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THE EVOLUTION OF THE DAFFODIL DNA PROJECT: FROM A SINGLE CLASSROOM PROJECT TO HIGH QUALITY CITIZEN SCIENCE ACROSS A COUNTRY

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ABSTRACT

The Daffodil DNA Project is an innovative educational initiative aimed at investigating the impact of sustained authentic project work on post-16 biology education. The project focuses on engaging students in collaborative inquiry and developing their understanding of biology concepts through the study of daffodil chloroplast genomics. This article provides an overview of the project's background, methods, and initial outcomes. Preliminary outcomes of the project have demonstrated its scientific impact, resulting in the generation of 9 new draft daffodil chloroplast genomes from this citizen science project. Furthermore, participating schools showcased their findings at the Royal Society Summer Science Exhibition, enhancing public engagement with the project. Initial feedback from students indicates the transformative nature of the project, with one student describing the experience as "life changing." The success of the Daffodil DNA Project can be attributed to effective collaboration between the University of Dundee, the James Hutton Institute, schools, and STEM partners. Regular communication and knowledge sharing among participants have contributed to the project's achievements and the development of a shared identity as scientists. Overall, the Daffodil DNA Project presents a promising model for inquiry-based learning in biology education, emphasising the importance of authentic scientific investigation and collaboration. Future research will delve into the educational benefits of this approach and its potential applicability in diverse classroom settings.

Keywords: Education, inquiry, collaboration, plant science, citizen science.

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INTRODUCTION

The aim of this article is to bridge the gap between the initial case study of the Jersey Daffodil Project (Hale, Harkess & Könyves, *2024*) and the current Daffodil DNA Project which is administered by the University of Dundee.

The initial rationale for the project

The curricula for post-16 biology may well resemble the cellular organisation of a palisade mesophyll cell, with key concepts compartmentalised within each specification (AQA, 2021; OCR, 2020; Pearson Edexcel, 2018; SQA, 2022). Just as the cell may well segregate the enzymes for oxidative phosphorylation within the mitochondria, concepts can be siloed in the classroom. However, the evolutionary advantage of compartmentalisation within the cell is all aimed at the success of the cell, the success of the cell within the tissue and how the tissue supports the leaf's function as an organ within the organism. This vertical organisation of key concepts in biology education is rarely considered (Moore-Anderson, 2021), and as such the connections between the biochemistry of the cell and the role of the organism in an ecosystem may not be explicitly taught or implicitly considered by the student.

The vision of building an interconnected sequence through the OCR Biology A specification was the inspiration for this project (Hale, 2023) but sited within the local environment (Hale, 2022a). By taking the time to notice nature during the spring of 2018, the diversity of daffodils was phenomenal. They were not the ubiquitous yellow flowers seen around Mothering Sunday in the UK, but a myriad of different forms. From approximately 84 species (Royal Horticultural Society, 2017), amazingly over 30,000 different cultivars have been named (Willis, 2012), often with minute differences between the cultivars.

Citizen Science in the Classroom

Citizen science is an inclusive set of activities that enable communities to be part of a research project (Cooper, 2012) such as by collecting raw data such as Flower-Insect Timed Counts (Persson *et al*., 2023) or performing labour-intensive transcription services from secondary sources (Hill *et al*., 2012). Citizen science has been shown to have beneficial impacts on learners, from the domain specific skills such as developing an understanding of the scientific content and process (Krach, Gottlieb & Harris, 2018), to developing STEM career aspirations (Hiller & Kitsantas, 2015).

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Initially the project looked to develop the "biologist's gaze" (Moore-Anderson, 2023) in students, whereby they see the similarities between individuals but start to acknowledge the differences. Specifically, students would need to take the knowledge of what makes a daffodil a daffodil, such as the parallel vascular network in the leaves, the number of petals and the corona as constants, with a few exceptions, and then look for the differences such as height, colours and corona morphology. Students, staff and the community were encouraged to upload their observations to an iNaturalist project (iNaturalist, 2023). Over 1,500 observations of daffodils were quickly added to the project. Grounded in citizen science, the students then selected the daffodils to biochemically interrogate as previously described (Hale, 2020).

