neuleaf.
Building the pipeline of future molecular farmers

Clara Llamas

MA Service Experience Design & Innovation
London College of Communication

November, 2018

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Disclaimer

This report and its appendices are the original work of the author and have not been submitted previously to any institution for assessment purposes. All sources used have been cited and acknowledged.

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Thank you.

Table of Contents

Statement of intent

This document describes the design journey of the service system neuleaf. neuleaf aims to expand awareness, engagement and understanding of plant molecular farming (PMF) among A Level Biology teachers and their students, with the goal to increase the pipeline of future plant molecular farmers.

Plant molecular farming is a niche biotechnology that has the potential to lower the costs of access to critical medicines in low to middle income countries. It uses plants as growth factories or 'bioreactors' for pharmaceutical products that are critical components in the manufacture of many useful drugs.

Research suggests that PMF could lower the production costs of critical pharmaceuticals by up to 80% compared to existing mammalian-based manufacturing models (GMONews, 2018).

The aim of this project is to raise interest, awareness and acceptance of plant molecular farming and showcase its potential.

In pursuit of this goal, the project research focus has undergone various transformations. Early focus was placed on the scientific communities of practice, then on primary school children and finally found its space among the teachers of young adults.

The service showcases PMF to science teachers and their students through a combination of theory and living practice in a school and extra-curricular activity setting.

neuleaf is built around the hands on activity of growing a plant. It then deploys a combination of theory and experiments, consistent with themes of the A Level curriculum. As such, it provides teachers and students the opportunity to explore a new biotechnology in an experimental and skills based manner, in alignment with key topics of the national curriculum.

Field of study

What is plant molecular farming?

Plant Molecular farming (also known as pharming, which is a portmanteau of 'farming' and 'pharmaceuticals') is the process of genetically modifying plants to make useful drugs. (Ma, J. 2011). This technology uses plants to produce large amounts of pharmaceutical substances such as vaccines and antibodies. It relies on the method used to produce genetically modified crops – the artificial introduction of genes into plants (Eisenach, C. 2017).

Plants are used as bioreactors (or factories) to grow pharmaceutical substances. The processes by which recombinant proteins -that is to say, proteins that are not native to a plant- can be reproduced by the plant, is something that also occurs naturally in the plant world and does not require or imply that genetic modification of the plant itself has occurred.

A number of vaccines, antibodies and other therapeutic substances made in plants such as tobacco, maize, potato and carrot are already commercially available or in advanced clinical trials (GMO News, 2018). Examples of substances that are successfully grown in plants include human haemoglobin, human growth factor, the Ebola vaccine Zmapp, influenza vaccines, trichosanthin (HIV inhibitor) or a colon cancer antigen, among others.

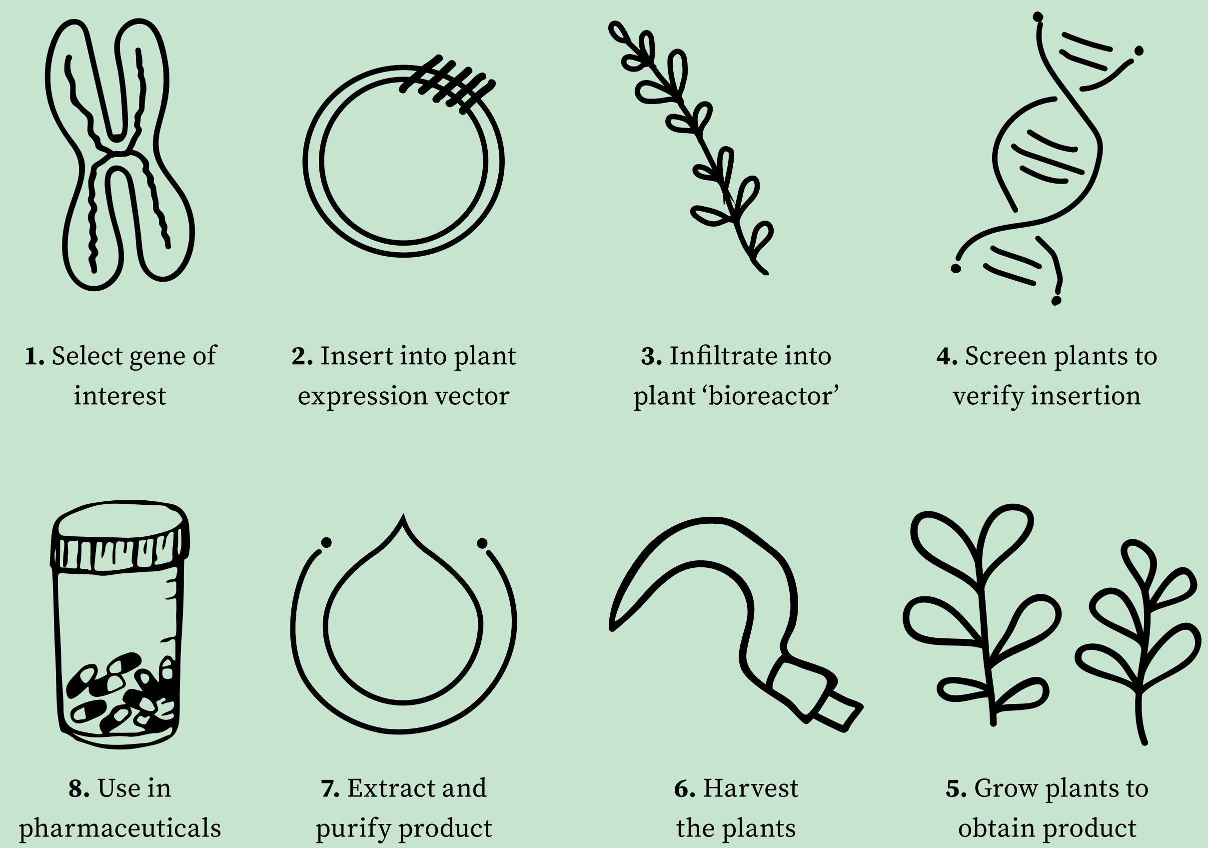
Research suggests that producing pharmaceuticals in plants is faster and cheaper than conventional production methods.

Normally, animal or microbial cell cultures are used to produce vaccines. However, costs associated with maintenance, safety, storage and transport are reported to be sometimes as much as 80% higher than plant-derived alternatives (GMO News, 2018).

There is evidence that the general public has negative opinions around genetically modified organisms (Bodnar, 2018; Pew Research, 2016). Therefore, showcasing the value of genetically modified organisms in a technology that could bring significant health improvements in low to middle income countries, seems desirable.

The efficacy of plant molecular farmed medicines has been demonstrated globally. Examples such as preventing rabies in South East Asia, HIV transmission in Africa or curing returning Ebola victims in Europe offer proof that plant-farmed antibodies are as effective as mammalian cell farmed ones (Ma, J. 2015).

Molecular farming approach



Products & their bioreactors

Vaccines

- Cancer vaccine (tobacco).
- HN protein of Newcastle disease virus (tobacco).
- Poultry vaccine (canola).
- Capsid protein Norwalk virus potato (tomato).
- H5N1 vaccine candidate (tobacco).
- Hepatitis B antigen (HBsAg) (lettuce, potato).
- Fusion proteins, epitopes from rabies (spinach).

Nutraceuticals

- Human intrinsic factor Coban (arabidopsis).
- ISOkine, DERMOkine (barley).
- Human lactofermin (rice).
- Human lysozyme (rice).
- Immunosphere (safflower).

Therapeutic human products

- Insulin (safflower).
- Lactoferon / interferon (duckweed).
- Fibrinolytic drug (duckweed).
- Hurran gluco-cerebrosidase (carrot).
- Human interleukin (rice).
- Galactosidase (tobacco).
- Apolipoprotein (safflower).

Antibodies

- Hepatitis B (tobacco).
- Immuno-globulin A (tobacco).
- IgG (ICAM1) (tobacco).
- Fv antibodies (tobacco).
- CaroRX, DoxoRX (tobacco).
- RhinoRX (tobacco).
- AntiBoNT/A scFv (tobacco).

Health worker in Liberia during an Ebola outbreak, 2014 © Time

The end of infectious disease globally

Achieving greater engagement with plant molecular farming matters because infectious disease is the number one killer in the developing world (WHO, 2016). Research suggests that PMF provides the potential to improve global access to essential medicines (Ma, J. 2015).

This might lead to breakthroughs in production capacity: higher speed compared to other production platforms; higher amounts of protein per gram of plant. As a result of improvements in extraction and transformation technologies, the PMF industry could come closer to large scale manufacturing of low-cost life saving drugs. This major project is embedded in a larger EU funded research project called Pharma Factory. Pharma Factory has the goal to increase engagement among the scientific community to accelerate improvements and discovery around 'transient expression' production platforms.

The project is an industry driven innovation action to improve and consolidate the competitiveness and scientific leadership in the field in Europe.

Lowering access barriers

Proponents of PMF, such as Professor Julian Ma of St. George's University of London, suggest that manufacturing closer to the point of delivery may create jobs and lower access barriers. He describes this as 'manufacturing in the region, for the region'.

It's possible because PMF allows plant-host organisms, such as tobacco, to act as vehicles for the growth of antibodies from which medicines are made, versus current mammalian cells methods requiring costly equipment, facilities and infrastructure. Plant molecular farming could, in the not so far future, successfully save lives in many places where infectious disease is a primary cause of death and resources are scarce (WHO, 2016).

Why transient expression?

Pharma Factory works in 'transient expression' production platforms for protein expression. Compared to other production platforms, these provide speed and high yield, and are suitable to address sudden viral epidemics, like Ebola.

Transient expression systems can be used as an alternative approach to produce recombinant proteins in three to five days (Yao, J. et al 2015). They also address the key issue of yield, which is the amount of useful protein that can be obtained per gram of leaf. Research suggests that it is likely that with further optimization of the transient expression system, large scale production in a short time period (seven days) will become feasible (ibid).

Building a pipeline

Future molecular farmers

The design direction has been influenced by a number of factors. The UK has a shortage of technical-level skills, ranking 16th out of 20 developed countries for the proportion of people with technical qualifications (Guardian website, 10/2018).

However, research suggests that schools help children develop lifelong interests in science and shape their careers by introducing experience based science related activities to them. Part of the UK Industrial Strategy is to boost interest in science subjects, especially as Brexit might increase the need for STEM graduates if immigration rules tighten (ibid).

Research around the Strategy for UK Biotechnology and Biological Sciences, as described by the Biotechnology and Biosciences Research Council in August of 2017, has the strategic goal to put British Biotechnology at the forefront of Europe in the key areas of 'people and talent', 'infrastructure' and 'collaborations and partnerships' (BBSRC, 2017).

UK POSITION

16/20

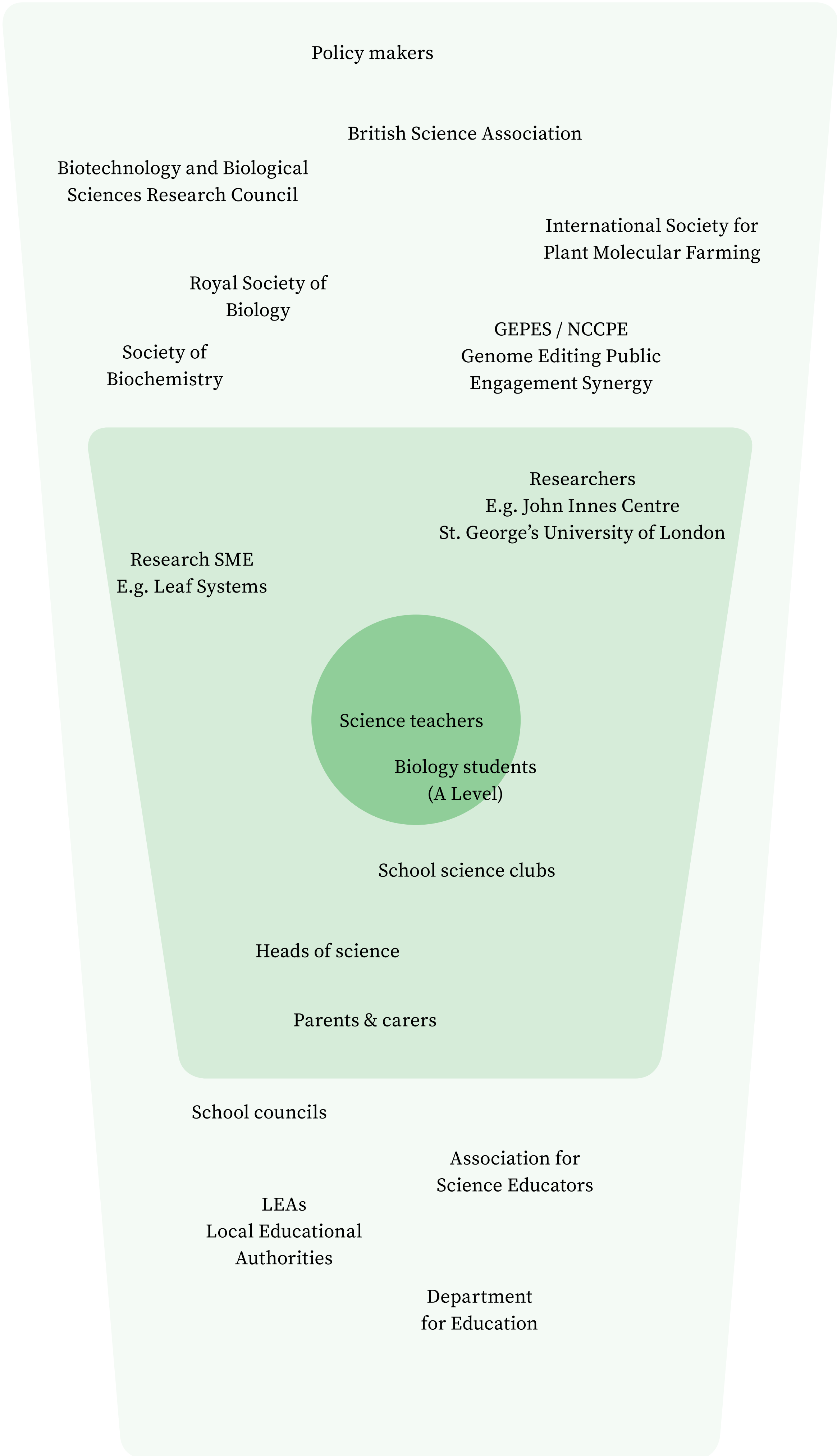
ranking of developed countries in proportion of people with technical skills

The design direction is also affected by the concept of 'science capital', which helps understand why some young people participate in post-16 science and others do not. It may shed light on why many young people do not see science careers as 'for me'.

Science capital 'can be imagined like a bag, containing all the science-related knowledge, attitudes, experiences and resources acquired through life'.

Science capital includes what science you know, how you think about science (your attitudes and dispositions), who you know (for example, if your parents are very interested in science) and what sort of everyday engagement you have with science" (Science Capital, King's College London website, 2017).

In The Enterprising Science Project, conducted between 2013 and 2017, research showed that the more science capital a young person has, the more likely they are to study science and to see science as 'for me'. neuleaf attempts to address some key dimensions affecting science capital, such as scientific literacy and talking about science in everyday life (ibid).



Stakeholders

The key stakeholders or clients of the service solution are secondary school teachers, more specifically teachers of A Level Biology. Secondary users of the solution are their students, who will engage directly with the service, expanding their knowledge in the classroom and in extracurricular activities and science clubs.

Targets have been selected based on insights reached during the research phase. It has been suggested by a number of experts during primary research that working with teachers can yield the greatest impact in terms of raising the profile of the discipline and helping build a pipeline of future molecular farmers.

Stakeholders extend into policy, education and research, scientific organisations and industry players (manufacturing SMEs, suppliers), as they will have an active part or be affected by the design outcomes.

Existing services

Raspberry Pi

Communities of practice around Raspberry Pi provide ideas on building engagement and sharing experiments. The Raspberry Pi is a low-cost small sized single-board series of computers. It was created in the UK by the Raspberry Pi Foundation, which has the goal to advance the education of adults and children in the field of computers.

GitHub

This open source repository for version control of software code provided ideas for collaboration and wikis. The open source nature of the platform, often used for open source collaboration, provided an inpirational service model where teachers could share knowledge.

TES Institute (Times Education)

The marketplace area of this online resource provided insight into current information exchange models between teachers.

Cisco pxGrid

pxGrid provides an interesting analogy of a product born for data exchange. It allows multiple security products to exchange data. By use of one API enabling open, automated data sharing and control, pxGrid can help an entire ecosystem of dissimilar technologies work together.

iGem Foundation

The iGEM Competition gives students the opportunity to push the boundaries of synthetic biology by tackling everyday issues facing the world. Multidisciplinary teams of university students work together to design, build, test, and measure a system using interchangeable biological parts and standard molecular biology techniques.

