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BRIEF REPORT

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# The Jersey Daffodil Project: Integrating nanopore sequencing into classrooms improves STEM skills, scientific identity and career development

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**Societal Impact Statement**

The Jersey Daffodil Project, a secondary school initiative, boosted students' aspirations in science careers. Fieldwork, DNA sequencing and discussions with scientists enriched their learning and aspirations. Surveys revealed a positive shift in students' views towards STEM careers. The project also influenced an entire cohort to pursue biological sciences in 2021. The use of cutting-edge technology reduced costs and time, showing promise for broader school collaboration. This project not only transforms science education but also inspires students, shaping their futures and fostering a new generation of scientists.

KEYWORDS
DNA sequencing, education, fieldwork, genomics, inquiry, nanopore

## 1 | INTRODUCTION

### 1.1 | Identifying the opportunities within the curriculum

The majority of the UK's conventional post-16 education structure involves students selecting three or four subjects with significant implications for their future careers. Students often choose subjects aligning with career aspirations, reflecting local job opportunities, such as opting for biology and chemistry to pursue medicine at university (Archer et al., 2020). Despite starting with aspirations in Physiology, students commonly develop an interest in Biochemistry during post-16 Biology education (Hale, 2020a), yet show limited enthusiasm for Plant Biology, Taxonomy, and Evolution.

One approach for improving attitudes towards these topics is to build classroom models of collaborative inquiry where the teacher, students and scientists are actively engaged in novel research where outcomes are unknown and protocols untested for the aims. Kirschner et al. (2006) argued that these open inquiries are ineffective due to the high cognitive load placed on the students. Students have to balance their procedural knowledge with their content knowledge when attempting to generate valid data (Vorholzer & von Aufschnaiter, 2019). Overall, this suggests that minimally guided inquiries are inefficient in terms of the acquisition of knowledge, with highly structured or explicit teaching increasing the learning of students. According to Bevins et al. (2019) and Childs and Baird (2020), this efficiency is something that is at the forefront of the minds of teachers in the United Kingdom, where there is pressure to deliver content and reward for students recalling knowledge in examinations, regardless of how this embraces the ethos of science (Chinn & Malhotra, 2002; Crawford, 2007).

However, by working collaboratively, the cognitive load on students' working memory can be managed and problems solved collectively. Furthermore, by situating the conceptual content within a context, it gives students more meaning to their knowledge (Ross et al., 2015). This has been demonstrated by Zohar and Nemet (2002) when comparing two groups of students: the experimental group received genetics lessons based on a socioscientific construct, and the control group received the same genetics lessons without the socio-scientific construct. The experimental group outperformed their control peers in a genetics knowledge assessment.

In this project, students are working with cutting-edge technology and undertaking authentic research. The context moves away from the typical hypothesis-testing inquiries found in classrooms (Ioannidou et al., 2022) towards a more open question. This may increase the personal investment in the project and thereby increase the psychological energy (Bevins & Price, 2016), which may in turn lead to greater learning as well as greater motivation to succeed in science. As a practitioner, the goal of improving student outcomes has always been the aim of any intervention.

### 1.2 | Daffodils

Inspired by the diverse local flora in Jersey, this project addresses some of the issues of plant awareness disparity (Parsley, 2020) by exploring the variety of daffodils growing along roadsides, tracks, field margins and woodlands, encouraging students to stop and notice plants. The variety traces back to the historical trade in daffodils, an industry contributing millions to the local economy (Jersey Evening Post, 2020). The repurposing of fields during wartime pushed these bulbs to field edges (Way, 2023), maintaining the variation that serves as a context for fieldwork and classification. With over 30,000 named daffodil cultivars selectively bred from a gene pool of approximately 67 species (Royal Horticultural Society, 2017; Willis, 2012), classification into 12 divisions is based on characteristics, including flower colours, and involves differentiation for naming (Kington, 2008). This detailed classification is challenging and subjective, often leading to disagreements. The plastic nature of plants, such as the subtleties of corona colours and shapes, however, suggests the potential for objective cultivar identification through DNA sequencing found in chloroplasts.

### 1.3 | Chloroplasts and DNA

Könyves et al. (2018) published the first chloroplast genome of a daffodil, providing an accurate reference point for future comparative analysis. The project capitalised on the chloroplast's compact size, employing nanopore sequencing for students to sequence naturalised daffodil chloroplast genomes, showcasing cutting-edge genetics research and promoting science as a career path (Hale, 2020b). This level of genuine research had not previously been attempted with post-16 students in secondary education.

## 2 | METHODS AND MATERIALS

The project involved students from neighbouring schools; however, due to the COVID-19 pandemic, collaboration was limited to Beaulieu Convent School students or those from collaborating schools taking A-level Biology at Beaulieu Convent School. The school is a non-selective independent institution in Jersey, with a broad range of prior attainment and special educational needs among A-level Biology students. Students in the 2019 cohort completed their education at the school before the commencement of the project. These individuals act as a control group for analysis. Students in the 2020 cohort undertook the project, as did the students in the 2021 cohort.

