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DID YOU HEAR THAT? USING UNDERWATER SOUNDSCAPES TO EVALUATE OCEAN HEALTH IN AOTEAROA, NEW ZEALAND

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Did You Hear That? Using Underwater Soundscapes to Evaluate Ocean Health in Aotearoa, New Zealand

Synopsis:

To tackle the issue of an increasingly noisy ocean, we developed a novel education tool to increase participation in STEAM. The programme, 'Sounds of the Sea' enables our next generation of changemakers to work through three modules (Bronze, Silver, and Gold), that traverse instrument building, scientific theory, and communication. This programme encourages students to combine elements of ecology, physics, technology, and storytelling to connect with the ocean and solve real-world problems.

Did you hear that?

Sounds of the Sea - Using underwater soundscapes to evaluate ocean health in Aotearoa, New Zealand.

Abstract

In 2021, we developed an underwater soundscape monitoring and education programme called *Sounds of the Sea (SOTS)*. The programme focused on marine soundscapes to showcase the nature of science through instrument building, data gathering, and whole systems thinking. A core aim of the programme funded by the New Zealand Government was to augment student participation in STEAM.

The SOTS programme has three main modules - Bronze, Silver and Gold - that span hybrid learning techniques including narrative thinking, scaffolded learning, and student agency. Specifically, the Bronze module covered theoretical concepts of underwater sound and anthropogenic impacts; Silver focused on building hydrophones and testing these in a controlled experimental setting; and Gold embraced student agency through the design and implementation of field investigations that focus on data collection, inference and the development of critical thinking skills.

A total of five school groups and over 180 students participated in the development of the programme, which traversed a variety of socio-economic settings and geographic ranges in Aotearoa New Zealand. In this paper we present the key results of the programme from both a developmental viewpoint (our perspectives) and from participant perspectives (interviews of lead teachers). We also discuss future plans for the programme, toolbox, and its potential integration into the New Zealand Science curriculum.

1.0 Introduction

Over the past two decades, there has been an increasing movement within the field of education to connect and weave together disciplines that were previously perceived as disparate (Guyotte et al., 2014). Conventionally grouped disciplines like science, technology, engineering, and mathematics (STEM) have expanded to include the arts (STEAM). This pedagogical shift has stemmed from a globally identified need to include and develop creativity, critical thinking, problem-solving, communication, and interpersonal skills characteristic to the field of arts, alongside interests in science, technology and mathematics in student learners of today (Burton et al., 2000; Perignat & Katz-Buonincontro, 2019).

In Aotearoa New Zealand, increasing student participation in secondary school science-based subjects to understand and even tackle complex global issues has been a directive of the New Zealand government over the last decade (MBIE, 2014). The main focus of this push is to swing the tide of falling participant rates in science-based subjects. According to the recent PISA (2022) report, Aotearoa New Zealand has sustained its decline in science, as well as mathematics and reading performance since 2018, which is below the OECD average. This is particularly true of Māori and Pacifica students due to various socio-economic structures that underpin inequity in learning opportunities.

In 2010, Aotearoa New Zealand's Ministry of Business, Innovation, and Employment (MBIE) developed a fund - Unlocking Curious Minds (UCM). The ethos of the fund was to engage students in science through the development and implementation of STEAM-based programmes that showcase the nature of science, often through tackling complex real-world problems (MBIE, 2014).

In 2021, we developed a conceptual programme entitled 'Sounds of the Sea', which was a successful recipient of funding under the UCM umbrella. We used sound as a vehicle to develop the programme as it is a concept that is taught in general science, however, the behaviour and impacts of sound within a marine context have been generally overlooked and unheard of. We identified that understanding the impacts of sound within the marine environment was an important learning tool as marine and coastal environments have globally become louder as a consequence of sustained pressure from human-based activities (Pine *et al.*, 2014). For a wide range of marine species, sound is crucial for communicating, foraging, reproduction, and orientation. As a consequence, noise pollution has significant potential to negatively impact animal behaviour and biodiversity. Further, as noise pollution is a human artefact, it also means that it is a unique environmental issue with direct mitigative strategies and solutions available, i.e., it is a problem that could, in theory, be 'switched off'. However, mitigating strategies and solutions rely on pro-environmental human behaviour, which is influenced by education and awareness (Hadzigeorgiou & Skoumois, 2013).

