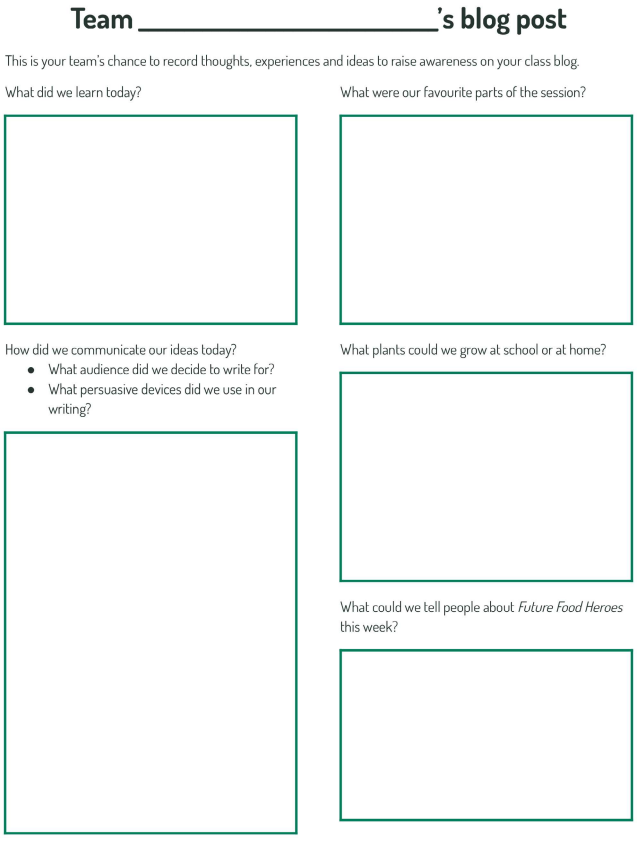


FIGURE 3 Examples of resources developed in the programme. (a) slide example from session one, (b) printed activity example from session four.

required to assemble the aquapod, create a care schedule and prepare the research centre. The research centre included information about their aquapod, which pupils built and created a maintenance schedule for; advice on adding fish to the aquapod; information on how to check and maintain water chemistry, water flow, fish health and seed germination rates.

All about food systems

Contextual teaching focussed on the need for sustainable food systems and modern solutions farmers use to help mitigate the effects of climate change, protect the environment and bring food to the community. Pupils were tasked with learning about sustainable farming by playing a board game (Figure 5a) and completing a quiz on our current food system (Figure 5b).


Team _____'s blog post

This is your team's chance to record thoughts, experiences and ideas to raise awareness on your class blog.

What did we learn today?

What were our favourite parts of the session?

How did we communicate our ideas today?
- What audience did we decide to write for?
- What persuasive devices did we use in our writing?

What plants could we grow at school or at home?

What could we tell people about *Future Food Heroes* this week?

FIGURE 4 Blog post sheet example developed in the programme.

Spread the word

Pupils were provided with knowledge of community issues and their persuasive writing techniques were trained by writing letters to someone they know. They would explain the benefits of growing food using an aquaponic system using language techniques.

Healthy shopping

Covering current nutritional guidelines and the four features of planet-healthy foods. Pupils would then complete the 20-min 'Healthy meals, healthy planet challenge' requiring the building of a meal and working out food miles and greenhouse gas emissions of that meal.

Create your product

After learning about brands and advertisement, session five involved developing an idea for an aquapod system by developing pupils' own 'imaginary product', creating a name, logo and catchphrase for it.

Create your pitch

In the final session, once they had learned the purpose of a pitch, the pupils presented their product design to the rest of the class. They were asked to explain their product and the process/advantages of aquaponics and their system, providing and receiving feedback from other pupils.

Practical part b sessions were focused on challenges and investigations and were approximately 40-min long. These sessions were designed with a lot of flexibility, being an optional part of the programme and an alternative for students who struggle to engage with traditional classroom learning methods. Key areas of focus were:

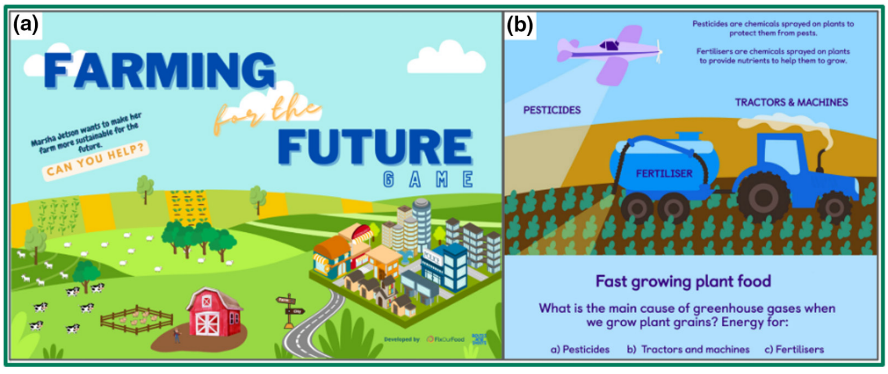


FIGURE 5 Programme activities developed. (a) Farm For the Future – board game activity, (b) online quiz activity example page.