Gatsby Plant Science Education Program

This program aims to make a demonstrable difference to the teaching and learning of plant science at all ages in the UK.

Society of Biology

Learned societies offer various engagement and outreach materials for teachers, including Biology Learning Resources and Biology Career Teacher Resources. There is a high focus on teacher's ongoing learning.

Project ENTHUSE

Enthuse brings government, charities and employers together to inspire STEM teaching by professional development. Celebration Awards for teachers and schools highlight commitment of teachers to improve their knowledge.

CREST Awards

A scheme for student-led project work in STEM subjects. CREST gives 5–19s the chance to choose their own subject and methodology completing a hands-on investigation. CREST provides activities and project ideas for a range of ages, group sizes and abilities. (British Science Association).

CLEAPPS

A major training provider delivering one-day courses for science teachers and technicians. It runs a 12 day technician training program which can contribute towards an NVQ qualification.

Primary Science Teaching Trust

The Primary Science Teaching Trust is a registered charity whose goal is to facilitate the development and dissemination of excellence in primary science.

Khan Academy, Biology & Kids

The mission of Khan Academy "is to provide a free, world-class education to anyone, anywhere". Khan Academy Kids is, as self-described, "the only free, comprehensive early learning app that will inspire a lifelong love of learning".

MEL Chemistry

Safe experiments delivered to home monthly. Relies on the premise that the best way to learn science is to combine theory with a hands-on approach.

DNA/Cell/Mitochondria

This Basher Science Card Game is 2 games in 1—play battle or match with fun science facts. Each character card teaches facts about an aspect of science (E.g. a virus) and includes a special power for use during play.

Foldit!

An online puzzle video game about protein folding. It is part of an experimental research project developed by the University of Washington, Center for Game Science.

EteRNA

A browser-based 'game with a purpose', developed by scientists at Carnegie Mellon University and Stanford University, that engages users to solve puzzles related to the folding of RNA molecules.

The Shed: Grow your own funky vegetables kit

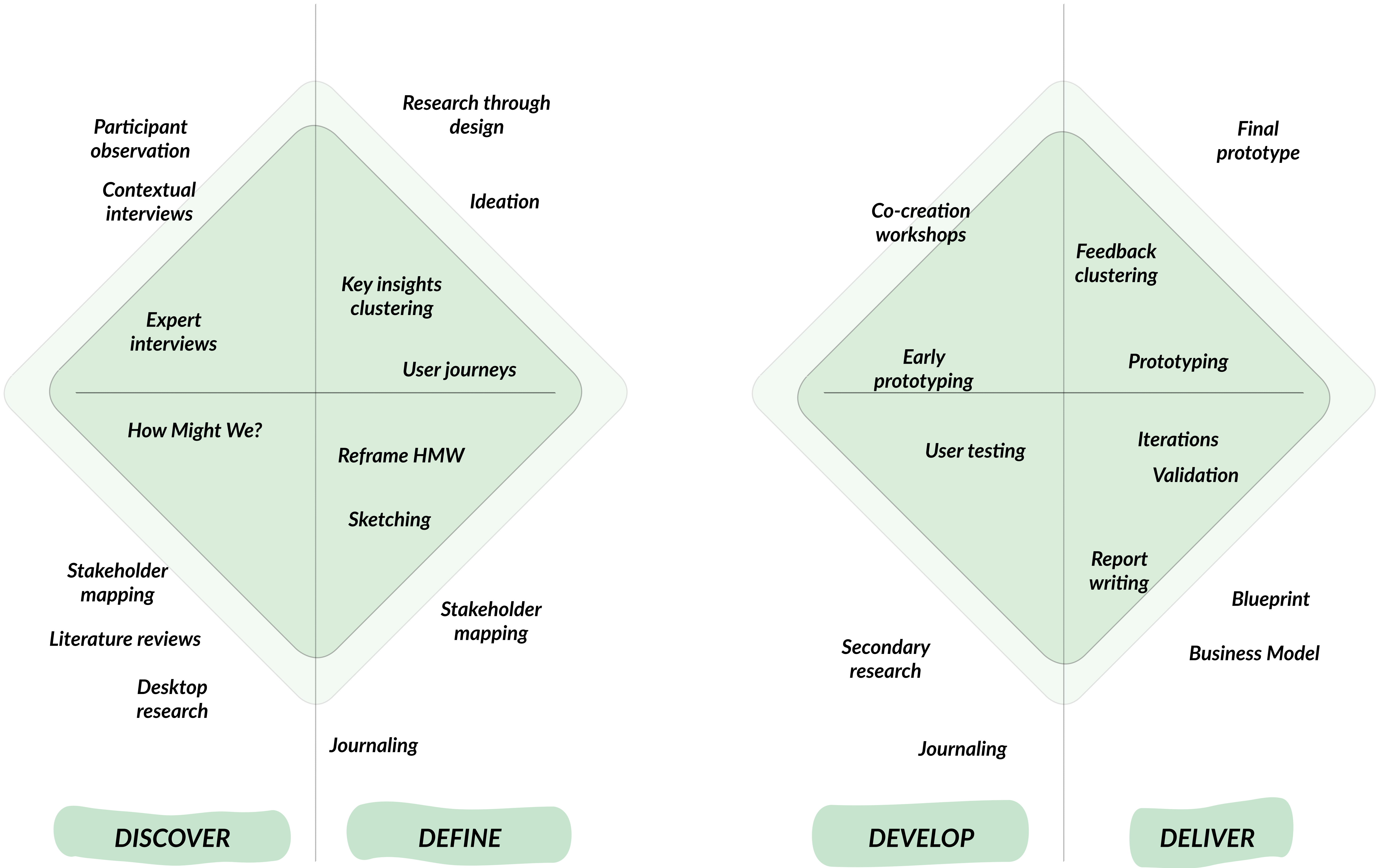
This growing kit for window sill growing of rare edible vegetables provides good insights and ideas into a product or service that may include seeds and sowing instructions for amateur gardeners.

Scientific Scissors

Scientific scissors, by the Biochemical Society, is an activity about Genome Editing: What is it? How does it work? What can we do with it? What should we do with it? Why is it important? The aim is to start conversations.

Research methods

Double diamond



Reflection on methods

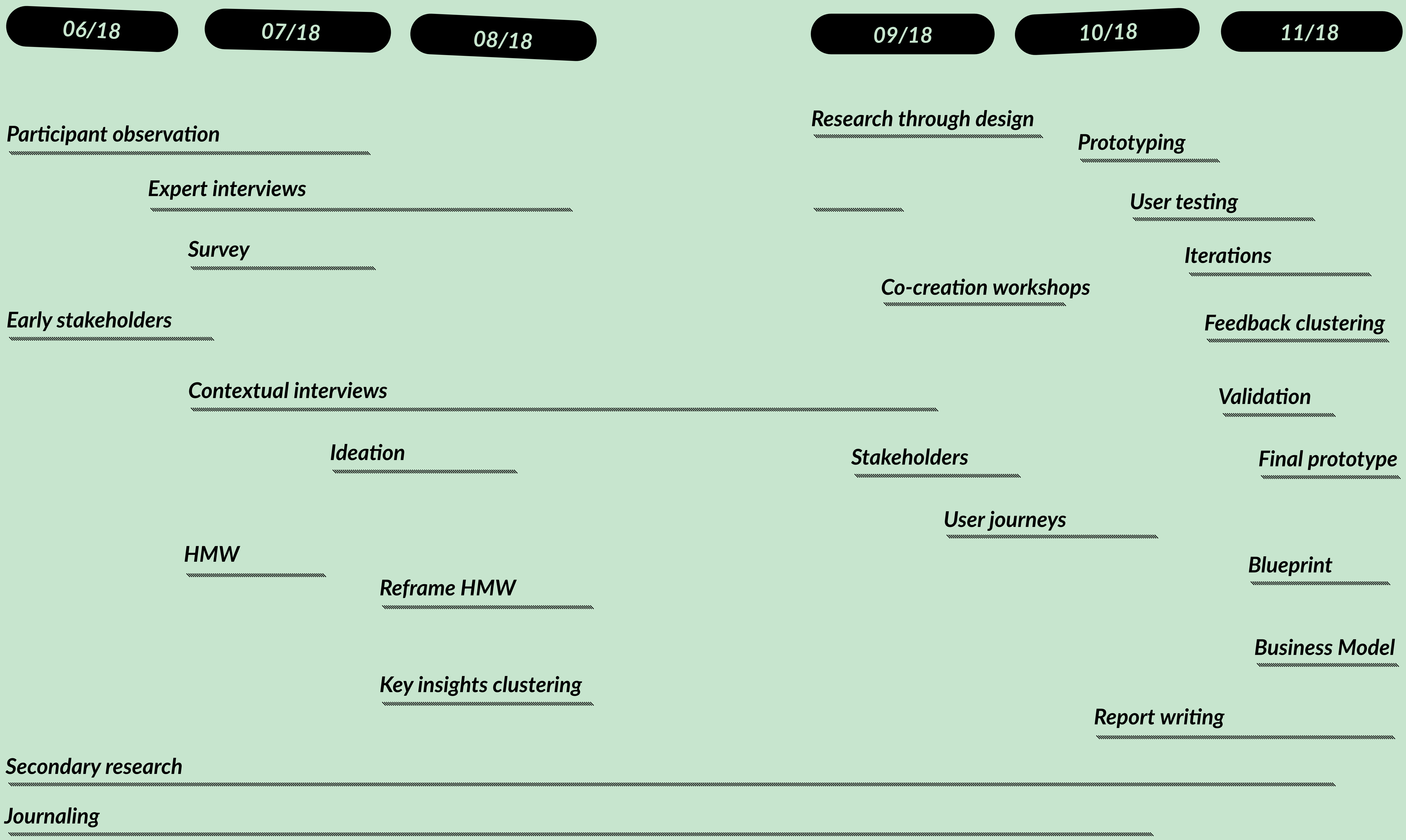
Ethnography at St. George's University of London was essential to understand the technologies first hand. This gave rich insights into the tactile and procedural nature of lab work, opening and expanding ideas on potential research through design actions and around the final product.

Interviews and surveys with key science community stakeholders provided insights into the scientific opportunities, as well as challenges for the mainstream adoption of plant molecular farming.

Interviewees from the education industry provided exceptional insights with regards to integration into the curriculum, as well as pedagogical approaches and trends and service delivery. Until the last phases of the project, research on plant biotechnologies has been ongoing, with a focus on prototyping final educational materials.

The speculative research through design project 'What if you could grow your own insulin at home?' has also informed the final design. While making it, it became clear that engaging via an activity such as growing a plant would be preferable. Also, core delivery issues related to costs were addressed at this time.

Timeline



06/18
07/18
08/18
09/18
10/18
11/18
Participant observation
Expert interviews
Survey
Early stakeholders
Contextual interviews
Ideation
HMW
Reframe HMW
Key insights clustering
Secondary research
Journaling
Research through design
Prototyping
User testing
Iterations
Co-creation workshops
Feedback clustering
Validation
Stakeholders
Final prototype
User journeys
Blueprint
Business Model
Report writing

Secondary research

Due to the complex nature of plant molecular farming and the researcher's lack of prior experience, secondary research has many hours spent on technologies.

Towards global health equality

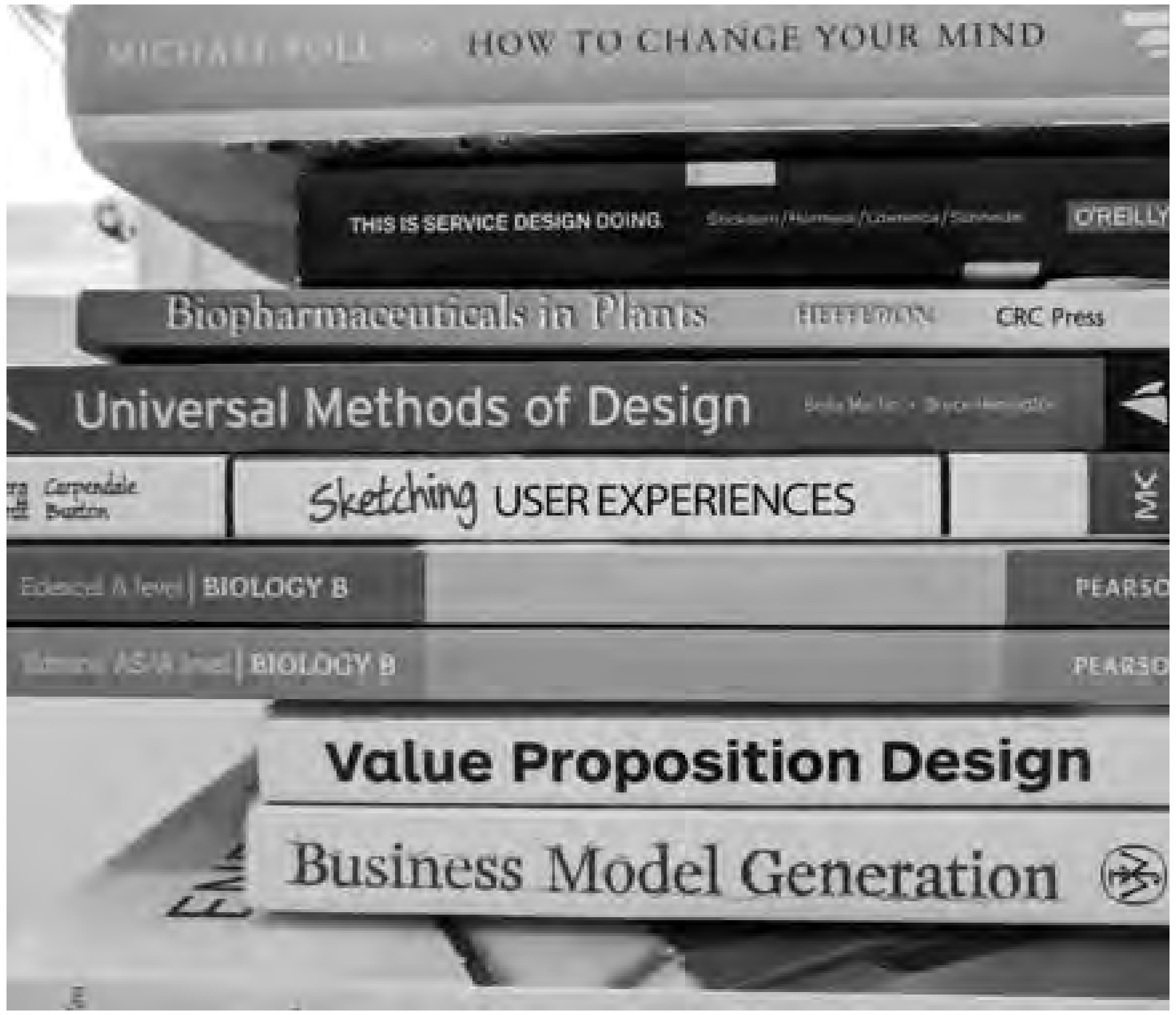
Desktop research focused on the key challenges and opportunities for PMF to become a mainstream model for the production of pharmaceuticals. These findings helped inform the design direction, confirming much of the information provided by scientists.

Desktop research in this area was also fuelled by the survey conducted in St George's, where it became apparent that many of the scientists were motivated to disrupt the current models of manufacturing, most notably to achieve affordable medicines in low income countries.

Influence of policy makers

Risks related to policy making and Brexit were also investigated. This research was fueled by comments made by principal scientists early on, as well as by risks emanating from key legislation approved in September by the European Court of Justice, with a strong negative impact on scientists working in gene editing (Science Business website, 2018).

Brexit risk scenarios for the UK biosciences community were examined. The Strategy for UK Biotechnology and Biological Sciences has been explored to identify needs and areas of value.



Education and outreach

As the design direction focused on teachers of young adults (16-18 year olds), services aimed at engaging them were explored. Equally, services that allow teachers to exchange knowledge and build community were benchmarked.

Literature supporting a more hands-on model of science education has been explored, such as Heather King's work at King's College London on 'science capital', as well as evidence of the value of skill and experiment based learning in science (Guardian website, 2018). As a result of narrowing the focus on science teachers, secondary research also ventured towards educational solutions focused on their ongoing education. Equally, the A Level and BTEC curriculum has been examined closely to align themes to appropriate subject knowledge.

The desktop research has also focused on the need to build a pipeline of future plant bioscientists, especially with a view to bridging the gap between theory and practice and increase the pipeline. Research on digital, physical and community-based solutions for engaging with STEM has been explored.