Cognisant of these elements, the SOTS programme has several key aims:

- Build a national underwater monitoring and education toolbox that showcases the nature of science through data gathering, whole systems thinking, and science communication.
- Employ student agency in synthesising abstract/complex concepts, technical skills, and real-world scenarios.
- Enhance STEAM-based skills including, but not limited to, critical thinking, problem-solving, innovation, creativity, exploration, and interpersonal communication.
- Foster and enhance personal connections with the marine ecosystem.

To achieve these aims, we developed three working modules for participants to complete - Bronze; Let's Explore It, Silver; Let's Build It, and Gold; Let's Use It (Appendix- 1). We then selected participatory schools that showed an interest in the SOTS programme and had students within the target audience bracket undertake the programme. In this paper, we outline the design and development process, including module content and the various iterations the SOTS programme went through as we refined various elements based on target audience feedback. We also discuss the programme's impact as conveyed to us by the lead teachers of each participatory group thus far and the potential pathways of SOTS going forward.

2.0 Methodology

2.1 Target audience and participation

The target audience spanned across the North and South Islands of Aotearoa New Zealand, from Northland to Marlborough as follows – Taipa Area School, Horizon School, Auckland-based Rangatahi (Māori youth), Highlands Intermediate School, and Marlborough Girls High School (Fig. 1). The targeted demographic was intermediate or middle-school students (NZ School Year 7-10 or 12 - 15 year olds) and was predominantly received by teachers wanting to incorporate it into their general science classes. This was beneficial, as science is a compulsory subject for all Year 7-10 students, making the programme accessible to a wider audience. It also allowed practitioners to utilise an interdisciplinary learning lens that pulled concepts and components of science (biology, physics), technology, communication, and mathematics. Targeting the intermediate/middle school age range also meant that the programme could help students determine and inspire future science-related study options in their consecutive senior years (NZ Year 11-13 or 16 - 17 year olds). There was also greater flexibility within the school calendar for Year 7-10s to undertake the project compared to more senior students with credit and assignment commitments.

The exception to this was Marlborough Girls College, for whom the SOTS programme was run with Year 12-13 students due to their enthusiastic teacher and novel course structure. Note: the rangatahi group also had participants that included Year 11-13. However, this was more so because the rangatahi group was part of a Ngāti Whātua Orākie Mārae holiday programme open to all students.

As we moved through the programme, we sought feedback from the participatory teachers via informal and semi-structured interviews, as well as a brief Google Forms online questionnaire (see Appendix- 2). This was to determine what was working, what was not, and what could be changed to elevate the programme and student learning experience. We also undertook a self-review after each module delivery.

Figure 1. Map of Aotearoa New Zealand, highlighting participatory schools in the SOTS programme. From top – bottom; Taipa Area School in Northland, Horizon School in Auckland, Auckland-based rangatahi from Ngāti Whātua Ōrākie Marae, Highlands Intermediate in New Plymouth, and Marlborough Girls College in Blenheim.

3.0 Results

3.1 Participation across target audience

A total of 182 participants spanning five diverse learning groups were involved in the Sounds of the Sea programme. Ages ranged from 10 to 17 years. Of these, 51 % were Māori and Pacifica, 48% were New Zealand European, with the remaining 1% being of Asian descent. In total, 182 students completed the Bronze module, 137 completed up to the Silver module, and 83 completed the Gold module, i.e., the whole programme. Of those 182 participants, 117 were female and 65 were male.

3.2 Programme development and iterations

For the most part, we followed the original plan for the project, albeit it was held up at times due to: 1) length of time taken to obtain University of Auckland Human Ethics approval, 2) stoppage/delays due to Covid-19; and, 3) disruptions to planned meetings and field sampling due to extreme weather events. Ideally, we would have liked to run the project with each learning group over several consecutive days to maintain momentum across the modules and emphasise each subsequent module's process and scaffolded learning approach. However, due to the aforementioned reasons this was not always possible. Thus, we had to work within the windows for delivery that were available on a school-by-school basis.