FUTURE FOOD HEROES

PPod Task
Maintenance checklist

Produce Pod Maintenance Checklist

Weekly Checks								
Tests		**Notes**	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**
Water quality	Strip 1	pH						
		Nitrite						
		Nitrate						
	Strip 2	Ammonia						
	Thermometer	Temperature						
Lower tank	Algae check	Wipe away with blue sponge						
Filter box	Polywool	Rinse in tap water						
	Algae check	Scrub clean						
Quarterly Checks								
Tests		**Notes**	**Spring**	**Summer**	**Autumn**	**Winter**		
Filter box	Bagged media	Rinse bagged media until water runs clear						
	Bioballs	Do not use cleaning liquids						

FIGURE 6 Aquapod maintenance checklist sheet. This sheet was printed and completed by students and then, readings were uploaded to the online platform.

Aquapod investigation

An investigation utilising the aquapod system in which teams rotated to get hands-on experience and undertake this activity under the teacher's supervision and guidance.

Journals

Students could take 5–10 min in each of these sessions to write about their favourite parts of the programme each week (including activities from the main session).

Challenges

A range of additional challenges focused on scientific drawing and building and crafting with waste materials.

Evaluation approach

The evaluation of the programme was conducted through a multi-faceted approach, including data from different sources outlined below.

Blog posts

Blog posts (Figure 4) were encouraged from each school for every session enabling participants to wrap up the session and write a blog post about the activities and events of the week. They were advised to complete it and upload it on the programme website, where the posts could be accessed and read by the programme team and all programme participants. The blog posts allowed us to engage with and get feedback from schools at different stages throughout the programme (not only upon completion). For detailed data breakdown, see Appendix A.

Teacher survey

Teachers who implemented the programme were invited to respond to a questionnaire comprising eight comprehensive questions. The survey aimed to collect teachers' feedback on the feasibility and execution of each component of the programme to enhance it for the upcoming years. For detailed information, see Appendix B.

Aquapod graph data

The aquapod data set was an optional data input allowing teachers and students to maintain a record of water

quality, water level and filter condition (Figure 6). Pupils were primarily encouraged to complete it as an extra activity alongside the central programme. This was used to assess the commitment of schools to their ongoing engagement with the programme. Engagement was assessed by observing the number of sessions filled in on the online platform.

Postcards

Children were asked to complete postcards to explore the acceptability of food grown using indoor farming methods followed by visits to a local vertical farm after completing the programme (Figure 7). Postcard content and corresponding answers are available in Appendix C.

RESULTS AND DISCUSSION

Programme implementation

The project's budget allowed us to have only five aquapods. We contacted 10 schools at the beginning of the academic year (September 2022) to seek interest in taking part. Of these, five schools were interested in signing up and we initiated the programme with these five schools. Reasons cited for the other schools not taking part included time constraints, lack of teacher capacity and/or incompatibility with schools' programs for the academic year. Subsequently, all five recruited schools initiated the programme between mid and late September. They were given flexibility in selecting their exact start date if it could be completed within the Autumn term. Out of the five schools that agreed to run the programme, only three actively engaged. One school stopped responding in the early stages (mid-September 2022) and another school completed only one session on the online platform.

Two schools reported successfully completing all six sessions (Schools One and Two). However, School One ran it as an after-school science club, opting for an eco-group approach involving students of different ages. This school provided detailed survey responses indicating a positive experience. School Two completed the entire programme, adhering to its designed structure and effectively reaching the intended target age group. A third school initially reported having completed only one session, but clarified during the teacher's feedback survey that they indeed finished all sessions, with time constraints limiting uploading of data onto the platform. Finally, the fourth school completed only one session and was unable to fulfil the produce pod data, blogs or surveys. During communication with this school, teachers reported several issues when delivering lessons and with aquapod assembly due to time constraints against other curriculum areas and the potential solution of creating an after-school club in the following term was mentioned as a possibility.