Interviews & survey

- Pascal Drake, St. George's University of London (SGUL)
- Cathy Moore, SGUL
- Julian Ma, SGUL
- Audrey Teh, SGUL
- Xinmeng Guan, SGUL
- Mathew Paul, SGUL
- James Brown, Biochemical Society
- Anneli Ritala, VTT Finland
- Lauri Reuter, VTT Finland
- Marek Kultys, Science Practice
- Jemima Rellie, Royal Collection Trust
- Peter Melbye, Pearson Education
- Jouni Lounasmaa, KAUTE Foundation
- Laura Foulsham, St. John Bosco College Battersea
- Matt Sear (in the image), St. John Bosco College Battersea
- Javier Aparicio González, St. John Bosco College Battersea
- Shani Henriques, St. John Bosco College Battersea
- Eugenie Ferrier, King's College London
- Clara Kieschnick, Stanford University
- Jessica Veno, London College of Communication

Primary research

Primary research has focused on the bioscientific community and educators. Furthermore, interviews with experts from outreach and innovation in other fields have taken place. Students, royal societies and the public have also been engaged.

During ethnographic work in St. George's University of London at the Hotung Molecular Immunology Unit (part of the Institute for Infection and Immunity) processes and protocols used by members of the laboratory working on recombinant DNA technologies and, specifically, using transient expression, where observed and practiced.

This provided useful insight into the daily work and dynamics of the laboratory, especially as pertains to having a hands-on understanding of experiments, protocols, equipment, ecosystem of providers and communication.

The insights gained were instrumental in the development of the speculative research through design piece 'What if you could grow your own insulin at home?', which has contributed to the advancement of the service concept by engaging the general public.

Of equal value were interviews with key scientists and staff in the lab, as well as a survey conducted with six lab members. This gave direction to the design by eliciting the challenges of the technologies and the driving motivations of scientists. These insights moved the direction towards an educational approach, focused on careers aligned to values such as 'changing global health equality' or finding alternative means to expensive and exclusive manufacturing models.

Interviews were conducted with key stakeholder groups, as well as with potential service providers and organisations which could shed light on where value would lie.

More detailed accounts of interviews in the Appendices.

Key interviewees, experts and stakeholders with whom chats and discussions have taken place are listed on page 30. Further insights also came from a number of casual conversations with other scientists, tutors, students and the general public who attended the installation 'What if you could grow your own insulin at home?.

Online survey

Where are the future molecular farmers?

An online survey was conducted among scientists at St. George's University of London, entitled 'Where are the future molecular farmers?'. It focused on the values and aspirations that drove the scientists into their field. It asked questions around misconceptions regarding genetically modified organisms. The survey also examined the added global value of using plants as bioreactors for pharmaceutical products.

Responses were coded for themes, where it emerged that a key driver for undertaking plant molecular farming in the group was the potential to disrupt the vaccines market, as well as to lower the barriers to access critical medicines for low income communities.

A key finding of this survey was the shared sense of purpose by respondents to 'change global health' for countries where basic medicines are inaccessible. Of similar importance to them was the idea of innovating ways of medicine production and distribution that could disrupt the status quo.

This influenced the design direction in key ways, notably the focus on showcasing potential for disruptive innovation and global impact.

View of the installation by Carlos Canali, Michael Sedbon and Clara Llamas at the London College of Communication.

Research through design

What if you could grow your own insulin at home?

Within the project, a speculative research through design sub-project was conducted. Conceiving and designing it was of special interest to crystallise some of the hands-on learnings made during ethnography, as well as to gain insights from the general public on the possibilities of novel distribution or manufacturing models for pharmaceuticals.

A detailed description of the project can be found in the Appendices. Members of the public asked important questions while interacting with the installation, especially related to policy, purification, and the value of exploring different ways to access medicines. Overall there was a positive perception of the provocation and the issues raised.

From a research perspective, it has provided invaluable insights into productisation of the service. The installation also revealed how the 'making' process helps develop skills and confidence in science practice.

Engagement with educators is key, as they shape students interests.

There is risk of a shortage of younger researchers in the pipeline.

Plant biotech opens opportunities for sustainable jobs and innovation.

Our field is very little known. In the research community it is seen as not being part of the mainstream and the general public do not know about the technology.

The service would help fill the knowledge gap for the teachers so they can educate better.

Teachers sometimes don't know the subjects because they're too new and they did not study them at university.

Schools don't have any money, so the service should be free or very cheap.

Science teachers are also scientists, they want to know what's the latest in their field. But they are super short on time.

There is limited focus on niche technologies in the official school books.

Investigative approaches and skills based learning are now key parts of the curriculum.

Teacher confidence and subject knowledge are key to student achievement.

Key insights

Insights from both primary and extended secondary research reveal a number of design opportunities. These are coded into key themes around innovation, raising awareness and expanding knowledge of niche biotechnology.

There is limited focus on innovative technologies in the education system. Bringing these to pre-university students is important, as research suggests competitiveness also depends on this pipeline.

A skills and experimental approach to life sciences is key for greater engagement and uptake. This is equally valid for teachers, who also need to be motivated and inspired.

Teachers and students are under dire time constraints. Thus, the service should be easy to adopt in a daily routine, as well as low cost for uptake in schools.

It arises from interviews, surveys and secondary research that not only is there a shortage of future bioscientists in the UK, but also there is a need to engage young people in innovative science topics, which would have a future impact on competitiveness and productivity. Research equally shows that this ties in well with aspirations to innovate 'for good'.

How might we expand knowledge and awareness of plant molecular farming and its potential among secondary school science teachers and their students?

Once research findings and insights are identified, user personas help understand the opportunities and gaps to define the design space.

Personas

NQT, 31
South London

Siobhain has worked in Africa and studied Biosciences as an undergraduate. She holds an MSc in Pedagogy.

Aspirations

Recently qualified as an NQT, she is committed and enthusiastic about her job in a South London college. She also runs after school science club. She wants to make an impact.

Pain points

She teaches 27 hours per week. She has almost no time, gets in at 7.30 and is never out before 6.30pm. Her main challenges are related to time and finding interesting things for science club.

Science Lead, 42
South London

Paul is the science lead at his school. He graduated in Biosciences and has a Master's degree. He quit his PhD studies.

Aspirations

He'd like to make an impact, but has been teaching for long and is tired of the bureaucracy in state schools. His wish is to get more interest in life sciences among students.

Pain points

Almost no time to manage everything and mentor new teachers. Short on technicians and always without a budget for new things.

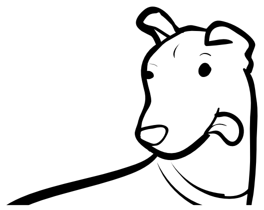
A weekday in the life

06.00

Siobhain wakes up early to be in South London on time, as she lives in the East and it may take a while.

Sleepy, enthusiastic.

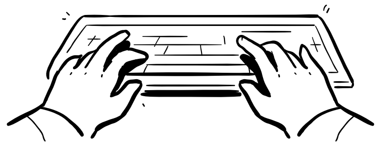
07.00



Before breakfast, she always takes out her dog for a brisk walk, breakfast, shower and off to work.

Excited, feeling energized.

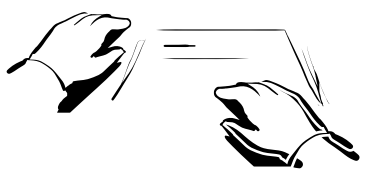
8:00



She’s already at school around this time. She usually starts off planning the day’s classes.

At times overwhelmed.

17.30



Still working on some reports for the head master, time flies when doing all this administrative workload. Will it ever end?

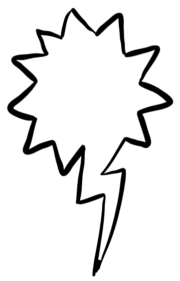
Tired, frustrated. Gosh!

18.00

Decides to call it a day. There are still some markings to be done and class to prepare, but now she is feeling too tired.

Exhausted, wants to leave.

19.15

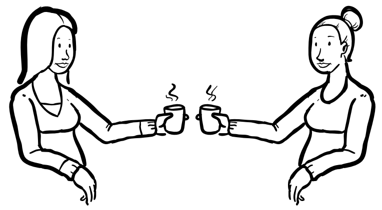


The tube was not working well and there was an incident. This is apparently more and more frequent in London. Argh!

Wants to roll into bed.

A day in the life helps us understand the life of an archetypical service user in order to define how to orchestrate neuleaf around their real everyday habits.

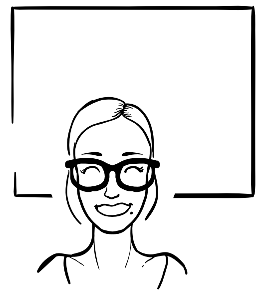
11:00



After two hours of teaching, she is taking a break in the teachers room and might chat with others.

Tired, but satisfied.

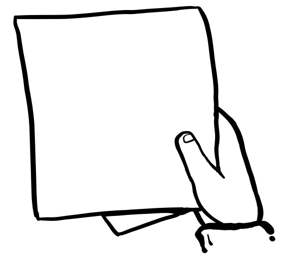
12:30



Back in the classroom, she’s ready to teach her two afternoon classes. She’s energized by Biology class.

Loves it. Enthusiastic.

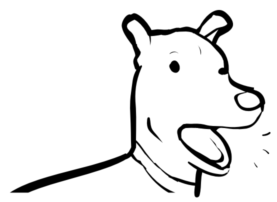
15:30



Classes now have ended, yet there is a lot of reporting to be done and science club needs to be prepared.

Tired, anxious.

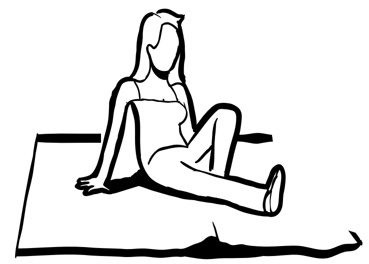
19.30



Time to relax, take the dog out for a walk and make some diner. May do Deliveroo, way too tired to cook anything today.

She’s tired, but satisfied.

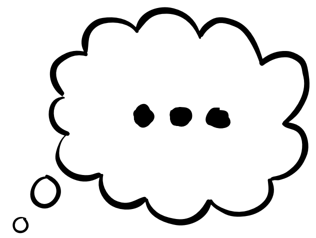
21.00



Some yoga might help wind down before bedtime. Feeling worried about new science club season, she’s got nothing lined up.

Ready to sleep, satisfied.

22:30



After some social media and a bit of TV, time to go to sleep. There’s an early morning to raise to and lots of young ones to teach!

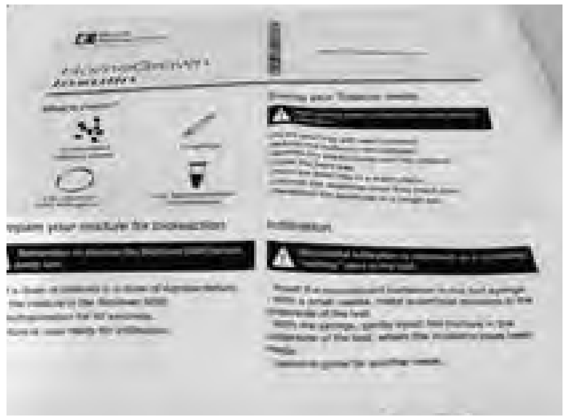
Tired, ready to dream.

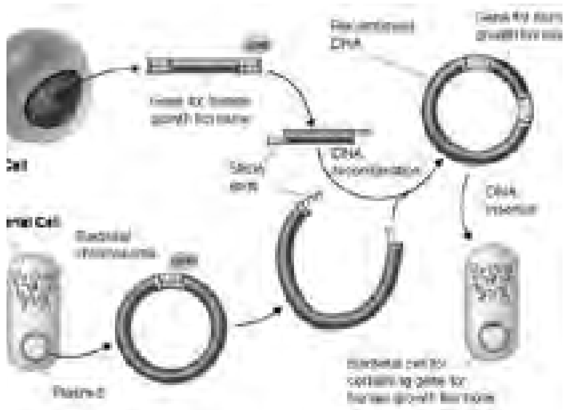
Design space

Building on the findings and insights of research, we seek crucial criteria to address the problems identified. Time constrained teachers and students would benefit from a low-cost, easy methodology to gain access and develop their knowledge of plant molecular farming.

The definition and development phases will address the design problem while accounting for key constraints of cost and time. Engagement models to ensure not only teacher acceptance, but also adoption, will be explored.

As seen in Siobhain's day, it is important to find a solution that may be adopted realistically within a heavily loaded daily schedule, with low barriers to entry and easy access and set up. It should also interesting and fun for the teachers themselves, as for their students.





Exploring concepts

Originally, concepts focused on teacher peer to peer resources and ongoing learning services. In early ideation, the main conceptual models focused on ease of knowledge acquisition for teachers, with a view on how to incorporate the service into the curriculum.

Models evolved into a more dedicated approach to plant molecular farming and, specifically activities such as science clubs. The service solution also evolved to be more inclusive of teachers and their pupils, by means of easy to use discussion cards and an app.

Experimentation and hands on learning being key, the idea of building engagement around growing a plant gained traction.

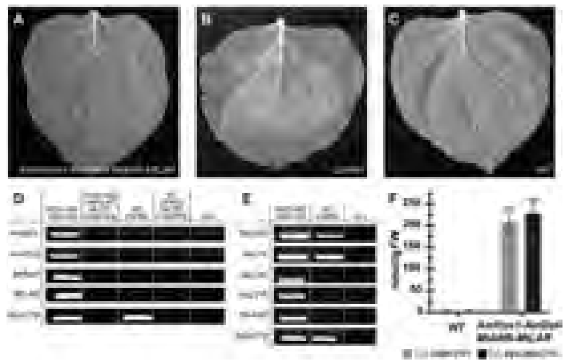
Making the hands-on elements of the service work alongside the activity of plant growing at low cost is critical. As such, early concepts include ideas around things like making paper your own paper plant pots.

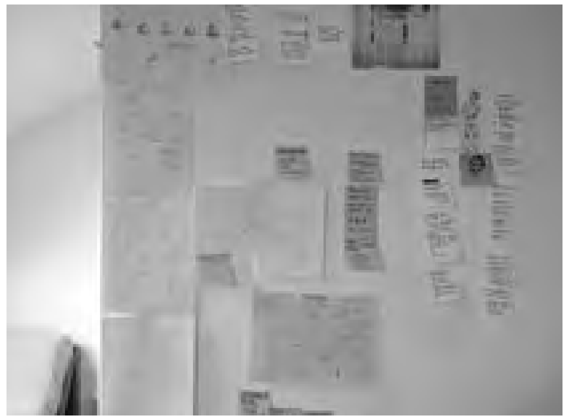
A commercial service that may be sold as a 'self-contained kit' (E.g. in a museum shop) for home growing and experimentation has been contemplated.

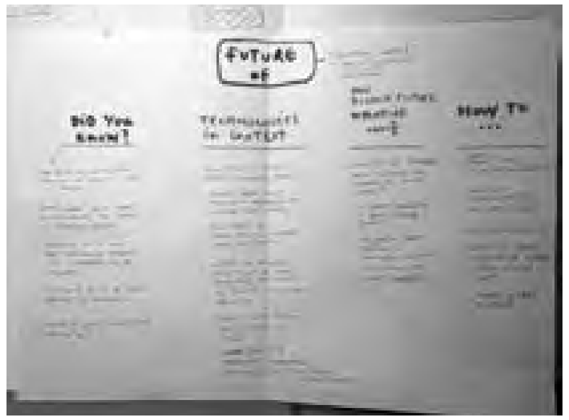
Prototyping

During research the plasticity of the service became visible. The idea of 'doing with your own hands in your own daily environment' was important. Equally, there was a focus on issues like ease of access (on the bus, on a train), ease of use (safe experiments with no special equipment) and alignment with the biology curriculum (subjects that are known to students, proportionate complexity levels).

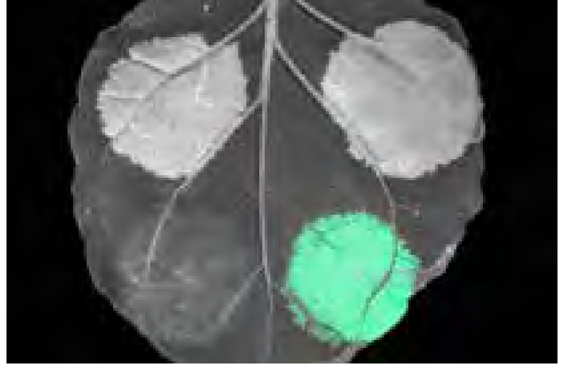
Prototypes for co-creation have been developed taking these into account. Also, issues related to cost and accessibility of content, given the little time teachers and students have, have been examined. This led to the initial idea of a phone app, drawing on highly usable examples like Khan Academy (ease of use, low access barriers, 100% free forever and gamification).