To meet University of Auckland Human Ethics approval, slight adjustments were made to the initial programme framework insofar as making it optional (for all participants). Towards project completion, we were confident that the implementation of the programme was fit for purpose. Moreover, guided by teacher feedback and self-reviews post-delivery, changes to the original programme framework included:

- Adding interactive components - games, quizzes, and worksheets - that enhanced identification of different underwater sounds and conceptual understanding of sound wave theory and piezoelectricity - Bronze module,
- Identifying key bottlenecks and time delays in constructing the hydrophones and then eliminating these so that this task could be completed within the allotted time; typically 1.5 hrs - Silver module,
- Refining experimental components to enhance data interpretation using spectrogram analysis - Silver module,
- Increasing the efficiency of project selection and hypothesis development to empower student agency in creating meaningful and achievable projects - Gold module.

3.3 Final Outputs

3.3.1 Teacher Resources

To ensure teachers felt confident and supported for delivering the contents of the programme, a SOTS Teacher Resource Guide was developed. The guide, available in both print and digital format, provides an in-depth overview of the SOTS programme, explanations for each of the three modules, interactive discussion questions and 'ponder points' to stimulate and challenge student's critical thinking. Access to additional online resources collated for each module, and relevance to the National Science Curriculum.

Other resources that compliment the Teacher Guide include:

- Module cards outlining learning objectives
- Equipment and gear list
- Video content on 'How to Build a Hydrophone'
- Google Drive portal with additional scientific papers and sound recordings
- Revision worksheets for students
- Certification of completion for students

At the completion of all three modules, teachers responsible for their learning group completed a feedback questionnaire with general results summarised in Table 1.

Table 1. Breakdown of teacher response in relation to questionnaire.

Component
Student response Teachers believed student response was high for the delivery of each module (all teachers' responses scored between 4 and 5).
Unaided programme delivery Teachers were confident delivering the programme in the absence of the project team (all teachers' responses scored between 3 and 5).
Relevance to curriculum Teachers felt the programme met elements of the school science curriculum (all teachers' responses scored between 4 and 5).
Critical thinking Teachers believed the programme tested students' ability to critically think about environmental issues to a high level (all teachers' responses scored between 4 and 5).
Technical skill development Teachers believed the programme encouraged students to use and develop technical skills (all teachers' responses scored between 4 and 5).

3.3.2 Toolbox development

A physical toolbox was developed to ensure all components (teaching resources and associated consumables) of the SOTS programme were collated and efficiently delivered (Fig. 2). It is envisioned that we will develop multiple sets of the physical toolboxes that can then be loaned out to schools for the duration of the programme. Whilst teachers take on the role of delivering the programme, the research team will still conduct outreach and adopt the role of facilitators for the required modules, as guided by the teacher.

At the time of writing, the toolbox includes printed resources, as well as equipment to make five hydrophones per toolbox. Keeping in mind a class size of approximately 25-30 students, the box allows students to work in small groups, making it manageable for teachers to deliver the activities. Initial iterations and prototypes used cardboard as the material of the toolbox to determine the feasibility of the product. Whilst cardboard was sustainable and lightweight, after reviewing and testing the rigour of the box, it was deemed unsuitable for long-term use. As a result, alternative plastic tubs with removable lids were offered as a more robust solution. Whilst a programme to loan the toolbox out to schools is still under development, the plastic boxes have proven better for travel and storage.

Figure 3. Cardboard toolbox iteration (left) with functional issues such as lack of durability and compartment organisation (right; top & bottom).

4.0 Discussion

At a broadscale level, participants were able to gain an understanding of underwater sound and noise pollution, concepts that are often deemed abstract but are important for evaluating the health of marine ecosystems. The project impacted students in multiple ways. For the majority taking part, it was their first time building scientific instruments. The "learning through building" process adopted for the project was an important part of its success as feedback from the teachers was that this component kept the students engaged. Further, there was a real sense of accomplishment once the students had built a working hydrophone, and they were able to enhance key STEAM-based skills of observation, creativity, critical thinking, problem solving, collaboration, and communication among team members (Burton, Horowitz & Abeles, 2000; Perignat & Katz-Buonincontro, 2019).

There were no major barriers to working with this age bracket as we identified key teachers and schools during the project conception. Several changes were made to the programme following working across the Year 7-10 bracket as we moved through the various modules. Some of the key changes were:

- Offering theoretical content as interactive learning, rather than passive learning.
- Altering how we deliver the programme content and instructions, e.g., development of instructional videos across modules.
- Tailoring the delivery to meet requirements of larger class sizes between 25-30 students.
- Moving the hydrophone building phase from the Bronze to the Silver module to maintain interest and engagement across the programme.
- Looking at complementary data acquisition opportunities that could be done in the field component alongside the hydrophone deployments, e.g., undertaking video recordings in tandem with sound recordings.