Programme execution

Participation

School One reported, through the teacher's survey, a well-organised overall experience, but emphasised the need for future improvements in plant care and time management. Occasionally sessions had to be cut due to time restrictions, highlighting the need for prioritising essential information at the beginning of sessions. Analysis of aquapod data from this school demonstrated

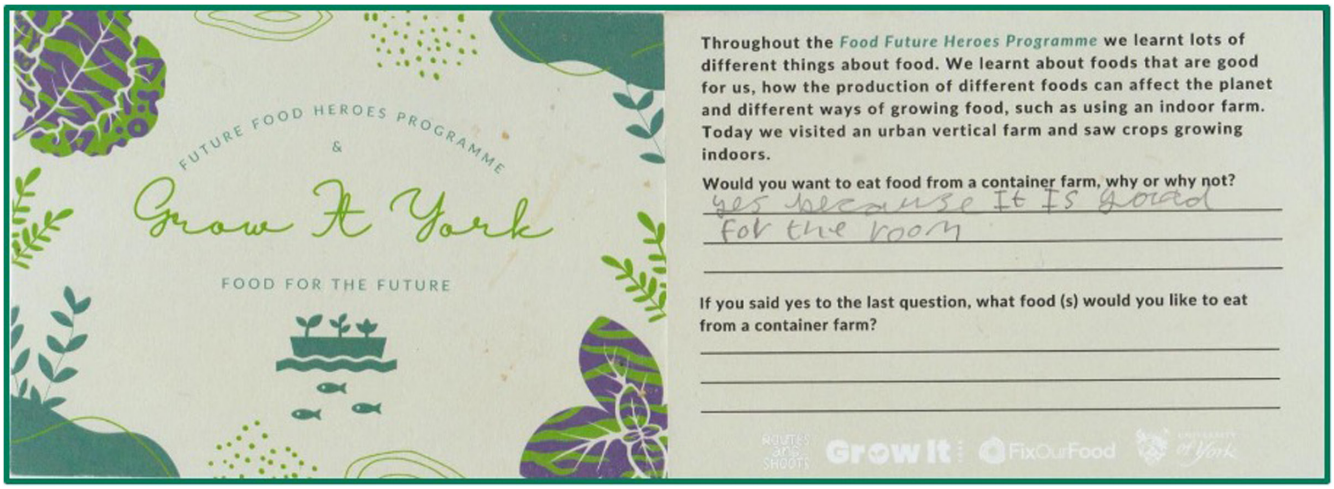


FIGURE 7 Programme's postcard example. Students visiting the vertical farm were invited to answer the two questions in the postcard.

strong commitment, with the completion of three components out of four for the entire 6-week period.

Schools Two and Three seamlessly integrated the programme into their Personal, Social, Health and Economic (PSHE) lessons, as revealed by information gathered from the teachers' survey. Specifically, School Two incorporated the programme into their PSHE curriculum, focusing on the crucial theme of caring for our planet. Meanwhile, School Three reported that the programme aligned well with its PSHE initiatives centred around sustainability and climate change.

Acknowledgement of challenges related to data uploading highlighted an area for improvement in future programme iterations. Analysis of aquapod data from School Two indicated completion of three components (50%) for a total of 3 weeks. Findings suggested a positive correlation between session completion and aquapod data recording. The absence of filled produce pod graph data for School Three not only raises implementation concerns but also highlights concerns about the requirement of schools to monitor data throughout the process (essential for tracking progress and addressing potential challenges).

Learning experience and outcomes

Throughout the programme, all schools reported positive outcomes, with students displaying enthusiasm and engagement with the activities, highlighting the positive impact of hands-on learning approaches. The teacher who ran the programme for School One was enthusiastic from the outset with the teacher survey stating the following:

> I think the introduction of aquaponics as a concept to pupils was invaluable, it will stay with them for the rest of their lives and we would so much like to take part in future to introduce other pupils to the scheme.

The assembly of the aquapod in session one, with feedback given through the blog posts and teacher's survey, was a favourite among students, emphasising teamwork and collaboration and creating a sense of ownership. According to the teacher running the programme at School One,

> 'The physical assembling of the apparatus was actually the pupils' favourite lesson. They found this challenging and exciting and it really engaged them effectively.

The hands-on approach not only enhanced learning but fostered a supportive environment for peer-to-peer learning. Additionally, as evidenced by the blog posts, students demonstrated a remarkable grasp of aquapod systems, showcasing their understanding of complex concepts and displaying strong problem-solving and critical thinking skills, for example on the interconnectedness of fish waste, ammonia and plant growth.

As demonstrated through blog posts, the creative and hands-on activities related to branding and product development provided an opportunity for students to explore and enhance the functionality and sustainability of the aquapod system, further enriching their learning experience.

Detailed and positive blog post data on session four from Schools One and Two focused on knowledge of the impact and variation in food miles, emissions and sustainability. A highlight was the flashcards, which both schools turned into a competitive game, to make and understand different meal food miles and emissions. School Two's blog post stated the following:

> Everyone loved this week. Today we learnt about the food pyramid as well as calculating air miles and emissions of our food. The lower the air miles and CO_2 emissions the better!

The teachers' survey indicated engagement with the online slide presentations, promoting research and effective communication. During the development of these materials, the research team invested time and effort into ensuring that the slides were informative, engaging and accessible to students of varying needs and backgrounds. Discussions centred around selecting appropriate language, covering a diverse range of topics and incorporating visually appealing imagery to enhance comprehension and retention of information. The positive feedback suggests knowledge was successfully conveyed to students and improved their understanding of aquapods.