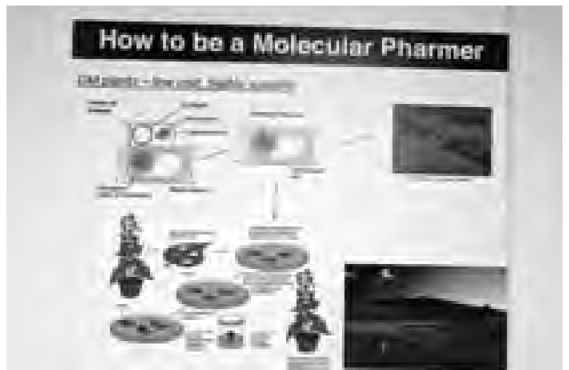





Newleaf
molecular pharming
for A Level and BTEC students
plant and facts +
Supports various
transient expression




WHAT IF YOU COULD GROW YOUR OWN INSULIN AT HOME?


How to be a Molecular Pharmer


TECHNOLOGY in ACTION
Plant molecular farming
DID YOU KNOW...?
Why this matter
Because until we could get it by means of Recombinant DNA technologies, we could only get it from pituitary glands of cadavers.

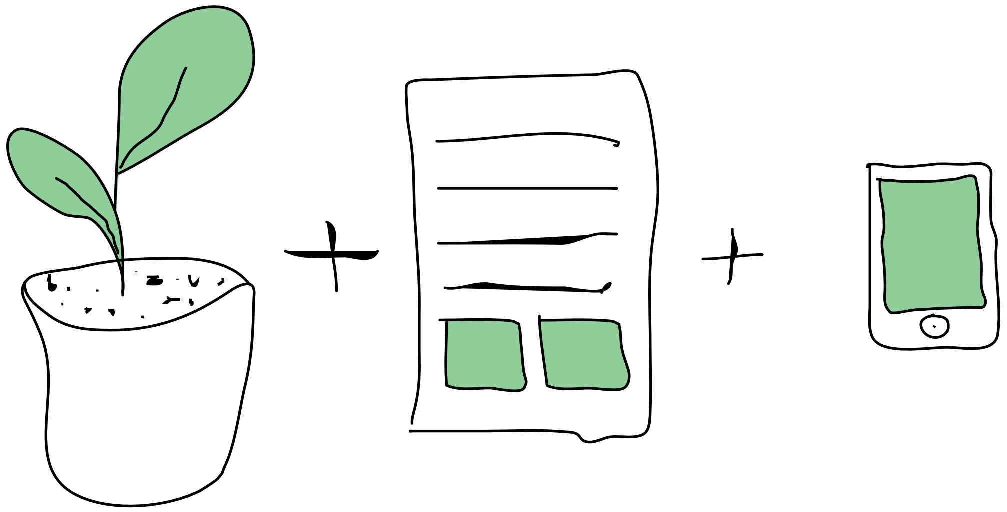
Co-designing

Due to the workload and time constraints of teachers during this period, co-creation and validation sessions had to co-exist. Early prototypes including concepts (growing a plant) as well as basic structure of the learning materials and delivery channels were explored.

This was done with paper prototypes and materials from lighting talks made in Service Design Fringe Festival. These helped transmit the concept in a short and concise form.

Insights gained in the session helped refine the design direction. In school co-creation there were two school teachers and two technicians, including the science lead. Co-creation and sharing of paper prototypes and concept also took place in the form of lighting talks to service design industry experts at a Service Design Network event as well as during Service Design Fringe Festival. Questions and suggestions from these sessions have been used to inform further iterations.

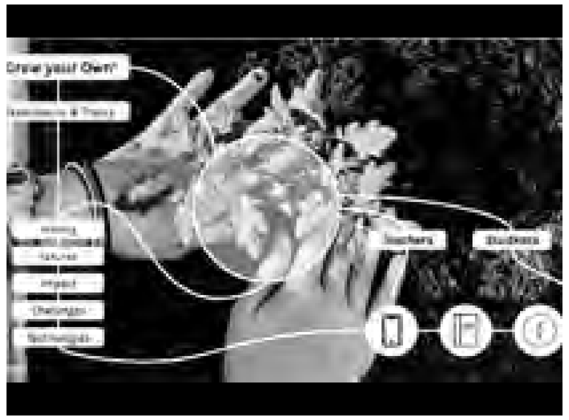
Co-creation kit



Plant growing concept described with help of large hand drawn canvas.

Info / facts / discussion cards for class use. Cardboard made, hand-made.

Mobile app paper prototype with science content / quizzes.



Feeding back

Feedback from co-creation was very positive. Yet, how to ensure that interest, acceptance and goodwill will transform into usage?

Key elements of feedback expanded on known topics and raised some new issues.

Should the digital version of the service be also for students? Equally, there were very specific issues around format (e.g. discussion cards for group work vs fact cards).

Funding again came up. Who would be the service provider? The service must be 'low' or 'no cost'. How might we ensure this? What will be the set up costs?

Further feedback focused on plant breeding. How resilient is Nicotiana benthamiana? Can we grow it on the window sill? Will we need expensive seeds, pots and fertilizers? Who will pay them? How will experiment results be visualised? Will they be shared?

Cost being of essence, a number of scenarios were accounted for to lower set up and running costs. When exploring experiments, feedback from St. George's University of London team brought in new data, which allowed to make a cost analysis in more detail.

Set up and running costs should verge to nothing.

Plants grown should thrive on window sills.

Materials should be in a discussion, not fact, format.

There should be outcomes of experiments to share.

Topics should align with national curriculum.

Service should be planned for extra-curricular use.

Iteration

Based on the key feedback collected from teachers, experts from the service design industry, experts from the education product industry and members of learned societies, key value aspects were re-examined for feasibility.

This process included further desktop research, interviews, co-discovery and validation. First touch points also raised issues at this point, as they relate to the service provider. How will teachers find out about the service?

Are the contents something that could get them excited? Equally, issues around service continuation and/or exit came up. These, alongside key findings from co-creation, informed the following iteration.

Further feedback

Reasonable design efforts have been made to mitigate key risk factors, mainly related to adoption and funding. Understanding motivations and fit of service providers was done by mapping key candidates against suitability, economic capability, impact and level of motivation.

> *If the service is affordable, easy to use and engaging, I think this is of huge value to biology teachers and students.*

Service designer, education / healthcare

> *Our society could be interested in becoming a service provider, this has definite high value to science education.*

Director, scientific society

> *This covers a critical aspect of innovation in science education that is not being properly addressed.*

Publisher, education sector

Service concept

What is neuleaf?

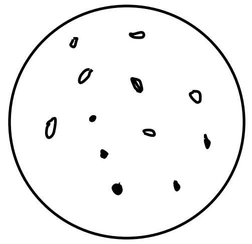
neuleaf offers Biology A Level teachers and their students an opportunity to learn about plant molecular farming in an experience based way in their everyday routine.

neuleaf allows them to experiment first hand with some of the biotechnologies used in PMF practice, while learning how this niche biotechnology may have a relevant global impact.

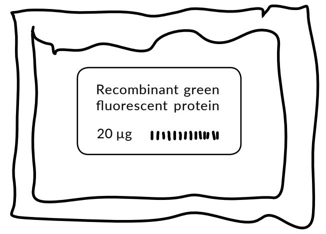
neuleaf can be used in schools, as a learning compliment alongside the official Biology A Level curriculum. Science Clubs are a perfect delivery venue. The contents of neuleaf span various topics within the A Level Biology curriculum, offering a perfect base for practical hands-on learning of the technologies studied and their applications in the context of this biotechnology.

neuleaf is accessible to any school in the UK and is easy to join and set up for teachers, as they will only need to acquire a small amount of low cost items from the project partners on the internet and download the free app to get started.

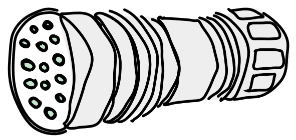
One, two, three



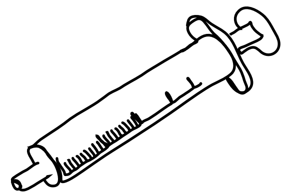
Nicotiana benthamiana seeds **(£2.05)** + pots / soil / nutrients **(£12-22).**



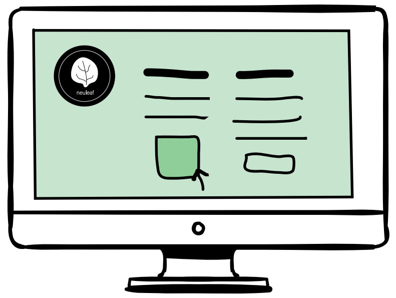
Fluorescent recombinant protein **(£79)** or a substitute, such as tonic water **(49p).**



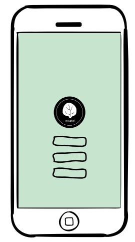
A hand held ultraviolet light **(£9.99)** to observe outcomes.



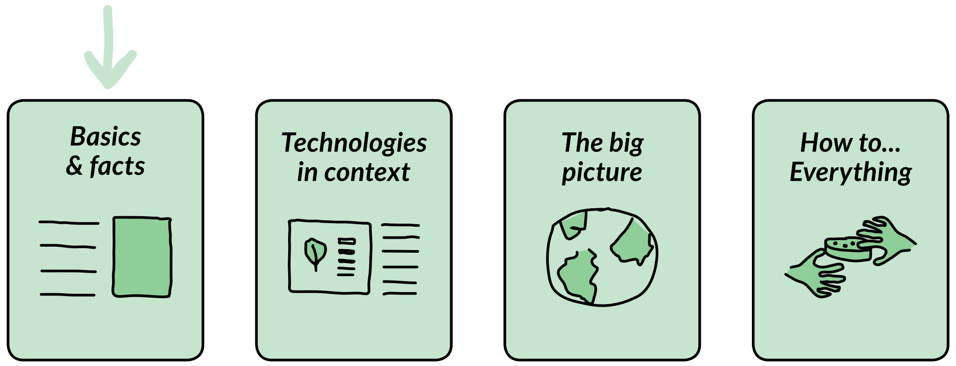
Basic syringes for agro-infiltration of the leaves **(20p / unit).**



Join the online community. Share experiments. Print neuleaf discussion cards for your school.



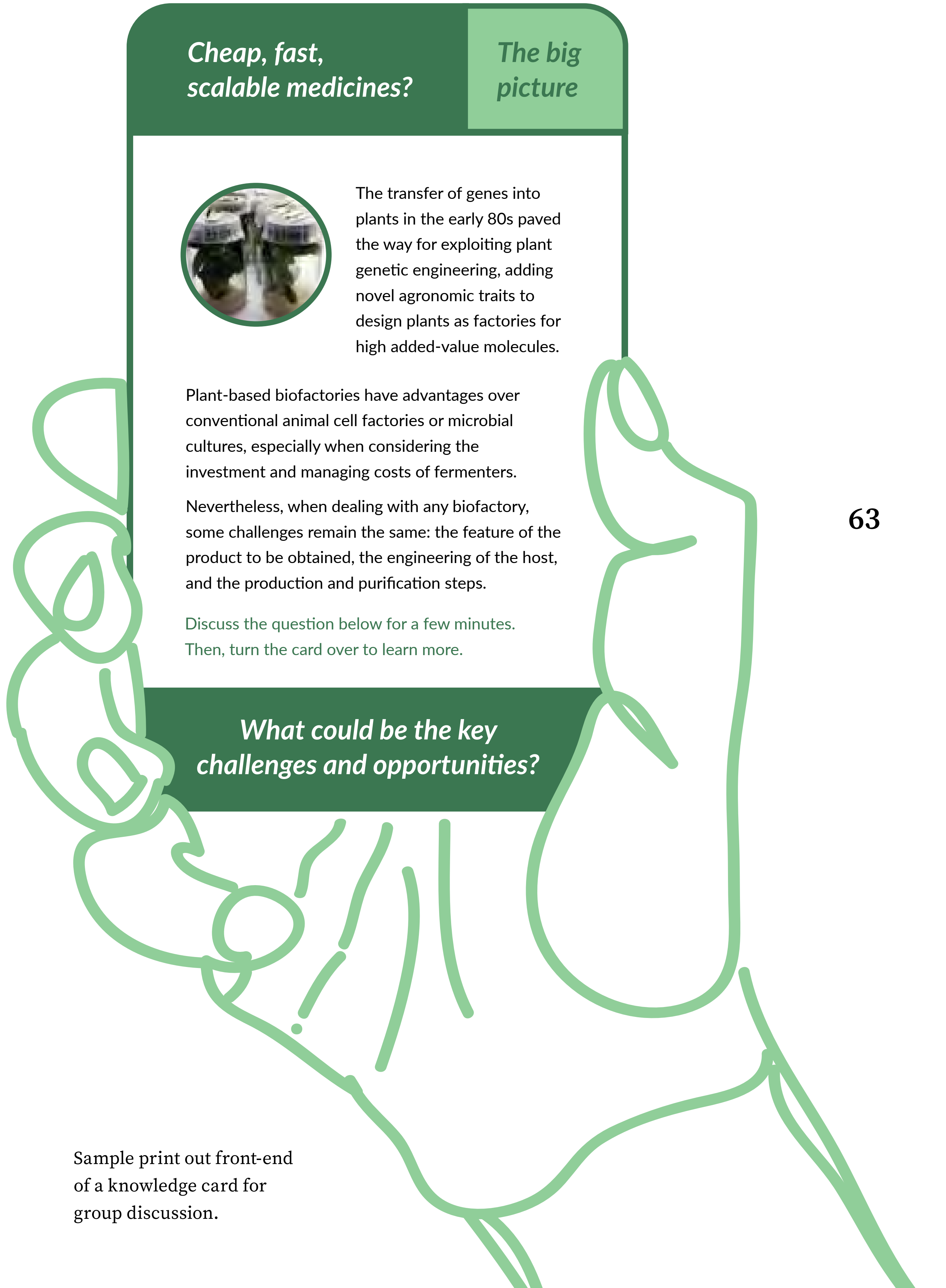
Download the app to gain subject matter expertise with videos, quizzes and facts.



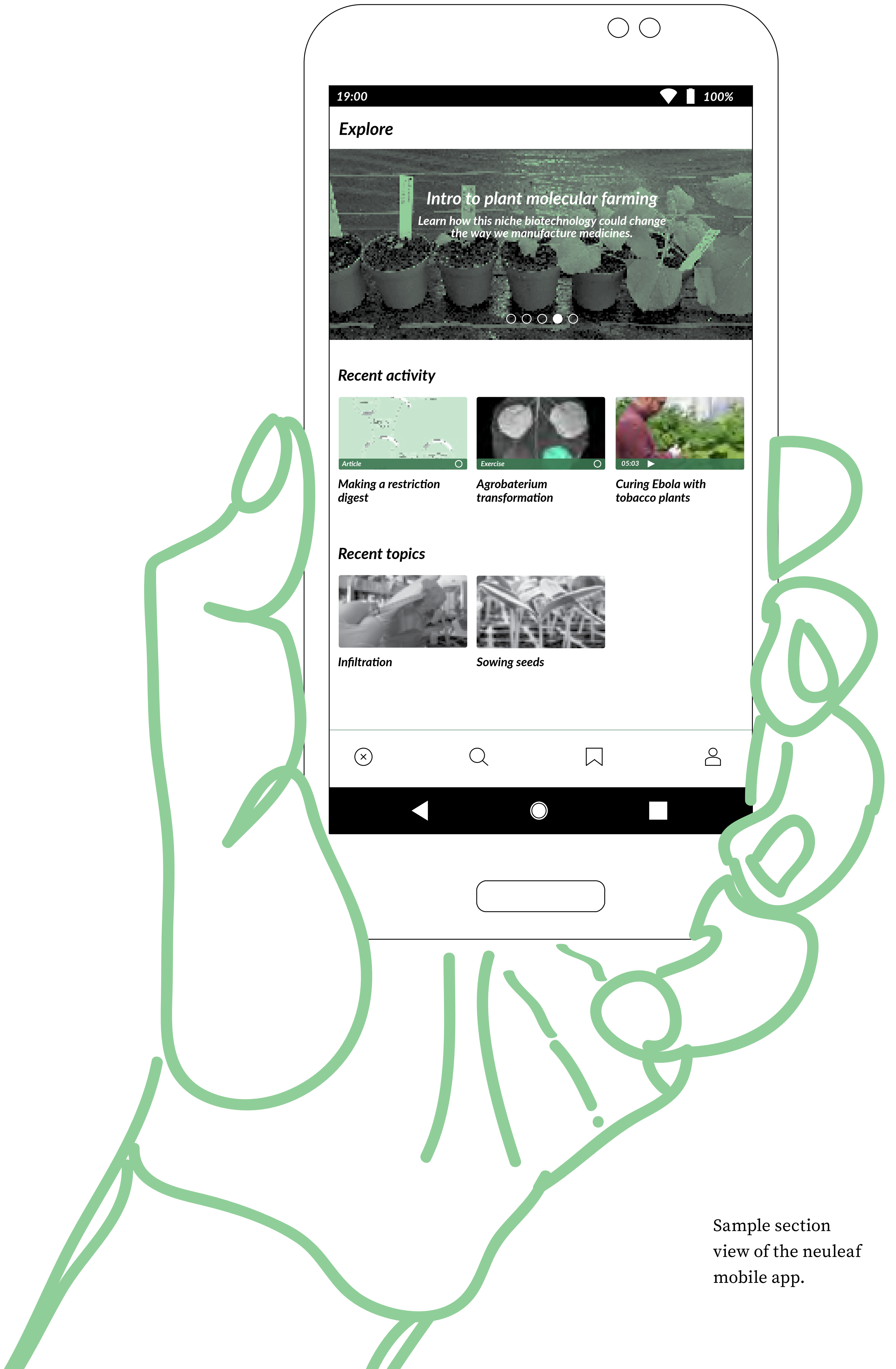
Discussion cards

Knowledge cards are core non-digital elements of the service for use in school. They are structured in four categories. The information contained in the cards is expanded upon in the app by means of videos, extensions and quizzes. They can be downloaded from the neuleaf website. Below, sample titles of cards.