Working with Marlborough Girls College allowed us to also evaluate the applicability of the project with senior students (beyond the target audience). To that end, the programme could be easily adapted to fit within their Environmental Studies framework, which pushed participants to not only identify environmental issues and collect data, but also offer solutions to these.

Teacher feedback is presented in Table 2.

Table 2. Teacher feedback on aspects of the Sounds of the Sea Programme. TAS (Taipa Area School); HS (Horizon School); HIS (Highlands Intermediate School).

General Feedback
• Really well delivered by programme leaders - the time frames were good. I think the silver module could be split into two parts though - building, then testing. TAS • Teacher resource guide y7-10 looks great, love the images and clear instructions and • I was very impressed with the structure HS • I really liked the clear structure for the kids - the programme made no assumptions of knowledge or skills without dumbing anything down. Hands on science. HS • All of the modules will fit in with my Marine Studies programme. I still need to do the Gold module programme. It will be good to gather some data HIS • Great job, a very worthwhile project. We have been fortunate enough to use it at year 12-13 and do meaningful field work. We really appreciate the support and the time given to work with our students. Thanks heaps MGS • I was so impressed with the student's response to the programme. Some of the questions that one young girl asked the programme team- it seemed that for some kids the programme had sparked a real interest in science. I loved the fact that the kids could see the practical outside nature that science could be. TAS

For all stages of the programme participants were involved and engaged with active scientists primarily face to face and on odd occasions remotely – the latter due to Covid-related issues. For many participants, this was their first time learning from and engaging with active researchers. The key to this approach was that at every step of the programme, participants could ask questions, learn and feel supported from active researchers. Researchers encouraged students to explore, question, problem-solve, and persevere through failure (i.e., non watertight hydrophones), key components of both scientific-based and artistic inquiry (Bresler, 2005; Perignat & Katz-Buonincontro, 2019). These factors inevitably led to very high levels of engagement.

The Bronze module was focused on establishing place and context with respect to underwater soundscapes and noise pollution and was part scene-setting as much as identifying environmental issues and the scientific method. This type of narrative thinking approach has been evaluated as an effective engagement technique (Hadzigeorgiou and Shulz 2019). Initial participant engagement was largely prompted by the research team through a presentation providing examples and research of real-world problems followed by a question-and-answer session. This was a key component for establishing initial rapport with each learning group and allowed us to gauge their level of ability.

The Silver module exposed students to abstract technology and science based concepts related to the inner workings of how hydrophones work (e.g., piezo-electric effect) and how this can be used to gather meaningful data. While the Silver module was primarily focused on hydrophone building and testing, the direct availability and access to electronics technicians was instrumental in improving student understanding around how scientific instruments are built, made watertight and tested. This was also beneficial for participant teachers if they felt a bit out-of-depth with the subject matter or lacked confidence in building scientific instruments.

Access to active researchers for the Gold module was instrumental in making the experience worthwhile and successful. The module allowed for student agency, however, access and building a working relationship with scientists allowed student ideas/hypotheses to be evaluated constructively, so that meaningful data from their local marine spaces could be collected from the onset. Furthermore, being able to work through results (post-survey) in a systematic way with researchers improved participant confidence and understanding for this component of the programme, including outputs.

Key elements of the project design that worked well included:

- Hydrophone building and testing;
- Encompassing interactive components (quizzes, activities) to help explain and reinforce theory (soundwaves, underwater sound, noise pollution); and,
- Providing opportunities for students to collect real-world data.

Another key success of the project design was the ability for participant teachers and students to work through the programme in a systematic way (Bronze, Silver and Gold). Furthermore, its flexibility in terms of time, i.e., that it could be taught across a week or extended to span a school term, depending on teacher capacity was also an asset. Of all the three modules, the Bronze module came under the most scrutiny, which resulted in the hydrophone building component moved to the Silver module. The Silver module was reduced and refined, whereas the Gold module remained relatively unchanged from its planned content.