The feedback from Schools One and Two, via teachers' survey and email, highlighted confusion about the board game in session two, signalling a need for clearer instructions. Students reported it not being enjoyable. School Two acknowledged challenges with the board game but did feel it developed students' adept critical thinking and considerations of sustainability.

School One's feedback on session five is also encouraging, with students showcasing creative thinking in developing slogans that promote sustainable food choices. Session six feedback focusses on student activities and reflections, revealing strong engagement in caring for the fish and fostering a sense of responsibility and connection to the ecosystem. Although Schools Two and Three marked the session as incomplete on the platform, all schools successfully completed the session. School One, in particular, showcased its accomplishments in the blog posts, emphasising a remarkable commitment to caring for its fish. The students detailed their engaging journey, highlighting the profound impact on communication skills

and systematic thinking. Describing their collaborative efforts in maintaining the system, such as passing the bucket in a repeated sequence, the students expressed a sense of accomplishment and sadness at the programme's conclusion, which reflects a deep attachment and comprehensive understanding of aquaponics, as shown in the blog post:

> Our Aquaponics knowledge is at a top level, and we hope sooner or later that the world will be more aware of this efficient farming technique. This approach is also extremely environmentally friendly and cost efficient.

School Two mentioned the completion of the programme on the teachers' survey and invited the researchers to the pitch presentations. Pupils and teachers also visited the vertical farm, which marks the successful completion of the programme. Furthermore, the researcher team's presence during the evaluation panel for the pitch presentations in session six at School Two made a positive impact on pupils. Having the opportunity for the pupils to showcase their projects in the presence of researchers, heightened their motivation and enthusiasm, according to teacher feedback. The direct engagement with the researchers not only provided a unique platform for students to articulate their ideas and achievements but also fostered a sense of validation for their efforts.

Postcards completed by School Two provided valuable evidence of the learning impact on pupils. Pupils expressed their preferences for food from the farm container, suggesting increased engagement through familiarity with grown produce. Twenty-two pupils completed the postcards after visiting the farm, illustrating the most mentioned groups of food they would eat from a food container. Fruits were the most popular, closely followed by vegetables. Even pupils who initially responded negatively to eating food from the farm container still expressed interest in the programme's potential. The variety of fruits and vegetables mentioned indicates stronger attention levels when aligned with familiarity, which could be linked to pupils growing their produce during the programme, leading to increased engagement. Some pupils mentioned 'Herbs,' 'Rocket,' 'Grains' and 'Trees,' reflecting more informed answers and suggesting an advanced comprehension of the programme, catering to diverse academic levels.

Aquapod assembly and maintenance

The primary challenge observed by schools was leakage during the assembly of the aquapod and malfunctioning pumps. In response, instructional videos and written guides were promptly dispatched to schools, aiming to assist in troubleshooting following communication through email or phone messages/calls. In cases where issues persisted despite these efforts, replacement parts were posted through first-class mail to minimise disruptions and mitigate any adverse effects on the programme's continuity. School Two encountered a few issues with maintaining the aquapod, which, throughout the programme, led to approximately four school visits by a research team member to provide support. School Three had difficulties with growing the plants. They reported that they found their classrooms to be too cold for the plants to grow efficiently and the teacher struggled with the noise from the machine, having to switch it off during lessons due to it being a distraction. School One reported in one of the blog posts that there was a need to reset the aquapod's filter, raising concerns about effective aquapod management. The varying experiences emphasised the need for tailored approaches to future aquapod use. School Three, via teachers' survey, reported facing challenges regarding water monitoring and the teacher expressed the need for additional background information to support plant growth. Future improvements might involve providing relevant research materials to assist educators in overcoming such challenges.

Procuring the required number of goldfish (two for the 60 l tank) presented difficulties for School One, encountering resistance from fish shops that limited their supply based on the tank's size. School Two struggled to raise the funds to purchase the fish. These issues were not considered as potential obstacles as the programme was developed. In future programme implementations, consideration might be given to providing support in overcoming this challenge, e.g. the research team deliver fish to the schools soon after aquapod assembly, ensuring a smoother start of the programme. Despite these challenges, School Two highlighted the excitement among pupils through the anticipation of naming and nurturing the fish. This underscores the value of entrusting groups with this responsibility, suggesting a positive and engaging aspect of the programme. Looking ahead, addressing logistical challenges in obtaining fish could enhance the overall experience for the schools involved.

Despite the logistical challenges, the students' favourite topics, according to blog posts, were reported to include fish, water management, ammonia and water temperature and students remained enthusiastic and eager to participate, underscoring the value of entrusting them with responsibilities and fostering a sense of ownership over the programme.