Basics & facts	*Technologies in context*	*The big picture*	*How to... Everything*
What is plant molecular farming? History.	Why chose plant molecular farming? Practice highlights	The PMF goal. Fast, scalable, cheap, sustainable medicines?	How to sow your seeds of Nicotiana benthamiana.
Why are we growing Nicotiana benthamiana?	What are the key protein expression techs in PMF? Why?	Can we save millions of people in low income countries?	How to make papier mache pots for your growing plants.
Features of Nicotiana benthamiana as a bioreactor.	Understanding protein expression technologies.	Every year 30 million flue vacciones grow in tobacco.	How to take care of your plants during half term break.
When were the first plant proteins developed? How?	Basics of transient expression techs and use in PMF.	What if vaccines could be made in open fields?	How to conduct infiltration on the leaf of a mature plant.
What is agrobacterium tumefasciens?	Producing recombinant proteins in plants.	Could we lower costs of medicines by up to 80%?	How to examine the outcomes of your protein infiltration.
What are the key properties of a. tumefasciens?	What are recombinant DNA technologies?	What would be the economic model growing in LMIC?	How is a restriction digest made in molecular labs?
Which and how many pharmaceuticals from PMF exist?	What is agrobacterium mediated infiltration?	Why are mammalian models for drug making so expensive?	How to prepare a vector with a gene of interest?
What are these pharmaceutical products used for?	PCR case studies in transient expression scenarios.		. . .

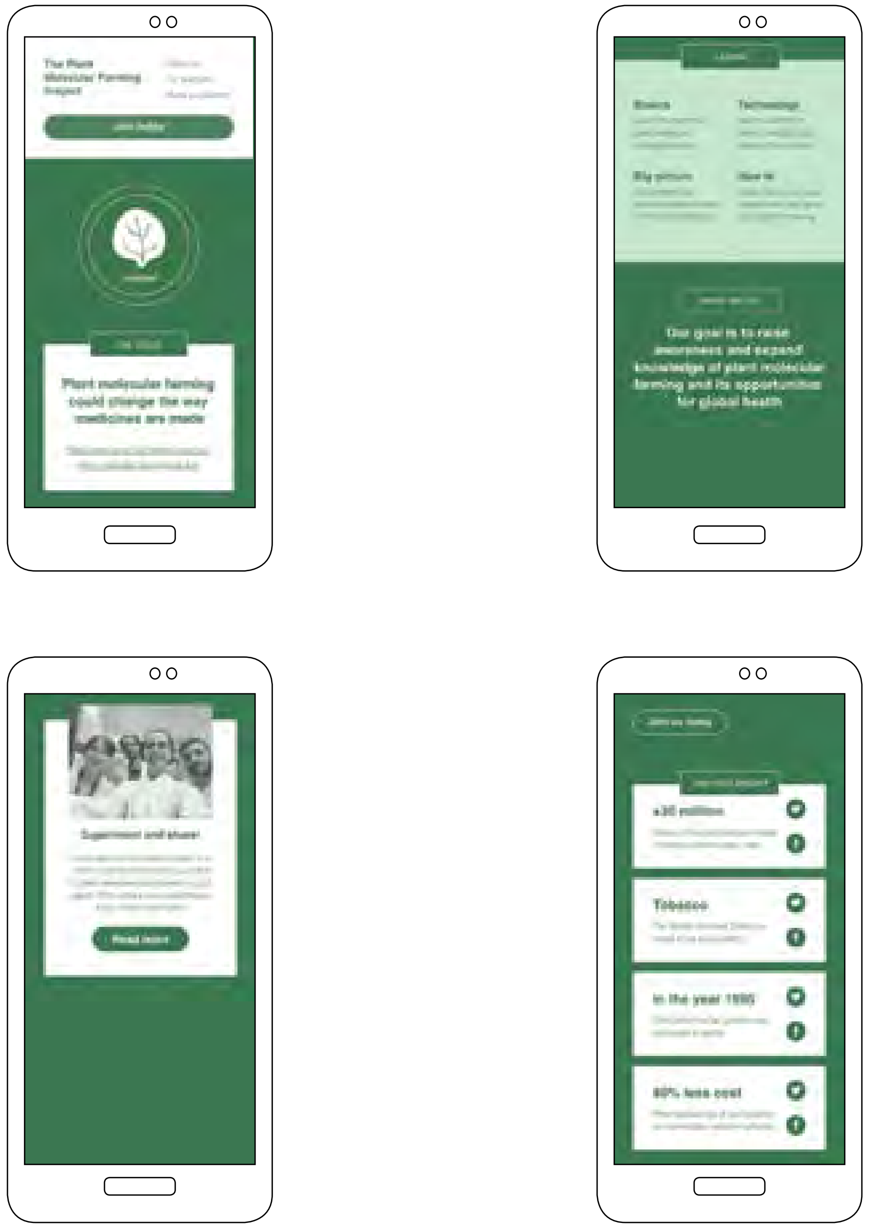


Sample print out front-end of a knowledge card for group discussion.



Sample section view of the neuleaf mobile app.

neuleaf mobile web UI



Mobile / web

- Register
- Community / Share
- Knowledge Cards
- Quizzes
- Videos
- Buy material
- Donate

Mobile app

- Knowledge Cards
- Tutorials
- Videos
- Quizzes
- Support
- Donate

Schema of key elements of web / app.

SWOT

Internal

Strengths

Flexible and practice based way to acquire new knowledge.

Easy to start using, low access barriers.

Compatible and complimentary to national curriculum.

Does not require start up costs and investment, no specialist equipment needed.

Weaknesses

Risk of limited adoption.

Risk of improper care of plants during school holidays.

Risk of lost enthusiasm if experiments fail.

External

Opportunities

Expansion into new topics and new experiences.

Expansion into other topics of plant breeding and biotechnologies, with industry specific cases.

Introduction of events and awards on a local, regional or national level to share experiments and outcomes.

Service extensions into other subjects.

Threats

Lack of funding from key partners.

Diminished acceptance from educational bodies.

Lack of support from Local Education Authorities.

Legislation and public acceptance of gene editing technologies.

Access to funding for plant molecular farming practice.

Business model canvas

Key partnerships

Royal Society of Biology.

Biochemical Society.

International Society of Plant Molecular Farming.

St. George's University of London, Hotung Unit.

British Bioscience Association.

Department for Education.

British Science Association.

UK Bioindustry Association.

John Innes Centre.

Leaf Systems.

Association of Science Educators.

GEPES / NCCPE.

Emerge Education.

STEM Insight / ENTHUSE Project.

Key activities

Produce learning materials.

Design and maintain web / app.

Nurture community.

Organise events.

Raise funding / find strategic partners / sponsors.

Outreach and engagement with schools and teachers.

Key resources

Development and UX (web, app).

Design (service, cards, experiments / subject and service experts).

Community management.

User support.

Management.

Outreach and engagement.

Value proposals

Expand knowledge and engagement in plant molecular farming among school teachers and their A Level Biology students.

Increase the pipeline of future molecular farmers in the UK.

Showcase disruptive niche biotechnologies in a practical hands-on format.

Customer relations

Update educational materials.

Maintain and upgrade digital assets.

Community nurturing and management.

Expand networks of experts / schools / teachers.

Channels

School Science Review.

Newsletters / social media.

Royal societies.

TES Institute (Times Educational Supplement).

Cleapps / Teachmeets / Science Teacher Association / The Biologist.

Customer segments

Secondary schools.

Science clubs.

Biology teachers of A Level students.

Plant molecular farming community of scientists.

Manufacturers of PMF products.

Universities (Biology & Biotechnology).

Healthcare organisations.

Health development organisations in low to middle income countries.

(World Health Organisation).

Cost structure

Web and app design / educational content design.

Outreach and engagement.

Community management / user support.

G&A / facilities / management.

Revenue

Sponsorships from plant molecular farming product manufacturers.

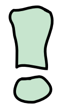
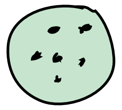
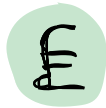
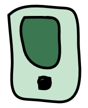
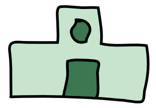
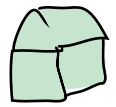
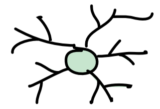
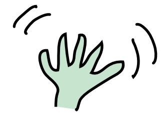
Biotechnology and Biosciences Research Council.

University outreach and innovation programs.

Sponsorships from learned societies (E.g. Royal Society of Biology).

Donations.

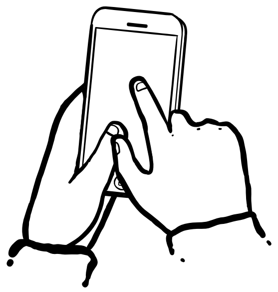
Blueprint

	Pre-service	In-service						Post-service
Physical evidence								
	Learn about it	**Start using**	**Kit up**	**Download app**	**In-school use**	**Off-school use**	**Sharing**	**Exit**
User actions	Reads about or finds out about service from outreach materials.	Makes decision to join. Sign up.	Gets seeds and other bits. Checks what's in school lab and what needs to be bought.	Gets the app online and starts to check it out.	Starts use of service with introductory materials in science club and class.	Uses app to watch video, learn and take quizzes.	Uploads experiment outcomes to web community.	Service is over, there is no action. May chose to stay in touch to follow activities.
Line of interaction								
Front-end	Recommendation from friend, teacher, headmaster. Outreach.	Option to sign up to online community.	Accessible vendors. Easy to purchase. Fast.	App is available for download.	Flow of service clearly described in app and website.	All digital materials clearly accessible.	Community management and access clearly accessible.	Provide access to newsletter and means to stay in touch.
Line of visibility								
Back-end	Outreach campaigns and partners established.	All digital service components, analogue components.	Agreements with seed vendors and others set up and running, including discounts.	Functioning software, bug free and with fast response times.	Clear service proposal in place in case of need during service use.	Functioning software, all quizzes ready.	100% community management support. Functioning software.	Support to nurture post-service relationship and futures plans.
Line of internal interaction								
Support processes	User support.	Tech support.	Pre and post-sales support.	Tech and content support.	Tech and content support.	Tech and content support	Community management and tech support.	Customer relations.

Onboarding journey

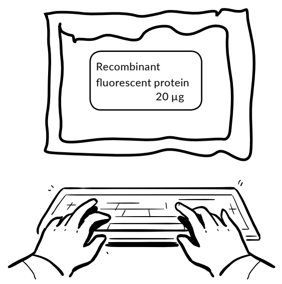
1. Paul reads about the neuleaf service in the Times Educational Supplement newsletter. Forwards the mail to Siobhain to give her ideas for science club.

2. Siobhain really likes what she's reading, especially the plant growing bits, so she goes to neuleaf mobile site to have a look.

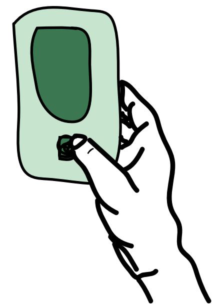


3. On the mobile site, she sees that it's easy to get the seeds and how simple and cheap it is to start learning PMF with neuleaf.

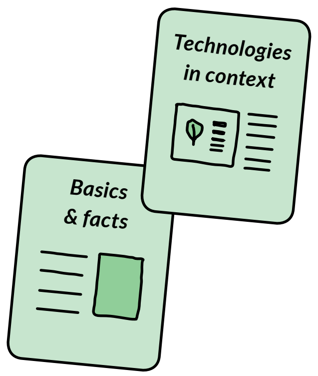
4. She examines the curriculum, it looks like neuleaf would fit very well if they start after Genetics, as the students would have covered some of the topics addressed.



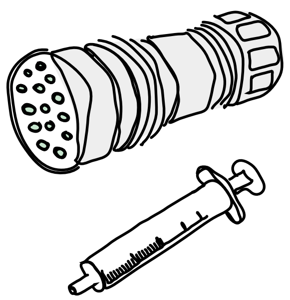
5. She will buy the seeds online from the project sponsor, Leaf Systems, and make sure she has everything else to start sowing.



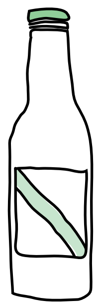
6. She starts using the app to gain subject knowledge. She will encourage students to also use it to quizz themselves. It also has excellent videos-tutorials!



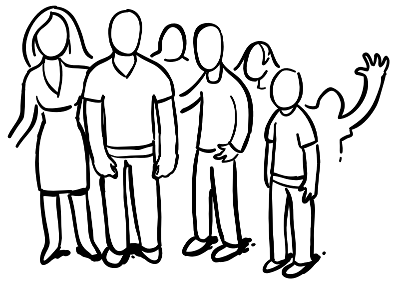
7. She can print out all the discussion cards from their website for use in science club, no need to buy expensive materials. They're great to create group talks.



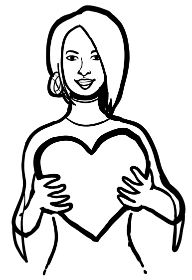
8. She must remember to check that they have hand-held UV lamps at the school, as well as syringes for the time when they will infiltrate the plants.



9. If the genetically modified fluorescent proteins are expensive, she will run the visualization experiment with tonic water. Quinine glows under UV light.



10. Awesome! On the web you can upload experiments and share experiences with other users of neuleaf all over the world. There is a wealth of tips and tricks too!



11. It's going to be a great year in science club. Really excited to have come across neuleaf. I wish there were more like it!

12. neuleaf has solved a need for this teacher. It also solves the need to showcase innovation, teacher's ongoing learning and building a pipeline of new scientists.

Reflection & conclusions

The topic of plant molecular farming was completely new to the researcher. However, the learnings achieved through research soon made its potential for global disruption of health systems visible.