For the most-part , we are confident that the main outcomes of the project were met. At a broad-scale level the project:

- Spanned a geographical range of Aotearoa New Zealand (Northland to Marlborough),
- Exposed participants to the scientific method and taught by active researchers,
- Focused on the process of building scientific instrumentation and testing, instead of just the final product,
- Provided palpable intrinsic rewards of sensory feedback from building scientific instrumentation,
- Allowed (in several instances) exposure to 'field work' through collection of real-world data,
- Enabled participants to critically think about their local rohe moana (local marine space) and how it may or may not be impacted by the global issue of underwater sound and noise pollution at a local scale,
- Proved applicability across the target year groups and beyond.

At the heart of the project was to expose participants to real-world issues and open channels for interdisciplinary critical thinking around concepts of noise pollution and environmental health and wellbeing. To that end we feel the project achieved its goals. For example, the cohort of Marlborough Girls College students that took the programme to completion have described the project as altering the way they perceive the Marlborough Sounds (highly impacted by noise) . This heightened understanding was also evident in their award-winning Science Fair presentation, which also focused on solution identification. The project process and solutions developed have since captured the interests of local media, and councillors.

Equally, post-survey discussions following the field-based surveys with Taipa Area School opened dialogue with participant students around how fish may move away from their rohe (area) in summer due to the volume of boat traffic and associated noise (observations made by them). We also discussed potential future noise-related impacts should coastal areas grow and become more developed.

For the project team, the success of the programme really hinged on whether it will be continued beyond the project timeframe. To that end, we are encouraged to see it being adopted into Marlborough Girls College Environmental Studies programme, Highlands Intermediate's Marine Studies Programme, and Taipa Area Schools science options. These school based opportunities and work with an external funding provider to integrate the SOTS programme into the national science curriculum, suggests that it has real merit and impact in expanding the STEAM education landscape of Aotearoa New Zealand, and beyond.

5.0 References

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Appendix 1.0 Sounds of the Sea programme modules

A1.1 Bronze module - Let's Explore It!

The Bronze module is focused primarily on narrative learning and context setting by exposing participants to the theory of underwater sound and noise pollution. Examples and contrasts are widely used from both global and local settings to reinforce the multi-scalar nature of the problem. The introductory material was typically delivered in a lecture-style presentation with audience directed questions, short interactive quizzes, and proposed group activities to maintain engagement.

Key aspects covered include:

- What is a soundscape (healthy versus unhealthy)
- Properties of sound within an aquatic environment
- How do we record sound - hydrophones
- How do hydrophones work - piezoelectric effect
- How we interpret sound data collected from hydrophones - introduce spectrograms
- Quiz - guess that sound.
- Group exercises related to abstract concepts like 'movement of waves and particles for loud vs quiet sounds.'

A1.2 Silver module - Let's Build It!

The silver module is primarily hands-on, enhancing students' technical skills through two key aspects - hydrophone building and hydrophone testing. Students worked in pairs to build a hydrophone, fostering collaboration and peer-learning, key goals from the outset of the programme.

Key components for the process of hydrophone building are outlined in Table 3 and Fig 3.

Table 3. Hydrophone components and materials for hydrophone building.

Hydrophone Components	Number	Details
Piezo disc 4.5 mm ⌀	1 ×	Purchased from an electronics supplier.
Circular base and top plate 10 mm ⌀	1 × of each	Laser cut from acrylic. The base plate has a centre hole which it tapped so the cable gland can be fastened. Each plate has eight matching fastening holes for hex bolts
Hex bolts and corresponding nuts	8 ×	Hex bolts are used to fasten the top and base plate and re fastened with socket wrench and allen key
O ring 6mm ⌀	1 ×	Used to make hydrophone waterproof

Flange	1 ×	To be screwed into top plate to keep
TRSS audio cable	1 ×	Solder red wire to red and black to green
Heat shrink tubing	2 ×	place over exposed solder
Additional materials		Sandpaper Quickfix glue Crescent x 2 and Allen key set Solder for wiring and solder iron Heat gun for shrink wrap