Overall programme design

Feedback was in general positive. Suggestions for improvement first and foremost concerned the teacher's

general enthusiasm for visiting the urban farm, which could eventually not be satisfied for two out of three schools. Better scheduling alignment from the programme's onset can help to prevent this disappointment and improve the overall engagement with and effectiveness of the programme.

Although School Two encountered issues related to using the online platform which they reported as having had an impact on communication and reporting, with difficulties in login and uploading data, communication between the research team and the school teams was generally smooth. All schools quickly reached out through phone, WhatsApp and email when issues arose, ensuring efficient communication. Teachers' feedback through the survey further confirmed that, from their perspective, communication with the research team was effective.

Regarding the primary goal of the programme, which aimed to engage students in producing food through aquapods, all schools encountered challenges to some extent. While the enthusiasm echoed in blog posts and teachers' surveys showcased the collective excitement among participating teachers and pupils to cultivate food using their aquapod systems, they faced challenges. Some grappled with water-related issues, others contended with room temperature fluctuations and some encountered obstacles during the germination process, underscoring the diverse array of hurdles in the pursuit of sustainable aquapod growing. School One was the only one able to grow and harvest coriander, with pupils using the produce in healthy meals at school.

Post-programme engagement

The post-programme engagement evaluation encompassed key elements, including the insightful visit to the vertical farm, soliciting feedback from teachers and offering guidance on any additional trials they wished to undertake in collaboration with the research team.

While the aquapods programme finished after 6 weeks, communication between the teachers and the researchers continued, formally and informally. Teacher feedback through the survey was sought 6 months after the completion of the programme, during the summer months of 2023. Furthermore, email and WhatsApp messages and visits to school were exchanged to obtain information from teachers and their perceptions of the programme, with Schools One and Two providing considerable and detailed feedback.

School Three's feedback emphasised communication challenges from their end during the summer break and the need for planned communication methods. The responses suggested tailored approaches for better engagement.

School Two was the only school able to visit the vertical farm and complete the postcards. The vertical farm visit was planned as an external element of the programme, which was eventually only taken up by one school. School One specifically emphasised this element to represent a limitation of the initiative. This issue has prompted the lead teacher to consider potential modifications to incorporate the farm visit into a dedicated session, aligning with the school's expectations and contributing to a more holistic programme experience.

After finishing the programme, only one of the schools (School Three) decided to continue using the aquapod immediately. The other schools indicated their intention to utilise it in the future, thus opting to retain the aquapod kit. School One reported putting the fish in the school pond and School Two, took them to a fish tank after the programme. School Three showed a keen interest in keeping the aquapod running and used it with another group of pupils in the following academic year. This school's utilisation of the pod indicates a positive outlook on the programme's effectiveness and suggests a willingness to continue engaging students with aquaponics in the future.

Considerations for further research and implementation

Aquapods in schools

The timing of the aquapod programme initiation around mid to late September, was meant to align well with school academic calendars. However, given the strict schedule teachers have to adhere to, it is crucial to note that the chosen time of year for programme initiation, as well as the amount of lead time for teachers to integrate the programme into existing schedules, can play a crucial role in its success. For instance, for this programme, teachers were first approached in June 2022 and the programme started in September of the same year. However, to allow schools to fully integrate the programme it may be beneficial to initiate the approach at an earlier stage. This facilitates effective planning and smooth integration into the school calendar. The programme was designed to align seamlessly with the curriculum, ensuring that it does not entail additional time on top of regular learning but serves as a means of incorporating key curriculum aspects. We did note that schools sometimes struggled to complete lessons and more direct collaboration with teachers ahead of programme implementation may help address this. In the future, assessing students' knowledge before and after the programme could enhance the evaluation of the programme's impact and effectiveness.

Building on previous research, as demonstrated by Baykir et al. (2023), challenges in the technology related to the assembly and maintenance of the aquapod have become evident. A notable example is the recurring issue of the aquapod's pump malfunction, also highlighted by Baykir et al. (2023). While efforts were made to provide ad hoc support through instructional videos, written guides and replacement parts, the need for someone to offer immediate support, either through virtual assistance or school visits, soon became evident, particularly for School Two, which regularly reached out to ask for assistance. Incorporating a mechanism for timely support enhances the overall effectiveness of the programme. Future iterations of the programme could benefit from incorporating a dedicated workshop or instructional session for both teachers and pupils. Such training can also have the effect of reducing teaching hierarchy and for teachers and pupils to act more as partners in running a project, empowering the pupils. Another recommendation is to provide an organised 'catch up' session after the first or second week. Not only may this create a prompt for teachers' engagement but also allows the researcher to see how things are going and help where needed. This could be carried out over the phone or an in-person visitation, thus combating issues with plants, fish and practical problems with the aquapods.