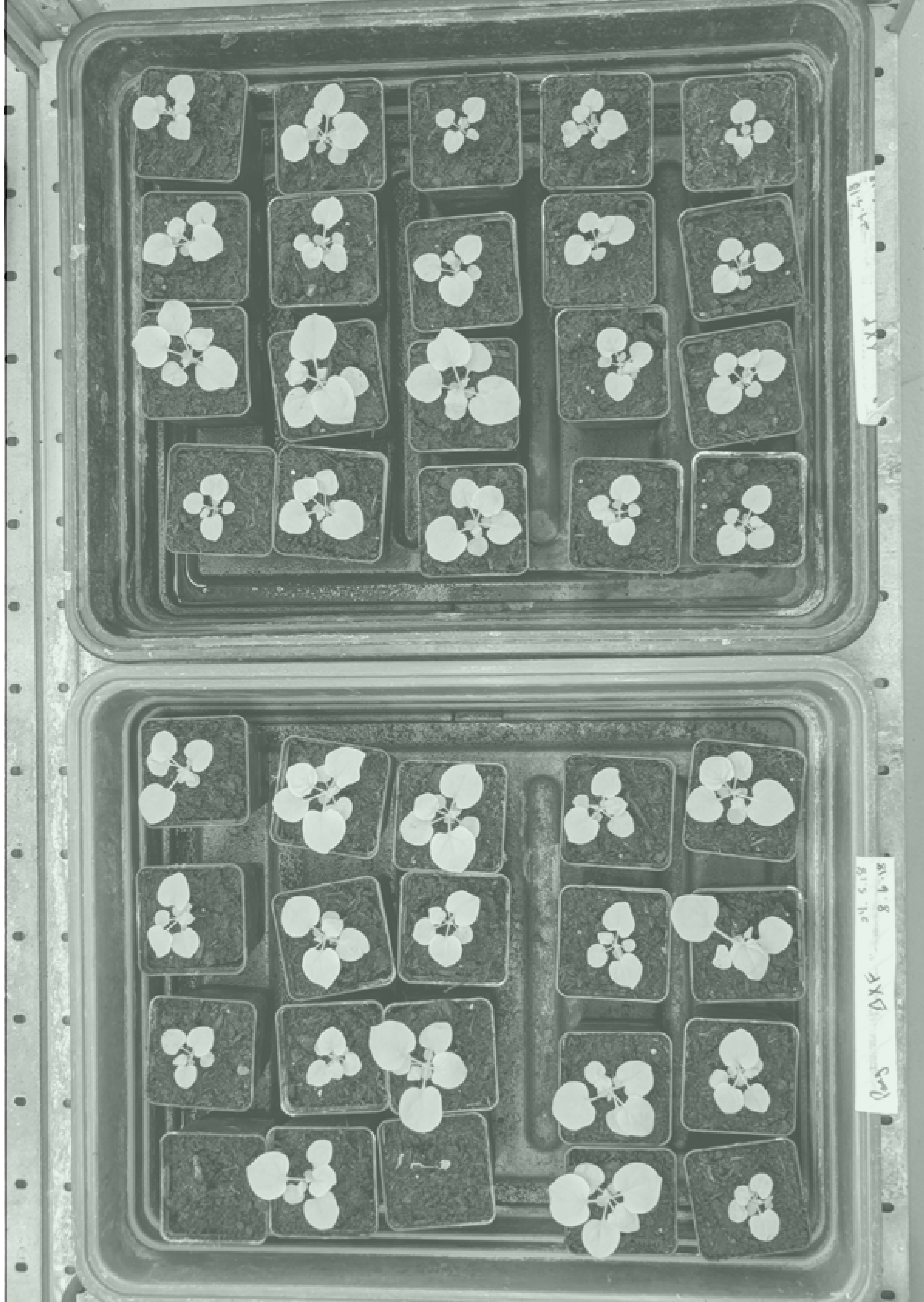
Competitiveness: Countries can take active leadership in designing services for the betterment of the global community, while focusing on nurturing scientific innovation as part of their competitive strategy. Education has a strategic role in this area, yet seems to often lag behind. neuleaf has the mission to fill this innovation gap, by putting a potentially disruptive biotechnology in the minds of future scientists. With teachers as core users, it aims to build a sense of discovery, raising their enthusiasm and subject knowledge, which research shows greatly impacts student achievement.

Global impact: The researcher understands design for sustainability as an ecosystem issue, touching the life of people on a global scale.

Plant molecular farming has a strong position in sustainability and equality. The concept of manufacturing affordable medicines in emerging markets and creating economic opportunities for the local communities is specially motivating.

Working on a global, complex scientific topic has provided the researcher a powerful test-bed to explore with no preconceptions, tackle a new discipline from scratch and design a solution that seeks innovation in education and global health.

Beyond plant molecules: The system, as a framework, can be extrapolated to other innovative technologies, not only in the life sciences, in order to inspire 'next generations' in various fields.



Bibliography

Bibliography

'2016 KS2 Science Sampling Framework' (no date). Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/439614/2016_KS2_Sciencesampling_framework_PDFA.pdf (Accessed: 26 September 2018).

Associated Press (no date) Tobacco Plants May Help Fight Ebola, Flu & More. Available at: https://www.youtube.com/watch?v=Kewa7u8S7go (Accessed: 3 May 2018).

Auger Loizeau (no date a). Available at: http://www.auger-loizeau.com/ (Accessed: 20 June 2018).

'Auger Loizeau' (no date b). Available at: http://www.auger-loizeau.com/ (Accessed: 20 June 2018).

B VICKERY, H. (1946) 'The contribution of the analytical chemist to protein chemistry.', Annals of the New York Academy of Sciences, 47, pp. 63–94.

BBC News (2014) 'National curriculum changes', 1 September. Available at: https://www.bbc.co.uk/news/education-28989714 (Accessed: 13 June 2018).

'BBSRCs strategic plan / Society of Biology response' (no date). Available at: https://www.rsb.org.uk/images/sampledata/BBSRCs_strategic_plan_-_Society_of_Biology_response_FINAL.pdf (Accessed: 20 June 2018).

Biological Transformation (no date) Fraunhofer-Gesellschaft. Available at: https://www.fraunhofer.de/en/research/current-research/biological-transformation.html (Accessed: 26 June 2018).

Biomass - Fraunhofer IME (no date) Fraunhofer Institute for Molecular Biology and Applied Ecology IME. Available at: https://www.ime.fraunhofer.de/en/Research_Divisions/business_fields_MB/Plant_biotechnology/Projects/Biomass.html (Accessed: 22 June 2018).

'Biosciences SR' (no date). Available at: http://www.etl.tla.ed.ac.uk/docs/BiosciencesSR.pdf (Accessed: 24 September 2018).

Biotechnology and Biological Sciences Research Council (BBSRC) (no date). Available at: https://bbsrc.ukri.org/ (Accessed: 13 June 2018).

Bolt Threads – Microsilk (no date). Available at: http://boltthreads.com/technology/microsilk/ (Accessed: 30 October 2018).

Borchelt, R. (2008) 'Engaging the scientific community with the public - communication as a dialogue, not a lecture', Science Progress, Spring-Summer, pp. 78–81.

'Brexit and GMO Farming in Great Britain' (no date). Available at: http://www.gmo-safety.eu/brexit-and-gmo-farming-in-great-britain/ (Accessed: 14 June 2018).

Brody, J. E. (2018) 'Are G.M.O. Foods Safe?', The New York Times, 9 June. Available at: https://www.nytimes.com/2018/04/23/well/eat/are-gmo-foods-safe.html (Accessed: 14 June 2018).

Calvert, J. (2012) 'Ownership and sharing in synthetic biology:: a "diverse ecology" of the open and the proprietary?', BioSocieties, 7(2), pp. 169–187. doi: 10.1057/biosoc.2012.3.

Cambridge International AS and A Level Biology (9700) (no date). Available at: http://www.cambridgeinternational.org/programmes-and-qualifications/cambridge-international-as-and-a-level-biology-9700/ (Accessed: 14 June 2018).

Canada, H. and Canada, H. (2014) General Questions and Answers on Plant Molecular Farming (PMF), aem. Available at: https://www.canada.ca/en/health-canada/services/drugs-health-products/biologics-radiopharmaceuticals-genetic-therapies/applications-submissions/guidance-documents/general-questions-answers-plant-molecular.html (Accessed: 8 August 2018).

'Could protein-powered "biocomputers" be the future of IT?' (2016) Information Age, 29 February. Available at: http://www.information-age.com/could-protein-powered-biocomputers-be-future-it-123461014/ (Accessed: 20 June 2018).

Crest Awards (no date) CREST Awards. Available at: https://www.crestawards.org/ (Accessed: 24 September 2018).

Digital Science Launches GRID, a New, Global, Open Database Offering Unique Information on Research Organisations (2015) Digital Science. Available at: https://www.digital-science.com/blog/news/digital-science-launches-grid-a-new-global-open-database-offering-unique-information-on-research-organisations/ (Accessed: 16 June 2018).

DIY Bacterial Gene Engineering CRISPR Kit (no date) The ODIN. Available at: http://www.the-odin.com/diy-crispr-kit/ (Accessed: 20 June 2018).

Ebola Drug ZMapp's Ready for African Testing (no date) NBC News. Available at: https://www.nbcnews.com/storyline/ebola-virus-outbreak/ebola-drug-zmapps-ready-african-testing-n305981 (Accessed: 14 June 2018).

Europe's most powerful education network (no date) Emerge Education. Available at: https://emerge.education/ (Accessed: 30 October 2018).

FastStats Centre for Disease Control (2017). Available at: https://www.cdc.gov/nchs/fastats/infectious-disease.htm (Accessed: 14 June 2018).

Fighting Ebola with tobacco plants bioengineered to produce spider silk (2018) Genetic Literacy Project. Available at: https://geneticliteracyproject.org/2018/03/29/fighting-ebola-with-tobacco-plants-bioengineered-to-produce-spider-silk/ (Accessed: 14 June 2018).

Fischer, R. and Schillberg, S. (2006) Molecular Farming: Plant-made Pharmaceuticals and Technical Proteins. John Wiley & Sons.

Foundation, R. P. (no date) Raspberry Pi — Teach, Learn, and Make with Raspberry Pi, Raspberry Pi. Available at: https://www.raspberrypi.org (Accessed: 21 October 2018).

Fraunhofer-Gesellschaft website (no date). Available at: https://www.fraunhofer.de/en.html (Accessed: 22 June 2018).

Freethink (no date) Could Growing Vaccines in Plants Save Lives? Available at: https://www.youtube.com/watch?v=kkAb2WB17l4 (Accessed: 16 June 2018).

Funk, C. and Kennedy, B. (2016) 'The New Food Fights: U.S. Public Divides Over Food Science', 1 December. Available at: http://www.pewinternet.org/2016/12/01/the-new-food-fights/ (Accessed: 30 April 2018).

GCE subject-level conditions and requirements for science (no date) GOV.UK. Available at: https://www.gov.uk/government/publications/gce-subject-level-conditions-and-requirements-for-science (Accessed: 26 September 2018).

Gelvin, S. B. (2003) 'Agrobacterium-Mediated Plant Transformation: the Biology behind the "Gene-Jockeying" Tool', Microbiology and Molecular Biology Reviews, 67(1), pp. 16–37. doi: 10.1128/MMBR.67.1.16-37.2003.

Genetic technologies (no date). Available at: https://royalsociety.org/topics-policy/projects/genetic-technologies/ (Accessed: 13 June 2018).

Giselle Gaas (19:56:29 UTC) 'Molecular pharming'. Available at: https://www.slideshare.net/watashiwasanelle/molecular-pharming (Accessed: 13 June 2018).

GMO: Harmful Effects (no date). Available at: http://enhs.umn.edu/current/5103/gm/harmful.html (Accessed: 14 June 2018).

'GMO SAFETY – All you want to know about GMO food and the health risks of genetically modified foods' (no date). Available at: http://www.gmo-safety.eu/ (Accessed: 13 June 2018).

'Good practical science report' (no date). Available at: http://www.gatsby.org.uk/uploads/education/reports/pdf/good-practical-science-report.pdf (Accessed: 11 October 2018).

Goyal, N. and Fussell, S. R. (2015) 'Designing for Collaborative Sensemaking: Leveraging Human Cognition For Complex Tasks', arXiv:1511.05737 [cs]. Available at: http://arxiv.org/abs/1511.05737 (Accessed: 8 May 2018).

H2020:-BB-2016-2017 Building the pipeline for commercial demonstration of Plant Molecular Factories (Pharma-Factory) (2016). London.

Hefferon, K. L. (2017) Biopharmaceuticals in plants. Towards the next century of medicine. Boca Raton, FL: CRC Press Taylor & Francis Group.

Henley, J. (2017) 'Brexit is hindering research collaboration, say EU universities', The Guardian, 25 October. Available at: https://www.theguardian.com/politics/2017/oct/25/brexit-is-hindering-research-collaboration-say-eu-universities (Accessed: 31 October 2018).

High Value Chemicals from Plants (no date). Available at: https://hvcfp.net/ (Accessed: 11 June 2018).

HIV vaccine elicits antibodies in animals that neutralize dozens of HIV strains: NIH study results represent major advance for structure-based HIV vaccine design (no date) ScienceDaily. Available at: https://www.sciencedaily.com/releases/2018/06/180604125008.htm (Accessed: 14 June 2018).

Hoja, U. and Sonnewald, U. (2012) 'Molecular Farming in Plants', in John Wiley & Sons, Ltd (ed.) eLS. Chichester, UK: John Wiley & Sons, Ltd. doi: 10.1002/9780470015902.a0003365.pub2.

Horn, M., Woodard, S. and Howard, J. (2004) Plant molecular farming: Systems and products. doi: 10.1007/s00299-004-0767-1.

How to grow an Ebola vaccine with a tobacco plant (2015) PBS NewsHour. Available at: https://www.pbs.org/newshour/show/how-to-grow-an-ebola-vaccine-with-a-tobacco-plant (Accessed: 16 June 2018).

https://royalsociety.org/topics-policy/projects/gm-plants/how-does-gm-differ-from-conventional-plant-breeding/ (no date). Available at: https://royalsociety.org/topics-policy/projects/gm-plants/how-does-gm-differ-from-conventional-plant-breeding/ (Accessed: 9 October 2018).

Human Tissue Act 2004 | Human Tissue Authority (no date). Available at: https://www.hta.gov.uk/policies/human-tissue-act-2004 (Accessed: 22 June 2018).

Hunt, C. and Premathilake, R. (no date) Prehistoric people started to spread domesticated bananas across the world 6,000 years ago, The Conversation. Available at: http://theconversation.com/prehistoric-people-started-to-spread-domesticated-bananas-across-the-world-6-000-years-ago-99547 (Accessed: 13 July 2018).

IBMP – Institut de biologie moléculaire des plantes (no date). Available at: http://www.ibmp.cnrs.fr/ibmp/ (Accessed: 22 June 2018).

Improving GCSE and A level standard setting: a world of learning (no date) GOV.UK. Available at: https://www.gov.uk/government/publications/improving-gcse-and-a-level-standard-setting-a-world-of-learning (Accessed: 26 September 2018).

'International A Level Biology Spec' (no date). Available at: https://qualifications.pearson.com/content/dam/pdf/International%20Advanced%20Level/Biology/2018/Specification-and-Sample-Assessment/International-A-Level-Biology-Spec.pdf (Accessed: 1 October 2018).

Invitation to comment - strategy for UK biotechnology and biological sciences (no date). Available at: https://bbsrc.ukri.org/news/policy/2017/170831-n-invitation-to-comment-strategy-uk-biotechnology-biological-sciences/ (Accessed: 13 June 2018).

J Villafranca, J. (2018) 'Current research in protein chemistry : techniques, structure, and function / published under the auspices of the protein society edited by Joseph J. Villafranca', SERBIULA (sistema Librum 2.0).

Janson, J.-C. (2018) 'The Development of Protein Chemistry Methods in Sweden'.

John Innes Centre (no date) Innes Lecture 2018. Available at: https://www.youtube.com/watch?time_continue=37&v=LZwh1vXHEZc (Accessed: 21 June 2018).

Julian Ma: I'm growing antibodies in tobacco plants to help prevent HIV | Science | The Guardian (no date). Available at: https://www.theguardian.com/technology/2011/aug/14/julian-ma-pharming-tobacco-hiv (Accessed: 13 June 2018).

K-C, M. J. et al. (2013) 'Realising the value of plant molecular pharming to benefit the poor in developing countries and emerging economies', Plant Biotechnology Journal, 11(9), pp. 1029–1033. doi: 10.1111/pbi.12127.

'Kerridge Designing Debate.pdf' (no date). Available at: https://research.gold.ac.uk/12694/1/Kerridge-Designing-Debate.pdf (Accessed: 12 June 2018).

Kidman, G. (no date) 'BIOTECHNOLOGY EDUCATION: TOPICS OF INTEREST TO STUDENTS AND TEACHERS', p. 16.

King's College London - Science Capital (no date). Available at: https://www.kcl.ac.uk/sspp/departments/education/research/research-centres/cppr/research/currentpro/enterprising-science/01science-capital.aspx (Accessed: 26 October 2018).

King's College London - The Enterprising Science Project (no date). Available at: https://www.kcl.ac.uk/sspp/departments/education/research/Research-Centres/cppr/Research/currentpro/Enterprising-Science/index.aspx (Accessed: 26 October 2018).

Kippin, H. (2013) Better cross-sector collaboration is about people not just structures. Available at: http://www.theguardian.com/public-leaders-network/2013/nov/21/cross-sector-collaboration-people-structures (Accessed: 9 March 2018).

Koskinen, I. et al. (2011) Design Research Through Practice: From the Lab, Field, and Showroom. Waltham, MA: Elsevier.

'Laboratory Environment' (no date b). Available at: http://www.haseloff-lab.org/resources/SynBio_reports/Practical-skills-molecular-biologists-guide.pdf (Accessed: 22 June 2018).

Labstep | How it works - Discover, create and share scientific protocols (no date). Available at: https://www.labstep.com/how-it-works (Accessed: 20 September 2018).

Living with HIV at 22 - one brave young woman's story (2016) Marie Claire. Available at: http://www.marieclaire.co.uk/reports/im-22-and-hiv-positive-but-determined-to-live-my-life-to-the-full-448961 (Accessed: 14 June 2018).

Ltd, D. (no date) Engaging Teachers: NFER Analysis of Teacher Retention, NFER. Available at: https://www.nfer.ac.uk/engaging-teachers-nfer-analysis-of-teacher-retention (Accessed: 10 October 2018).

Ma, J. K.-C., Drake, P. M. W. and Christou, P. (2003) 'Genetic modification: The production of recombinant pharmaceutical proteins in plants', Nature Reviews Genetics, 4(10), pp. 794–805. doi: 10.1038/nrg1177.