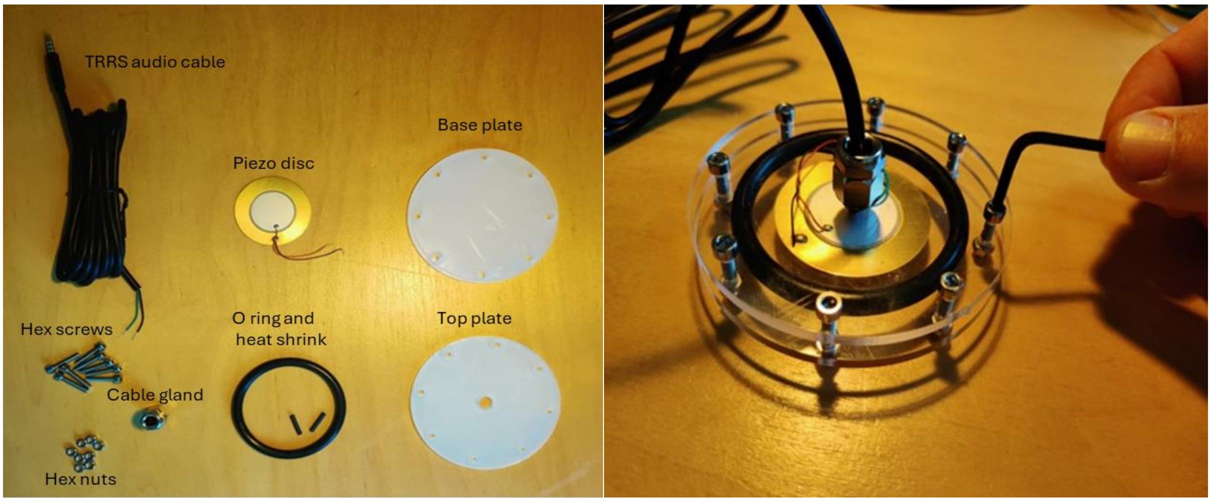

Figure 3. Hydrophone building components (left), and completed hydrophone (right).

Following building, participants moved onto testing their hydrophones in three controlled experiments using a hand held blender to mimic a boat propeller to generate sound. This testing allowed students to synthesise their technical skills with the conceptual learnings of the inner workings of a hydrophone, as well as its application to real life settings. Furthermore, foundational scientific concepts related to experimental design were also reinforced and practiced, allowing students to learn through doing. From teachers, participants and a researcher's point of view, the Silver module was one of the highlights and key engagement tools, irrespective of the learning group in the SOTS programme.

A1.3 Gold module Let’s Use It!

The Gold module integrates aspects of the Bronze and Silver with a focus on student agency and inquiry in creatively developing a scientific investigation. Throughout the module, students were encouraged to head outdoors and physically immerse and explore their local marine spaces using their hydrophones through a hypothesis testing framework. In order to aid learning and solidify complex and abstract ideas, two case-studies were also provided to teachers as part of the module resource toolkit. At the completion of their investigation, students were encouraged to present their findings using a variety of media and communication tools to highlight the importance and interconnectedness of science, technology, and arts.

Appendix 2.0 Teacher Questionnaire

How many students were involved in the project?

On a scale of 1-5 (1 being low participation, 5 being high participation), how engaged were the students during the Bronze module?

On a scale of 1-5 (1 being low participation, 5 being high participation), how engaged were the students during the Silver module?

On a scale of 1-5 (1 being low participation, 5 being high participation), how engaged were the students during the Gold module?

On a scale of 1-5 (1 being difficult, 5 being easy) how do you feel the material was comprehended by the students?

On a scale of 1-5 (1 being low, 5 being high) how do you feel the participants responded to the delivery of the programme by the project team?

On a scale of 1-5 (1 being not confident, 5 being confident), how do you feel about delivering the programme yourself in the absence of the project team?

On a scale of 1-5 (1 being low, 5 being high), do you feel the project meets elements of the school science curriculum?

On a scale of 1-5 (1 being low, 5 being high), do you think the programme tests the students to critically think about environmental issues and sustainability?

On a scale of 1-5 (1 being low, 5 being high), how well do you think the programme encourages students to use and develop technical skills?

On a scale of 1-5 (1 being unlikely, 5 being certainly), would you look at teaching some or all of the components of the programme at a future date? Please specify in the following text box.

Which (if any) components of the programme would you be comfortable teaching at a future date?

How do you think the programme could be improved?

What additional content/resources do you think would be valuable for teachers to help deliver the programme?

Assuming further support from the project team, would you be willing to act as an ambassador for the programme in your local area? This would entail leading the programme in your school and dissemination of information to other schools should the opportunity arise.

Any additional comments?