Hosting the programme as an after-school club emerged as a successful model to counteract start-up challenges, relieve the pressure on individual teachers (with more teachers able to help) and broaden participation. The opportunities with such an approach are evidenced in School One's approach, which appeared to run the most fluid version of the programme as an after-school club and did not encounter the same issues as the schools carrying out the sessions within the school day. However, it should be considered that this approach may restrict participation to only those pupils involved in the club.

Ensuring the inclusion of a visit to the vertical farm into one of the sessions was suggested by School One and was considered valuable for a more comprehensive understanding of aquaponics. School Two, which visited the vertical farm, supported this opinion, as per teacher feedback. Integrating a (vertical) farm visit into a dedicated session, however, requires careful planning to accommodate for the academic schedule. Moreover, the timing of the visit may have influenced take up, given that it was scheduled towards the conclusion of the programme and close to the schools' Christmas break.

Obtaining fish emerged as a common challenge for schools. The option of providing fish upfront or exploring ways to assist schools in overcoming potential barriers related to obtaining fish is required, for example the research team deliver fish to the schools soon after aquapod assembly. This could prevent delays and ensure a more seamless execution of the aquapod initiative.

Lastly, the programme discussed in this paper was designed around online engagement and communication. This means of engaging did not prove to be as effective as expected. Most crucially, the frequency and depth of feedback and updates differed between the schools. To monitor progress more systematically, a recommendation is to build a physical school visit halfway through the programme, as well as a post-programme wrap-up visit. For instance, teacher feedback highlighted that increased in-person interactions with School Two proved beneficial for the smooth execution of the programme. This directly addresses one of the aims of the study, to evaluate whether teachers could deliver the programme independently, indicating that a greater level of external involvement is needed for optimal programme delivery and outcomes.

Food system, STEM/STEAM and the national curriculum

The feedback from participating schools suggests the programme was overall positively received, with an emphasis on heightened student engagement during the practical sessions. The hands-on approach to the aquapod system setup is highlighted for its capacity to promote teamwork, collaboration and a supportive learning environment. While the data acknowledges challenges, including the need for better communication and coordination, clarity of instructions in certain sessions and concerns about programme continuity and documentation, it highlights the positive effects of integrating practical experiences into the curriculum, emphasising also the significance of physical visits to the vertical farm to enhance students' understanding further.

Specific areas of success identified through the evaluation concern students' understanding of aquapods, fish tank preparation and the connection between fish waste, ammonia and plant growth. As such, the study supports previous scholarly work (Baykır et al. 2023; Thompson et al., 2023), suggesting that with the implementation of an aquapod initiative in schools merged with the national curriculum, educators can seamlessly integrate knowledge of scientific and technological principles and connect lessons from biology, chemistry, physics, mathematics and environmental science. Noteworthy examples of key links between the programme and the national curriculum include:

> Design and Technology: the programme helped pupils understand and apply the principles of a healthy and varied diet and grasp the concept of seasonality, recognizing the origins and processing methods of diverse ingredients.

English: pupils were encouraged to pose relevant questions that extend their understanding and knowledge.

Mathematics: the programme encouraged pupils to tackle problems involving multiplication and division, utilising their knowledge of factors, multiples, squares and cubes.

Science: the programme helped prompt pupils to describe the life processes of reproduction in certain plants and animals.

These interconnected learning points enrich students' educational experiences and contribute to a holistic understanding of STEM/STEAM concepts. Most importantly, the physical activities in engaging with the aquapods proved to be a suitable framework to bring wider food system-related topics into the classroom. Teachers from both Schools Two and Three reported that the programme was aligned with PHSE education learning about caring for the planet and there was a general sense that the programme enabled pupils to become more aware of the need for sustainability and using locally/home-grown produce where possible and plant-based foods in general. In this sense, the programme showed that aquaponics in schools is a useful vehicle to address not only other STEM/STEAM topics but also wider food system issues. The impact of this initiative is expected to motivate a desire among the students to participate in future programmes and introduce their peers to the scheme.

CONCLUSION

This study highlighted the potential benefits of the aquapods to stimulate children's interest and understanding of sustainability, climate change and healthy eating. In particular, schools that were able to implement the aquapod programme and use the resources, expressed enjoyment of the practical exercises and highlighted the need for both mental and physical stimulation to maintain engagement. However, the implementation approach was not feasible in all schools, due to other competing demands that schools face. The study also highlighted the need for external support for a successful aquaponics programme, placing constraints on the geographical location of participating schools (i.e. near that support) and the need for ongoing funding. The feasibility of this could be enhanced by bringing participating teachers to one central location (rather than visiting each school) and the development of a set of FAQs and online workshops as more schools participate and similar issues are encountered. The UK Government's education strategy for sustainability and climate change has set targets for 2030 that include driving knowledge that prepares 'all young people for a world impacted by climate change through learning and practical experience' (Department for Education, 2023). Thus, there is a clear need to consider how the current curriculum needs to change to allow schools to embrace programmes like the aquapods, that allow children to have first-hand experience in how to prepare for such global challenges.