Marres, N. (2015) Material Participation. Basingstoke: Palgrave Macmillan.

Martin, B. and Hanington, B. (2012) Universal Methods of Design. Beverly: Rockport Publishers.

Mensvoort.com – Home of artist, technologist and philosopher Koert van Mensvoort – work (no date). Available at: https://www.mensvoort.com/work/ (Accessed: 20 June 2018).

'Modern Meadow / About' (no date) Modern Meadow. Available at: http://www.modernmeadow.com/about-us/ (Accessed: 30 October 2018).

'Molecular Farming – How Plants Produce the Vaccines of Tomorrow • theGIST' (2011) theGIST, 17 March. Available at: https://the-gist.org/2011/03/molecular-farming-%e2%80%93-how-plants-produce-the-vaccines-of-tomorrow/ (Accessed: 13 June 2018).

Molecular Farming - Transgenic non food GM / GMO plant pharming & biopharming (no date). Available at: http://www.molecularfarming.com/ (Accessed: 14 June 2018).

National Education Union (NEU) | NUT - The Teachers' Union (no date). Available at: https://www.teachers.org.uk/ (Accessed: 13 June 2018).

Neslen, A. (2018) 'Gene-edited plants and animals are GM foods, EU court rules', The Guardian, 25 July. Available at: https://www.theguardian.com/environment/2018/jul/25/gene-editing-is-gm-europes-highest-court-rules (Accessed: 27 September 2018).

Nirmal Kumar (04:10:31 UTC) 'Molecular farming'. Available at: https://www.slideshare.net/urwithnirmal/molecular-farming?next_slideshow=1 (Accessed: 13 June 2018).

Nutraceutical Business Review (no date). Available at: https://www.nutraceuticalbusinessreview.com/ (Accessed: 26 May 2018).

O'Carroll, L. (2014) 'Ebola survivor Ian Crozier: "Everyone thought he was going to die"', The Guardian, 8 December. Available at: http://www.theguardian.com/world/2014/dec/08/ebola-survivor-ian-crozier-doctor-antibodies-will-pooley (Accessed: 14 June 2018).

Officina Corpuscoli - Trans-Disciplinary Design & Research (no date) Officina Corpuscoli. Available at: http://www.corpuscoli.com/ (Accessed: 22 June 2018).

'One of the World's Most Hated Plants Is Becoming a Public Health Rock Star' (2018) leapsmag, 1 June. Available at: https://leapsmag.com/one-of-the-worlds-most-hated-plants-is-becoming-a-public-health-rock-star/ (Accessed: 4 July 2018).

Overview of Protein Expression Systems - UK (no date). Available at: https://www.thermofisher.com/uk/en/home/life-science/protein-biology/protein-biology-learning-center/protein-biology-resource-library/pierce-protein-methods/overview-protein-expression-systems.html (Accessed: 14 June 2018).

Pavliscak, P. (2017) Guidelines for how to design for emotions, O'Reilly Media. Available at: https://www.oreilly.com/ideas/guidelines-for-how-to-design-for-emotions (Accessed: 8 May 2018).

Pharma-Factory - Business & Management, & Science - UAL (no date). Available at: http://www.arts.ac.uk/research/current-research/ual-research-projects/business--management--science/pharma-factory/ (Accessed: 3 May 2018).

'Pharming (genetics)' (2018) Wikipedia. Available at: https://en.wikipedia.org/w/index.php?title=Pharming_(genetics)&oldid=836274344 (Accessed: 14 June 2018).

'Plant Molecular Farming. Opportunities and Challenges' (no date), p. 148.

Plant Molecular Pharming for the Treatment of Chronic and Infectious Diseases | Annual Review of Plant Biology (no date). Available at: https://www.annualreviews.org/doi/full/10.1146/annurev-arplant-050213-035850 (Accessed: 26 September 2018).

Plant-made pharmaceuticals: an ongoing debate (no date). Available at: http://www.agwest.sk.ca/events/details.html (Accessed: 3 May 2018).

Protein Expression Kits and Reagents (no date). Available at: https://www.promega.co.uk/products/protein-expression/protein-expression-kits-and-reagents/ (Accessed: 14 June 2018).

ReasonTV (no date) DIY Biohackers Are Editing Genes in Garages and Kitchens. Available at: https://www.youtube.com/watch?v=s5s1uqI5HmY (Accessed: 8 August 2018).

Rech, E. et al. (2014) 'Recombinant proteins in plants', BMC Proceedings, 8(Suppl 4), p. O1. doi: 10.1186/1753-6561-8-S4-O1.

Recombinant Protein Definition | Recombinant-Protein.com (2016). Available at: https://www.biologicscorp.com/blog/recombinant-protein-definition/ (Accessed: 29 April 2018).

Regalado, A. (no date) Doing Biotech in My Bedroom, MIT Technology Review. Available at: https://www.technologyreview.com/s/426885/doing-biotech-in-my-bedroom/ (Accessed: 10 September 2018).

Sands, P. and Galizzi, P. (eds) (2006) 'Directive 2001/18/EC of the European Parliament and of the Council of 12 March 2001 on the deliberate release into the environment of genetically modified organisms and repealing Council Directive 90/220/EEC (OJ L 106 17.04.2001 p. 1)', in Documents in European Community Environmental Law. 2nd edn. Cambridge: Cambridge University Press, pp. 787–836. doi: 10.1017/CBO9780511610851.051.

Savage, M. and editor, O. policy (2017) 'Want your child to be an engineer? Give them a falcon or go stargazing', The Observer, 21 October. Available at: https://www.theguardian.com/lifeandstyle/2017/oct/21/hobbies-key-to-childrens-interest-in-maths-science-engineering (Accessed: 31 October 2018).

Schematic description of transient expression using pEAQ vectors.... (no date) ResearchGate. Available at: https://www.researchgate.net/figure/Schematic-description-of-transient-expression-using-pEAQ-vectors-Courtesy-of-Peyret-et_fig1_290550937 (Accessed: 13 June 2018).

Sciencesowhat (no date) Future jobs: Pharmer. Available at: https://www.youtube.com/watch?v=RBQZBWJgRTo (Accessed: 5 September 2018).

Scientists urge new EU rules on gene editing crops | Science|Business (no date). Available at: https://sciencebusiness.net/news/scientists-urge-new-eu-rules-gene-editing-crops (Accessed: 24 September 2018).

Shomu's Biology (no date a) Genetic engineering in plants. Available at: https://www.youtube.com/watch?time_continue=196&v=eMdWguzXDgY (Accessed: 4 July 2018).

Shomu's Biology (no date b) Recombinant DNA technology lecture | basics of recombinant DNA. Available at: https://www.youtube.com/watch?time_continue=1&v=3Z5j0xl8knY (Accessed: 4 July 2018).

Small, J. (2018) 'What's Wrong with Blue Apron?', Chris Newman, 7 June. Available at: https://medium.com/@cnative100/whats-wrong-with-blue-apron-60bd26f31676 (Accessed: 22 June 2018).

Society, B. (2017) 'Scientific Scissors – The first cut', Biochemical Society, 5 April. Available at: https://biochemicalsociety.wordpress.com/2017/04/05/scientific-scissors-the-first-cut/ (Accessed: 22 June 2018).

Speculative design: A design niche or a new tool for government innovation? | Nesta (no date). Available at: http://www.nesta.org.uk/blog/speculative-design-design-niche-or-new-tool-government-innovation (Accessed: 8 May 2018).

STEM Insight | STEM (no date). Available at: https://www.stem.org.uk/stem-insight (Accessed: 24 September 2018).

Stephen Bennett - Foresight (no date). Available at: https://foresightprojects.blog.gov.uk/author/stephenbennett/ (Accessed: 20 June 2018).

Stickdorn, M. et al. (2018) This is Service Design Doing. Sebastopol, CA: O'Reilly.

Stickdorn, M. and Schneider, J. (2011) This is Service Design Thinking. Amsterdam: BIS Publishers.

'Strategy for UK biotechnology and biological sciences/invitation to comment' (no date), p.5.

Talking about design for relationships at ServDes 2018 (no date) Liveworkstudio. Available at: https://www.liveworkstudio.com/blog/talking-about-design-for-relationships-at-servdes-2018/ (Accessed: 27 July 2018).

Teachers' standards (no date) GOV.UK. Available at: https://www.gov.uk/government/publications/teachers-standards (Accessed: 25 September 2018).

TEDx Talks (no date a) How to improve global health with a lethal killer | Julian Ma | TEDxWandsworth. Available at: https://www.youtube.com/watch?v=V2DgJBx3cyA (Accessed: 1 May 2018).

TEDx Talks (no date b) You are what you think you eat | Lauri Reuter | TEDxHelsinkiUniversity. Available at: https://www.youtube.com/watch?v=KJKi5SjCOBM (Accessed: 27 July 2018).

Terreform ONE (Open Network Ecology) New York City (no date). Available at: http://www.terreform.org/ (Accessed: 6 August 2018).

The scary truth behind fear of GMOs (2018). Available at: https://www.biofortified.org/2018/02/scary-truth-gmo-fear/ (Accessed: 30 April 2018).

Tickle, L. (2010) 'Fighting HIV in developing countries – with tobacco', The Guardian, 2 February. Available at: http://www.theguardian.com/education/2010/feb/02/tobacco-hiv-research-notes (Accessed: 14 June 2018).

'Transferable Skills Mapping for Biology' (no date). Available at: https://qualifications.pearson.com/content/dam/pdf/International%20Advanced%20Level/Biology/2018/Teaching-and-Learning-Materials/Transferable-Skills-Mapping-for-Biology.pdf (Accessed: 3 October 2018).

Transgenic plants - Latest research and news | Nature (no date). Available at: https://www.nature.com/subjects/transgenic-plants (Accessed: 13 June 2018).

Tschofen, M. et al. (2016) 'Plant Molecular Farming: Much More than Medicines', Annual Review of Analytical Chemistry, 9(1), pp. 271–294. doi: 10.1146/annurev-anchem-071015-041706.

UCL (2018) Science Capital Research, Institute of Education. Available at: https://www.ucl.ac.uk/ioe/departments-and-centres/departments/education-practice-and-society/science-capital-research-0 (Accessed: 31 October 2018).

Urban And Rural Activists Are Transforming Women's Lives - It Is Something I See Proof Of Every Day (2018) HuffPost UK. Available at: http://www.huffingtonpost.co.uk/entry/urban-and-rural-activists-are-transforming-womens-lives-it-is-something-i-see-proof-of-every-day_uk_5aa013b5e4b0e9381c1493df (Accessed: 14 June 2018).

VTT - Pharma Factory (no date). Available at: https://pharmafactory.org/VTT (Accessed: 5 July 2018).

Welcome to the International Society of Plant Molecular Farming! | The International Society for Plant Molecular Farming (no date). Available at: http://societyformolecularfarming.org/ (Accessed: 12 June 2018).

What are genetic technologies? (no date). Available at: https://royalsociety.org/topics-policy/projects/genetic-technologies/what-are-genetic-technologies/ (Accessed: 13 June 2018).

What does good technical support look like in a science department? | STEM (no date). Available at: https://www.stem.org.uk/news-and-views/opinions/what-does-good-technical-support-look-science-department (Accessed: 11 October 2018).

WHO | Infectious diseases (no date) WHO. Available at: http://www.who.int/topics/infectious_diseases/en/ (Accessed: 14 June 2018).

Why An Imperfect HIV Vaccine Could Be Better Than None At All (no date) NPR.org. Available at: https://www.npr.org/sections/health-shots/2018/03/21/593438652/why-an-imperfect-hiv-vaccine-could-be-better-than-none-at-all (Accessed: 14 June 2018).

Why Are We So Afraid of GMOs? (2017). Available at: https://www.medicalbag.com/the-fit-md/why-are-we-so-afraid-of-gmos/article/653830/ (Accessed: 30 April 2018).

Why Story Matters (SSIR) (no date). Available at: https://ssir.org/articles/entry/why_story_matters (Accessed: 12 July 2018).

Why We Scientists Do Instagram (no date) FromTheLabBench. Available at: http://www.fromthelabbench.com/from-the-lab-bench-science-blog/2018/3/25/why-we-scientists-do-instagram (Accessed: 21 June 2018).

www-core (webteam) (no date) Wellcome Sanger Institute sequences reference genomes of 3,000 dangerous bacteria. Available at: https://www.sanger.ac.uk/news/view/wellcome-sanger-institute-sequences-reference-genomes-3000-dangerous-bacteria (Accessed: 3 October 2018).

Yao, J. et al. (2015) 'Plants as Factories for Human Pharmaceuticals: Applications and Challenges', International Journal of Molecular Sciences, 16(12), pp. 28549–28565. doi: 10.3390/ijms161226122.

Appendices

St. George's University of London

Pascal Drake

Initial talks with Pascal Drake, Honorable Lecturer at the Institute for Infection and Immunity, revealed the concerns around science funding post-Brexit. An Emergency Brexit Committee has been set up in St. George's. In the lab, there is acute awareness of the risks, as they are funded by the European Commission and a single foreign donor. Issues around interest and accessibility were also addressed.

In spite of its potential to transform how we treat and manage infectious disease globally, plant molecular farming is still niche.

PMF would benefit from building engagement and raising awareness in order to recruit more researchers and accelerate progress.

Associations to genetically modified plants in the food industry and the anti-GMO sentiment among the public could have a negative impact on its development. During the summer a landmark case was approved by the European Court of Justice on gene edited plants and animals. It declares that gene-edited plants and animals are GM foods, and means they will be regulated under the same rules as genetically modified organisms ('Gene-edited plants and animals are GM foods, EU court rules', The Guardian, 07/2018). Another critical insight from discussions with Dr Drake was around the need of 'more diversity in molecular farming'. There is a trend towards consolidation on mammalian cell types, grown in expensive bio-fermenters, which make for costly drugs ('Plant Molecular farming for the Treatment of Chronic and Infectious Diseases', Annual Review of Plant Biology, 2014).

'Using different platforms offers overlapping and complimentary benefits'.

The notion of diversity towards plant platforms, as well as protein expression systems, is a model worthy of exploration, most notably when the goal is lowering costs for those who are in greater need of inexpensive treatments.

Insights and concerns, raised by Pascal impacted the research direction, as it seems that research is threatened by funding shortages due to Brexit, but also by the EU position on gene editing, which negatively impacts the speed and sustainability of cutting-edge technologies (E.g. Crispr).

Interviews took place alongside lab work, including conducting polymerase chain reaction, restriction digest, vector preparation or infiltration of Nicotiana benthamiana.

VTT, Finland

Anneli Ritala

Anneli Ritala is a Principal Researcher in plant Biotechnology at VTT, Finland's largest research organization. She discussed extensively her views on the lack of understanding of plant biotechnologies in general by the general public. Issues around open research and sharing knowledge and experiments early on were explored in the interview. While seen as 'interesting', probably not ideal 'based on how things work'. Often research is done for private organizations with strong Non-Disclosure Agreements in place, which would make a more open research approach undesirable. 'I could follow and take advantage of the knowledge of others, but thinking of my employer, I would not be able to contribute, as my work is owned by them'.

With regards to technologies to express proteins, Anneli explains that 'transient expression is just one tool among tools'. Young future scientists should learn it and know what can be done with it, but consider it one tool.

In the case of transient or any expression technology, when choosing one or another, many considerations come into play: the proteins' features, expected yield, how fast and how much? How often? So, there's no one right answer to this. However, in regards to transient expression, 'it is very fast, so it's a good solution if you need to produce a vaccine fast'.

In the case of microbicidal applications, as per the work Julian Ma does on HIV, it would make sense to take manufacturing closer to the point of delivery and use transient expression. Those microbicidal solutions which are needed, for example in Africa, could be developed there.

There are many diseases we could not treat today if we did not have genetically modified organisms.

In biotechnology, 'we use antibiotic resistant genes as selection markers, this might also be something that people find scary, if it would escape to nature'.

Anneli introduced the idea that the service could be targeted for teachers. Teachers should know better and make the decisions on science to raise new topics and science futures. It would be about making students more aware of the technologies and what could be their outcomes.

'The service would help fill the knowledge gap for the teachers so they can educate better'. In Finland Anneli is a Member of the Board of Biotechnology, which tries to help politicians, lawmakers and the public to understand the science better. 'We have often discussed that secondary school biology and science teachers would be a really important target'.

VTT, Finland

Lauri Reuter

Lauri Reuter leads the Disruptive Technologies practice at VTT, Finland's largest research organization. In his view it is important to 'separate the topic of PMF from GMO foods and genetically modified organisms more generally', as normally the discussion turns to food systems, which have a strong place in the publics imagination.

Lauri's view of engagement with young adults in plant bioscience depends on their level of subject knowledge. In this respect, if they would know protein expression technologies, why not work on experiments? Would transient expression be of interest to them?