Initial Findings from the Jersey Daffodil Project

The initial results during the Jersey Daffodil DNA project (Hale *et al*., 2023a; Hale *et al*., 2023b) allowed students to perform basic phylogenetic analysis using Geneious Prime 2019.1 (Hale, Harkess & Könyves, *in press*), however it was the impact on student learning and aspirations that warranted further study.

The cancellation of examinations following lockdowns during the COVID-19 pandemic and the need for evidence-based teacher assessed grades presented the opportunity to directly compare students that did not undertake the Jersey Daffodil Project with those that had with the same examination paper in the same controlled conditions. As described in Hale, Harkess & Könyves (*in press*), the results were phenomenal showing a marked improvement where the mean raw score increased by nearly a third. It should also be noted that the attitudes towards science, technology, engineering and mathematics (STEM subjects) also improved. This study did not identify the key drivers for these impacts on students. Potentially, it could be due to the narrative of the daffodil through the course, the improved teacher subject knowledge, the frequent opportunity to discuss biology that historically students find challenging (Hale, Harkess & Könyves, *in press*) or the role of inquiry-based learning in biology.

Collaborative inquiry and cognitive load

Through the Jersey Daffodil Project, a model of collaborative inquiry was developed whereby the students and teacher were equals in scientific endeavour, genuinely producing data that was new to science outside of the knowledge and experiences of all parties. The concept of collaborative inquiry has not been researched in the past, despite the role of collaboration being identified as a tool to increase engagement (Jao & McDougall, 2016) and motivation (Miller & Benz, 2008). Although inquiry in science education has been a key part of many curricula, it is not consistently defined, frequently conflated with practical science (Ioannidou, Finch & Erduran, 2022). Additionally, how inquiry is enacted within the classroom varies across a spectrum of highly structured confirmatory investigations to completely open discovery-based learning with students in control of every decision (Akuma & Callaghan, 2018; Bevans & Price, 2016).

The further towards the open-ended inquiry the student is pushed, the greater the challenge there is on the student to develop a deeper learning of a particular topic (Barron & Darling-Hammond, 2008). It could be argued that this mandatory responsibility for their own learning leads to greater learning, but the efficacy has been robustly challenged (Kirschner, Sweller, & Clark, 2006) within the framework of cognitive load theory (Sweller, Ayres, & Kalyuga, 2011). As such there has been little research in the UK on the role of inquiry in the UK's science classrooms in recent years.

Cognitive Load Theory is a framework which offers an explanation as to why students may struggle to learn when presented with new material (Sweller, 2010). It takes into account the working memory being applied to the learning alongside the novel information and how it is presented. It has been elicited that discovery-based inquiries place too much load on the working memory of novice learners to enable effective learning to happen (Kirschner, Sweller, & Clark, 2006). Therefore, there is a need to scaffold inquiry activities to make them accessible to students.

Understandably, with the rich curricula of post-16 biology (QA, 2021; OCR, 2020; Pearson Edexcel, 2018; SQA, 2022) many teachers state that there are simply not enough hours in the course to deliver effective inquiry (Bevins, Lehane & Booth, 2019; Fitzgerald, Danaia & McKinnon, 2019; Sadler, Barab & Scott, 2007) so the question to be asked is whether the Jersey Daffodil DNA Project could be enacted within different classrooms successfully, and thus the Daffodil DNA Project was born.

The aims of the Daffodil DNA Project are:

1. To identify and assess any value of sustained authentic project work impact on post-16 student aspirations related to STEM fields.