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CONFLICT OF INTEREST STATEMENT

Farm Urban Ltd. run educational programmes involving aquapods with schools in Liverpool with funding from regional companies and organisations. All other authors have no conflicts of interest to disclose.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in the Appendices and from the corresponding author upon reasonable request.

ETHICS STATEMENT

No personal data were collected in the project and it was approved as part of the FixOurFood ethics approval from the University of York, Health Sciences Research Governance Committee (HSRGC/2021/466/D).

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APPENDIX A

Blog posts uploaded on the online platform for the three schools participating in the Future Food Heroes Programme

Session	School 1	School 2	School 3
1	Today we have learned how to make and prepare a fish tank. Our favourite parts of the session were testing trial and error and assembling the fish tank. We used our different strengths by learning each other's strengths and then focusing them on what they are good at. Everyone was included by giving everyone a job and including everyone's ideas. We are growing veg in our produce pod this year. We are going to grow … in our produce pod	We have learnt all about aquapods. We know that the fish live at the bottom and plants grow in the top level. The fish waste and uneaten food create ammonia. The filter in the aquapod turns this into nitrates for the plants to help them to grow. We all loved building the aquapod in teams to create the final product. Team 1 liked choosing the LED light colour for the fish tank. We are looking forward to getting our fish and naming them. We made sure everyone was included by splitting into 4 teams and each taking turns to do a part of the aquapod. We are growing coriander, we are waiting for the seeds to germinate.	Year 5 and Year 6 worked together this afternoon to build the pod and plant the seeds. We are very excited to see what it looks like when it's up and running! • Only session completed • No produce pods were filled in • Issues mentioned above in the interview
2	Today we learnt about sustainable Farming, using a board game to develop our understanding of the programme. Our thoughts on the game was that it was slightly confusing to get the hang of it but it soon worked out. Our favourite parts of the session was learning more about the fish and discovering the ways of the water. We also loved talking about the ammonia levels and checking the water temperature	The game was very hard to play, we didn't know what game pieces to use for some of the choices but we thought about how we can make better choices such as adding more trees or hedgerows, beehives and using wind turbines to create more sustainable energy.	No information recorded
3	Today we made Google slides all about 'Aquaponics'. Children made their work very clear and easy to read. I think that many of the children now understand the system a lot better!	No information recorded	No information recorded
4	This week, we discussed the impact and changes of food miles and emissions. We found it easy to understand the 'Game'. We found it fun and interesting to learn about the importance of the task. Everyone decided we should turn it into competition and it was a race to make and understand the meal making and it all went well. Everyone loved this week.	Today we learnt about the food pyramid as well as calculating air miles and emissions of our food. The lower the air miles and CO2 emissions the better! We found that bread with vegetable spread was one of the best options that was best for the planet. Today we also had to reset the aquapod as the water had become murky and the ammonia level was high. We don't think the filter is working.	
5	Today, we created our own logos. Here is a 'Flavour' of some of our slogans that we have created: Get more on the go, Good food and good you and Good for me. Everyone really enjoyed this week and LOVED to create their Ideas!	Yesterday we created our own products and brands to sell and promote people to use Aquaponics. AH had the idea of adding a science lab to the Aquapod. AG had the idea of adding hooks and shelves for the kit and equipment. BP thought we could have a desk attached to the side to make it have a dual purpose	No information recorded
6	This week we have had a huge clean out! It's a very interesting programme and we have tried very hard to look after the wonderful stars of our programme…THE FISH! Over the weeks, it has been extraordinary working on our programme and it has really helped our communication skills. Also, it's helped our systematic thinking by working in a repeated system, e.g. pass the bucket to him to empty and fill up and pass it to her to empty and start again. We are all upset that this is our last lesson but we are going to remember all we have learned and make the absolute most of it. Our Aquaponics knowledge is at a top level and we hope sooner or later that the world will be more aware of this efficient farming technique. This approach is also extremely environmentally friendly and cost efficient.	Not marked as complete	No information recorded