What matters? plasticity (doing things), evolution (as a learning angle) and breeding (understand the compounds those plants can make as bioreactors).

In his view, it is of the essence that people understand that 'plant biology is technology', and that this could include decoupling of the soil from agriculture.

'What if we could grow plants in labs, and only the best bits of the plants?' He proposes concepts around cellular agriculture as a means to achieve decoupling between food or plants and nature, and also to explore the idea of contained environments that would lead to optimization of resources. In this respect he mentions companies like Bolt Threads (harnessing proteins found in nature to create materials and ingredients with practical and revolutionary uses) and Modern Meadow (biofabrication pioneers) to remind of the decoupling of food, plants or materials and nature.

'What we do might not survive in nature, but get us what we want working with nature'.

Biochemical Society

James Brown

James Brown, who leads engagement for the Biochemical Society, pointed to a number of resources for educators.

'Working with teachers is a good and quick way' to make an impact on students. But 'they are very short on time'.

He can relate to this with ease, as for six years he was a science teacher at a secondary school. However, in his view, 'science teachers were scientists first, so they really want to know what they're doing and stay on top of the latest trends'.

The STEM Insight program for teachers was of interest. He equally addressed attention to the Crest Awards, which have also provided ideas and inspiration. In James' view and based on his outreach experience, 'schools are starting to look at citizen science projects and collaborative research' with more interest.

James pointed to examples of student engagement such as those conducted by the Microbiology Society on Antibiotic Resistance, where students engage in lab experiments to find antibacterial compounds or the Sequencing Genomes project at the Wellcome Sanger Institute. Even the link of science and design as a concept in itself might raise teacher interest. Linking to curriculum is important and easy to do, as is making sure that resources can be picked and mixed: 'make it modular'.

Teachers undergo training, but more and more frequently it's about assessment, marking or exams and less about new content. Societies like the Royal Society of Chemistry, Royal Society of Biology and Institute of Physics run teacher training and conferences which aim to update their knowledge.

Perhaps the leader in this area is STEM Learning, who offer a lot of training events. Similarly the ASE (Association for Science Educators) has an annual conference, magazine and regular events. Conferences like this often have talks on new areas, 'for example at this year's ASE we are putting on a series of talks on new developments in biology'. TeachMeets are opportunities for teachers to get together and discuss best practice. There are also great resource sharing sites such as the TES website. CLEAPPS is a great organisation for sharing experiments and advice.

Popular sources like New Scientist magazine and online groups are also good ways for teachers to keep updated. There are a number of magazines (E.g. School Science Review, The Biologist, The Biochemist) that highlight new research. One of the most common ways to stay updated is from exam specs and text books. However, for teachers, it's hard to find time and more often than not it is driven by exam specs.

Saint John Bosco School, Battersea

Laura Foulsham & Matt Sear

Matt Sear is a NQT in Saint John Bosco College, Battersea, working with A Level and BTEC students. Laura Foulsham is the Head of Science at the same school. Interviews with them showed a marked interest in opportunities to showcase innovation. In Laura's words, and based on research conducted in King's College London by Heather King:

'Teacher subject knowledge confidence and enthusiasm are keys for student attainment and interest'.

Laura shared concern for the fact that, if teachers have graduated many years ago and they do not keep expanding their own knowledge of new biotechnologies, they might not feel confident or simply might lack awareness of these to teach them. Matt and Laura both raise concerns on the 'perceived inferiority' of BTEC curriculum and skills and capability based learning among both parents and students.

Although current BTEC curriculum is graded on an equivalence to A Levels, there is still a common misconception that BTEC is for students who 'cannot manage' exam based learning.

In Matt's view, especially in science subjects, skills and experiment based learning is not only excellent but frequently superior in learning outcomes.

He misses a focus on 'developing scientific skills by experimentation, problem solving and analysis, which is often lost in favor of exam-focused education'. He favours engagement models such as Science Live at the Natural History Museum and various forms of role-play and experiment based engagement to develop student interest.

With regards to BTEC (the more applied science and investigative learning approach eligible to students in this cohort), Laura explains, 'it is still seen as inferior because it has a lower entry barrier', and yet 'it has been fully rewritten and is by no means easier than A Levels'. Perhaps the main difference is, she adds, that in BTEC all three sciences are taken together.

They are enthusiastic about the value of 'personalization and localization' to teach science, and more practical and problem-solving learning.

Matt supports the rise of the 'me scientist', teaching students science topics in everyday contexts and using everyday language. In his view, this builds engagement and accessibility. He ties this into the concept of 'science capital' developed by Heather King of King's College London.

With regards to daily life, both teachers mention time as a key constraint, for themselves as well as for students. Laura explains that, as Head of Science, she has 27 hours a week of teaching, where everyone else has 29. This, given the large amounts of marking, reporting and administrative work being done by teachers, means that 'we're in at 7.30am and we're leaving the building at 6.00pm more or less each day'. With the tightness of their workload, it is of essence that the service does not add too much extra work and service adoption is simple. Of equal importance is the issue of cost. Schools are really strapped for funds, so if the solution requires costly equipment or investment, it will be extremely hard to secure it. In this respect, Laura advocates for a model which would, ideally, be funded by industry players in this space, or by learned societies with funds to push these forward, but not by educational companies such as Pearson.

Other key topics addressed have been lack of funding for experiments, which is a big issue in schools. Also, technicians are poorly paid and often the profession does not attract many scientists, making them have to rely on the knowledge of a non-scientist or just goodwill.

Pearson Education

Peter Melbye

Peter Melbye is VP Enterprise Architecture, Core & Growth at Pearson Education. He is also chair of the progressive Dania School in North London, a primary education institution inspired by Danish and Swedish early years educational models.

Peter believes in the exploration of topics of the student's interest to shape the curriculum, something they are experimenting with in the Dania School. In his view, Pearson Education is a poor choice for service delivery, since they are a large and conservative educational provider who will focus on tried and tested themes, rather than present in their textbooks innovative or niche technologies.

'Conservatism is at play when putting science texts together for schools; general scientific consensus has to be there before it goes into educational materials'.

The core challenge for engaging with teachers, and also students, is time. There is a huge shortage of it for both groups.

In this respect, he asks the question: where is the opportunity to speak to that demographic? In his view, in extracurricular activities.

He suggests focusing on 'Science Clubs', 'Theme Weeks', project oriented work and 'Speaker Circuits', as well as other interactions with students outside the core delivery of the curriculum inside the classroom.

Peter suggests, as potential service operators, 'more progressive educational organizations and companies'. He mentions Emerge Education, an ecosystem nurturing innovative start-ups in the education sector.

In his view, there could be interest and opportunities to develop this concept under their umbrella. Despite constraints in established educational sector companies, he believes there are opportunities to develop the service in the school context.

While tying into the curriculum is nice, it is not mandatory in his view. However, age and subject knowledge appropriateness is the key, as well as a model to engage teachers and students that is easy and entertaining, especially taking their time constraints into account.

The Royal Collection Trust

Jemima Rellie

Jemima Rellie, Director of Content and Audiences at Royal Collection Trust, shared what engagement strategies work best for cultural institutions. Searching for ideas to extrapolate to the research area, as well engagement models for young adults, her work in the cultural sector appeared relevant.

The three key goals to engage publics with culture are to increase 'access, understanding and appreciation'.

Her view is that digital natives expect to be a 'contributing part' of cultural experiences, so these may deliver 'experience and meaning' to them. Since cultural and heritage organizations do not always have the skills to drive and curate these meaningful experiences, they tend to work in strategic partnerships to achieve 'distinctiveness'. This kind of collaboration, she states rotundly, is a key principle used to extend reach and realize the 'purposefulness' younger audiences seek.

The key insights derived from this fit well into insights from science school teachers, who have stated that the rise of the 'me scientist' is a key tool for young adults to engage in science topics.

The most notable impact of this interview is the understanding that collaborations with other providers to extend service reach and impact might offer an excellent opportunity for service development.

Student's voices

Jessica Veno, Eugenie Ferrier & Clara Inés Kieschnick

Jessica Veno is postgraduate student at the London College of Communication. Over a casual conversation with her, she made remarks of interest with regards to how people make decisions about their careers:

'I did A Level Biology and loved it, but did not have a clue where biology would take me, so I moved onto something else. However, with the right guidance, I might have continued'.

On associations with genetically modified organisms, she mentioned that 'during my studies in high school, we never heard anything good about GMO foods.

Eugenie Ferrier is a third year Neurosciences student at King's College London. In her view focusing on high school students directly provides 'a too wide view of the problem, since we all develop an interest in biosciences for totally different reasons'. She reflects on issues around trying to build a 'catch all' solution to galvanize young adults into biology, considering that, in her life, the most important lead towards science came not from her family but rather from her teachers.

As such, a focus on helping teachers develop an interest and showcase practical outcomes and career opportunities in biosciences might prove more fruitful than focusing on students directly.

Clara Inés Kieschnick is about to start first year at Stanford University. She comes from a family of historians and has had limited exposure to science topics at home.

However, she is very interested in animal life and would like to study biological sciences. She is still uncertain as to what areas and if, perhaps, veterinary sciences are more in her realm of interest. For the time being, she's likely to explore and learn more 'about the real challenges of studying life sciences'.

What if you could grown your own insulin at home?

During 'Everything Happens so Much', an exhibition held at London College of Communication during London Design Festival 2018, three MA students from Service Experience and Interaction Design created an installation to probe people's reactions to the question:

What if you could grow your own insulin at home?

It is September of 2030. A kitchen counter provokes the audience into considering the possibilities of growing pharmaceutical substances at home. They can examine a number of speculative objects, which build a narrative that starts in the mid-80s. The narrative is based on the entrepreneurial experience of Arman Moridi, an Iranian molecular scientist, and presents a home space where we can grow insulin by means of plant molecular farming technologies. A number of industrial objects have been developed by the bioscience company Moridi Farma. These allow us to access technologies currently in the realm of research laboratories or biohacker communities.

In the kitchen, the BioOven 5000 can perform a Polymerase Chain Reaction (PCR), has an Incubator Shaker and includes an Electroporation function. You can also heat, grill or defrost food. A product called HomeGrown Insulin rests on the counter. It is accessible for home delivery, in a small box with simple instructions. With it, you can grow an Australian tobacco plant widely used in plant molecular farming and infiltrate it with a plasmid containing your gene of interest, in this case the insulin gene (INS). Then, within two to three weeks, you will be able to 'harvest' your insulin. Also on the counter, a September 2030 edition of Bioscience magazine weaves the story of the different speculative objects on display by means of a time line and an article.

A number of enablers make the scenario possible, such as deregulation of medicine production and the development of hybrid home-lab equipment for personal use. The product HomeGrown Insulin exists.

Medical Deregulation Act of 2020

In a time line interweaving reality and fiction, we discover how shortages of medicines, resulting from a no-deal Brexit, led the UK Government to deregulate the market for pharmaceutical products. Arman Moridi, a London-based exile of the 2019 US-Iran Crisis, provides the scientific nous and business drive to launch a business that thrives on this deregulation.

As a result, HomeGrown Insulin and the BioOven 5000 occupy their functional (and fictional) context in the kitchen. In another corner of the counter, wooden spoons, a whisk or a bowl of apples rest calmly alongside pipettes, syringes, test tubes filled with plasmids and petri dishes in which plants, currently domesticated mainly in labs, peacefully germinate.

Accessibility and new delivery models

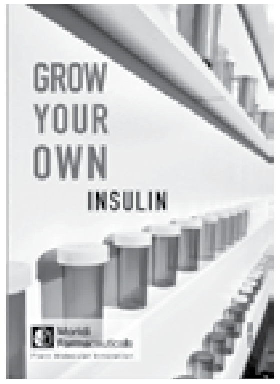
While some scientific aspects remain unsolved in 2018 (e.g. dosage or purification), the installation raises questions on the status quo in manufacture and delivery models for everyday medicines.

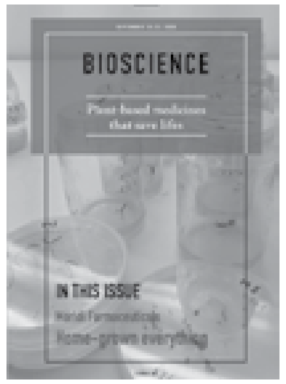
Although the use-case is based in the UK, it also raises issues around access to critical drugs in low income countries. This is relevant, as in these markets, the impact of molecular farming could increase as the platforms are standardized and optimized for clinical development. This would offer new opportunities to produce inexpensive medicines in regions that are typically excluded by current business models. Feedback from visitors to the installation was positive. A medical student, while understanding towards the limitations regarding dosage, was positive about near future applications for drugs where dosage is not a big issue. A bioscientist at the launch party suggested the use of this kind of speculation for engagement with publics in other contexts outside design schools, such as biochemistry conferences or outreach events to engage non-scientific audiences with biosciences. Overall, visitors at the installation were at once intrigued, accepting and curious about the possibilities and feasibility of the situation presented to them.

Background

The installation has been conceived and executed by Carlos Canali, Clara Llamas (MA Service Experience Design and Innovation) and Michael Sedbon (MA Interaction Design).

Diegetic objects





Bioscience magazine

Bioscience is a holo-printed consumer magazine for anyone interested in the home production of pharmaceuticals. It has a readership of 15 million in the United Kingdom and a US edition. The September 18–23, 2030 copy on display features the story of Arman Moridi, founder of Moridi Farma and a key character making the kitchen lab installation possible.

By 2030, the company product HomeGrown Insulin has topped £250 million in sales revenues. The company is ready for international expansion. The magazine also describes a timeline of events surrounding the company, accounting for external factors, such as the US-Iran Crisis of 2019 and the 2020 Act of Medical De-Regulation in the UK.

In the image, front and back cover of the magazine.

BioOven 5000

A hybrid oven developed by Moridi Farma with Xarsung Electronics. It has the functions of a microwave, as well as functions for tasks traditionally used in molecular biology labs

Polymerase Chain Reaction (aka PCR) is a common laboratory technique used to make many copies (millions or billions) of a particular region of DNA. This is achieved in a series of temperature changes. It is routinely used in DNA cloning, medical diagnostics, and forensic DNA analysis.

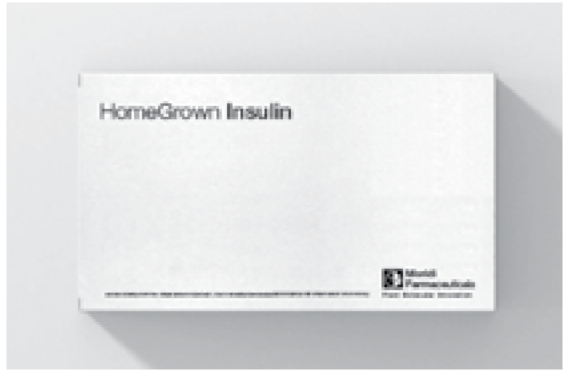
The **Incubator Shaker** function helps create the optimal conditions for cell growth by providing the agitation or shaking necessary to incorporate oxygen and evenly distribute nutrients throughout the culture media.

Electroporation is a microbiology technique in which an electrical field is applied to cells in order to increase the permeability of the cell membrane. This makes it possible for chemicals, drugs, or DNA to be introduced into a cell and helps BioOven 5000 users with the introduction of foreign genes into tissue cells.

Tobacco (Nicotiana benthamiana)

Nicotiana benthamiana is a close relative of tobacco and a species indigenous to Australia. It was used by people of Australia as a stimulant, since it contains nicotine, before the introduction of commercial tobacco (Nicotiana tabacum and rustica). Due to the large number of plant pathogens able to infect it, Nicotiana benthamiana is widely used in the field of plant virology. It is also an excellent target plant for agroinfiltration. This is a method used in plant biology to induce transient expression of genes in a plant and produce a desired protein.

Nicotiana benthamiana is also an excellent platform, or bioreactor, for the industrial production of pharmaceutical proteins and antibodies that may be used in medicines. Normally, animal or microbial cell cultures are used to produce vaccines. However, the costs associated with maintenance, safety, storage and transport are reported to be sometimes as much as 80% higher than using plant-derived alternatives such as Nicotiana benthamiana.



HomeGrown Insulin Kit

HomeGrown Insulin is Moridi Farma's flagship product. It is designed for the home manufacturing of insulin and has a customer base of two million users in the United Kingdom. The product works best when used in combination with the BioOven 5000, also manufactured by Moridi Farma and developed in collaboration with Xarsung Electronics.

The product package and instructions reflect the ease of use for home consumers. They can have a de-stressing experience growing their own plants and subsequently use them as bioreactors to produce their own insulin. In 2030, manufacturing insulin inside plants, in the peace and quiet of your home kitchen, is a reality.

neuleaf

Clara Llamas
MASEDI 2017-18