2. To identify and assess the value of context-based inquiry work on the domain specific knowledge of post-16 students.

3. To determine whether sustained collaborative inquiry work has a positive effect on student STEM values.

4. To identify and assess any value of supported projects as a mechanism for subject specific professional development.

METHODS

Ethics

To minimise risk and allow swift data collection upon the commencement of the project, the decision was made to only use students over the age of 16. Teachers recruited their own students to the project. Although data from the teachers and scientists could be directly attributed at the point of collection, names and genders were anonymised with identifiable data excluded from the data following transcription. All participants were reminded of their right to withdrawal without any negative impacts. Schools and scientists agreed with informed consent to take part in the study following ethics approval by the University of Dundee (E2020-145).

Recruitment of schools

In the spring of 2021, schools were invited by the University of Dundee to attend one of two introductory presentations held virtually. Fourteen schools attended the sessions across Scotland with nine schools formally applying to participate. These schools were supported in applying for a Royal Society Partnership Grant alongside scientists (STEM partners) from the University of Dundee and the James Hutton Institute. In 2022 a further two schools joined through word of mouth.

STEM partners recruitment

A key aspect of the Royal Society Partnership relies upon schools working with active scientists. These scientists were voluntarily recruited through Public Engagement networks within the University of Dundee and James Hutton Institute in 2021. Thirteen scientists initially volunteered to support the project and individual schools. The majority of these scientists have continued to contribute to the project with further scientists onboarding in 2022.

Cultivar selection

University of Dundee Botanic Gardens liaised with Croft 16 and National Trust for Scotland to ascertain where there were opportunities to explore breeding within heritage daffodils. Collectively it was decided to investigate “Albatross”, “Empress”, “Lady Margaret Boscawen”, “Loch Fyne”, “Lucifer”, “Minnie Hume”, “Ornatus”, *Narcissus radiiflora* var. *Poeticus*, and “*Princeps*” as these cultivars would enable a breeding history to be tested using biochemistry. Details of the recorded history of these cultivars can be found at https://dag.compbio.dundee.ac.uk/daffodils/. Each school received two cultivars, allowing the possible replication of data.

Wet laboratory procedures

In November 2021 and November 2022, teachers and technicians were invited to the University of Dundee and the James Hutton Institute to learn the required wet laboratory procedures. In the following spring, the teaching staff were supported by their STEM partner in the schools' laboratories/classrooms.

Each daffodil leaf was destarched by placing it in a dark cupboard 24 hours prior to DNA extraction. Approximately 0.1g of leaf material was mascerated with silica sand before students extracted the DNA using the Qiagen DNeasy kit (Qiagen, Manchester, UK). Each daffodil was subsequently sequenced using the Rapid DNA Sequencing Kit SQK-RAD004 (ONT, Oxford, UK) and the Flow Cell (R9.4.1, FLO-MIN106D) on the MinION device (ONT, Oxford, UK). Schools were provided with videos of each step (Duce, 2022).

Dry lab procedures

Basecalling was undertaken using Guppy v6.1.1 using default parameters. The students were then able to align their reads against the reference *N. poeticus* chloroplast genome (MH706763) using Geneious 2022.1. In addition to this, data was transferred to the University of Dundee and further analysed (Abbott, 2023) to produce higher quality assemblies. Details of the bioinformatics pipeline can be found at https://dag.compbio.dundee.ac.uk/daffodils/.

Assessing the impact of the project on individuals

Students were provided with a pre-and post-project questionnaire hosted on JISC to allow teachers to administer these questionnaires within the classroom at a convenient time. Teachers were interviewed so that individual responses could be tracked and this enabled changes on a personal level to be determined. In order to triangulate student changes with the teacher data, generalised data regarding students had to be collected, whereas specific data could be collected regarding the teachers' own project journey. Similarly, scientists were interviewed. Interviews were conducted via Microsoft Teams and recorded. Automated transcriptions were then assessed for accuracy and manually corrected before identifiable features were removed prior to analysis.