APPENDIX B

Survey conducted with teachers participating in the programme

Questions	School 1	School 2	School 3
Question 1: Were you successful in running the entire programme?	We were successful in running the whole programme and we ran it as an after school science based club	We ran it for the full 6 weeks but some sessions were cut a bit short due to time restrictions.	We did all of the sessions, which were really good and fit with our PSHE work on sustainability and climate change. The actual growing of the plants was a bit more tricky as it was too cold in the classroom overnight at points so they didn't grow as well as we'd hoped. We also took readings from the tank but not as often as we should have (time constraints in school) so did not upload to the platform but did use it for the videos and lesson plans.
Question 2: How did you find navigating the online platform?	The online platform was absolutely fine, great to upload information, navigate between pages and load content	It was fairly easy to navigate. The uploading of data was confusing so I don't think we actually recorded any of our PH results etc	See above. Was fine to navigate although we had a few issues getting on at the start.
Question 3: How did you find the physical assembling of the aqua-pod? (How was the session with students, did it work properly throughout, is the school planning to use it in the future)	The physical assembling of the apparatus was actually the pupils favourite lesson. They found this challenging and exciting and it really engaged them effectively	It was straightforward to set up, I made an error with the filter but Alana quickly helped me get a replacement so we could get started. The students enjoyed building it. We have since taken it apart as one of the fish passed away and we were struggling to remember to water the plants so they died also. Sorry.	We set it up fine and the videos were useful. The children enjoyed this. There were some issues with leaking and it is very loud so I have to switch it off during teaching sessions as it is distracting! We may use it in the future but possibly not in the classroom.
Question 4: Which parts were hard to complete? (Yours and your students experience)	No part of the programme was difficult to finish as such.	Keeping the plants alive	The monitoring of the water and uploading of data – school is just so busy that I couldn't fit it in – so sorry.
Question 5: Were there any parts of the programme you didn't cover or felt were not necessary to answer?	The thing that I would change or that was not so effective was the board game session. The resources seemed fine, it was colourful and creative but children did not find the game so fun. I think it seemed too boring for them and they didn't enjoy playing it.	There were some small parts of lessons I had to skip due to time but can't remember now which parts as it varied depending on time. But we covered the majority of it.	No
Question 6: How did you find communication between researchers and yourselves?	The communication between our school and the research team was fantastic. Every single time I needed to speak to the researchers I could always schedule a call or get an email response – thank you!!	Great communication and they were super informative and helpful throughout	Great communication and they were super informative and helpful throughout
Question 7: Do you feel the programme had long term impacts on the students participating?	I think the introduction of aquaponics as a concept to children was invaluable, it will stay with them for the rest of their lives and we would so much like to take part in future to introduce other pupils to the scheme	I think it has made lots of them think about caring for our planet as we tied the project in with our PSHE learning about caring for our planet.	Yes, there are some children who have these at home that I never knew about so they came into their own as their knowledge was vital! All children are more aware of the need for sustainability and plant-based foods. They are more aware of the carbon-mileage and using locally home-grown produce where possible.
Question 8: If you were to complete again, what would you change or do differently?	I loved the assembling of the equipment and I loved the slides and the online platform. Next time, I would like a different game made if possible	Look after the plants better The game that we played was quite tricky as there were so many parts and we ended up just playing it all together – if I were to do it again we would have split off into smaller groups if we had longer.	The noise element is the main issue for me but the children love having the fish in the class. I would need to research it a bit more to help the plants grow better next time and deal with the temperature fluctuations in the classroom.

APPENDIX C

Postcards

The postcard presented two questions, which students were invited to answer. The content of the postcard is described below.

> Throughout the Food Future Heroes Programme we learnt lots of different things about food. We learnt about foods that are good for us, how the production of different foods can affect the planet and different ways of growing food, such as using an indoor farm. Today we visited an urban vertical farm and saw crops growing indoors.

Postcard questions and answers provided by students visiting the vertical farm.

Question	Children responses
1. Would you want to eat food from a container farm, why or why not?	• Yes, because it's healthy • I would eat food from a container farm because it is an efficient and creative way to produce • Yes, because it is faster and I don't have to wait so much • Yes, because it is good for the room • Yes, because you get to try new stuff • Yes, because maybe we could eat like vegetables • Yes, because it is ok to eat (because they don't use chemicals) • Yes, because it can be good • Yes, because it is healthier and stronger and easier • I would eat from a container farm because it is 'tasty?' • Yes because maybe we could eat like vegetables • I would eat from it so we don't have to go picking outside • No, because it might not be ready or be made properly • No, because I feel like it is gross incase it did not get cleaned • No, because my 'tummy?' But yes in the middle
2. If you said yes to the last question, what food would you like to eat from a container farm?	• Carrots, cucumber, lettuce, apples, strawberries and oranges and grapes, blackcurrants • … and rocket • Cucumber, strawberries, potatoes • Carrots apples, pears, beans, raisins and pineapple and fish • Cucumber carrots, strawberries and potatoes, corn, tomatoes • Potato, sweetcorn, cucumber and strawberries • Carrot cucumber, potatoes, strawberries, corn, kale • Cucumber, strawberries • I don't know what there is • Watermelon, carrot, fish • Fruit, vegetables, grapes, fish, raisins, pineapple, melon • Strawberry, grapes, apples, carrots • Fruit, pear, apples, pineapple, fish, grapes, carrots • Fruit and vegetables and grains/ herbs I would eat fish grown from a container farm • I would eat fish, watermelon, pineapple, trees • Strawberries, tomatoes, potatoes • Rocket, carrots, kale • Strawberries, carrots, apples • I would like to eat fruit and vegetables