RESULTS

Initial outcomes:

The impacts on the classroom are still being collected, however the scientific output has been highly successful, leading to nine new daffodil chloroplast genomes of varying completeness. This data has been deposited in the European Nucleotide Archive (Project: PRJEB578320). A comparison of similarity in phylogenetic analysis of the daffodil chloroplast sequences is shown in Fig. 1.

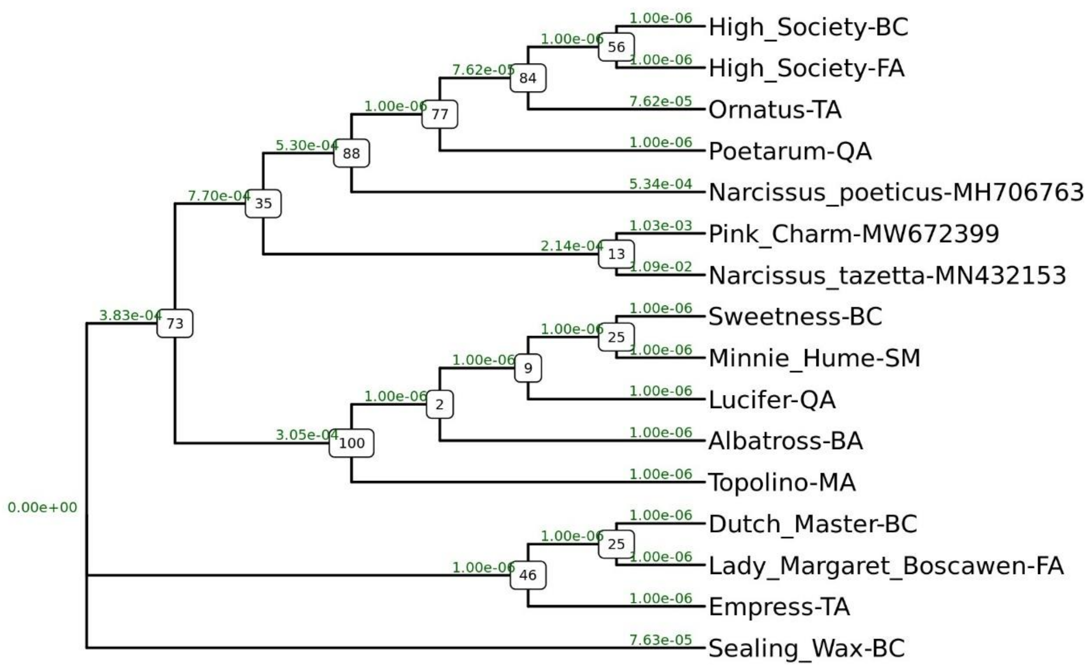

Figure 1. The resultant phylogenetic analysis based upon longread similarities of each school's final assembly.

Two of the participating schools represented the project at the Royal Society Summer Science Exhibition in 2022, engaging the public with their science. One student fed back to the Royal Society that this experience was "life changing."

CONCLUSION

The Daffodil DNA Project has significantly evolved from the initial seed in Jersey. Whereas the initial investigation was grounded in citizen science, the decision to angle the discovery to horticulture and conservation of heritage cultivars has opened up a new avenue of discovery that potentially has commercial benefits as well as providing evidence of the interrelatedness of the different cultivars.

From the small concept study in Jersey, the Daffodil DNA Project has shown that students, teachers and their STEM partners can produce high quality data that is genuinely new to science, undoubtedly impacting on each and every participant's identity as scientists. A key aspect of the success has been the regular communication between the University of Dundee, the James Hutton Institute and the participating schools. As each collaboration is autonomous in their decision making and timelines, this has allowed each participant the opportunity to share their knowledge and experiences in an open monthly forum knowing the contribution will be valued by someone in the group.

As the qualitative data trickles into the project from the schools and STEM partners, it will ensure that its benefits can be explained.

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