Surveys assessed STEM subject and career attitudes, combining 2019 and 2020 cohorts ($n = 29$, Notes S1), with a follow-up after project completion ($n = 13$, Notes S2). Questions were developed from the Institute of Mechanical Engineering's STEM Workshop Impact Tool (IMechE, 2019) in discussion with STEM Learning UK (Hale, 2020). Students responded via a 4-point Likert scale. Students also reflected on soft skills development. A post-project nature connectedness survey was conducted ($n = 14$) (Richardson et al., 2019, Notes S3).

Using iNaturalist (an application for recording observations), students documented observed daffodils, collectively selecting specimens for sequencing. The selection of specimens was purely student-led based upon ease of collection, whether the specimen was in flower, and general aesthetic qualities. Due to the pandemic, the RHS Colour Chart was unavailable and was replaced by paint colour charts. Leaves and flowers were collected, with students preparing herbarium vouchers (RHS, 2023). These vouchers of the dried specimens allowed a catalogue to be compiled and will allow further analysis of each specimen.

Students (2020 cohort) extracted DNA using the Qiagen DNAeasy Plant Mini Kit (Qiagen, Manchester, UK) using approximately 0.1 g of leaf material. The extracted DNA was 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). Basecalling was undertaken using Guppy v3.6.0 using default parameters, with the data analysed by students using Geneious Prime (http://www.geneious.com, 2020.1). Reads were referenced assembled against a *Narcissus poeticus* chloroplast genome (MH706763).

The following year (2021 cohort), leaves were destarched overnight in a dark cupboard. Students isolated chloroplasts using parts of the Sigma-Aldrich Chloroplast Isolation Kit CPISO-1KT (Merck, Darmstadt, Germany). Working with a chilled pestle and mortar, approximately 1 g of leaf material was macerated with 1 $cm^3$ of chilled chloroplast isolation buffer and centrifuged at 1000 rpm for 30 s. This allowed the removal of cell walls. The supernatant was then centrifuged for 6 min at 1000 rpm. This produced a pellet of chloroplasts. The supernatant was removed, and the DNA was extracted from this pellet using the Qiagen DNAeasy Plant Mini Kit (Qiagen, Manchester, UK). The extracted DNA was sequenced using the Rapid DNA Sequencing Kit SQK-RAD004 (ONT, Oxford, UK) and the Flongle Flow Cell (R9.4.1 FLO-FLO106D). Basecalling was undertaken using Guppy v4.4.2 using default parameters, with data subsequently analysed by students using Geneious Prime (2021.1). Reads were referenced assembled against a *Narcissus tazetta* subsp. *chinensis* chloroplast genome (MN432153). For the 2019 and 2020 cohorts, DNA extraction used Qiagen DNAeasy Plant Mini Kit, sequenced with Oxford Nanopore Technology (ONT). The 2021 cohort isolated chloroplasts with Sigma-Aldrich Chloroplast Isolation Kit, sequenced using ONT with the Flongle Flow Cell. Students conducted basecalling and data analysis using Geneious Prime, referencing reads against *N. poeticus* and *N. tazetta* subsp. chinensis chloroplast genomes.

Virtual workplace encounters involved student interactions with scientists over Skype and Zoom, exploring various roles in plant science mirroring the activities of the students through the project. Scientists were recruited through informal connections. Typically, they would provide an overview of their organisation and the role they play before opening the floor to questions from the students. Many scientists engaged with the students by asking them questions relating to the project.

The cancellation of UK exams in 2020 and 2021 provided a unique opportunity. The 2019 examination material was kept secure by examination boards and schools. This allowed a direct comparison between a control cohort (2019, $n = 14$, students who had not been involved in the Jersey Daffodil Project) and an experimental cohort (2021, $n = 5$, students who had taken part in the Jersey Daffodil Project) from Beaulieu Convent School, sitting the same examination paper under the same conditions. The interquartile range, means and ranges were compared, with an experienced assessor marking the experimental group due to lockdowns. Data from collaborating schools were unavailable. Numbers in the experimental group were impacted due to lockdowns preventing assessment of students who would have sat examinations in 2020.

## 3 | RESULTS

### 3.1 | Attitudes towards STEM subjects

The radar plot in Figure 1 shows how the students' attitudes towards STEM careers changed over the year of the project for each experimental cohort (2020 and 2021). Using the 4-point Likert scale, where zero (the centre of the plot) represents 'strongly disagree' and three represents 'strongly agree' in response to each of the statements on the vertices. Students reported positive changes in their awareness of possible careers, maintaining their high initial interest in a Science career (93% pre-project to 100% post-project), but more students also wanted to use computational skills in any future career (pre: 38%, post: 62%). Over 90% of students also reported improving or significantly improving the following skills: using initiative and being self-motivated; teamwork; negotiation skills; valuing diversity and differences; problem solving; and numeracy and ICT skills.

We found that students developed competency in the laboratory 'hard skills' such as micropipetting incredibly quickly through repetition of chloroplast isolation, DNA library preparation and flow-cell loading. The repetition of techniques has allowed students to coach each other and give a closer reflection of what a scientific career resembles in contrast to 'whizz-bang' outreach activities (entertaining demonstrations, typically involving explosions). From the 2020 cohort, 100% of the students applied for biological (including biochemistry, but not including healthcare aligned subjects) undergraduate courses, with the desire to continue studying plants being a key motivator. There may have been an impact of the global pandemic

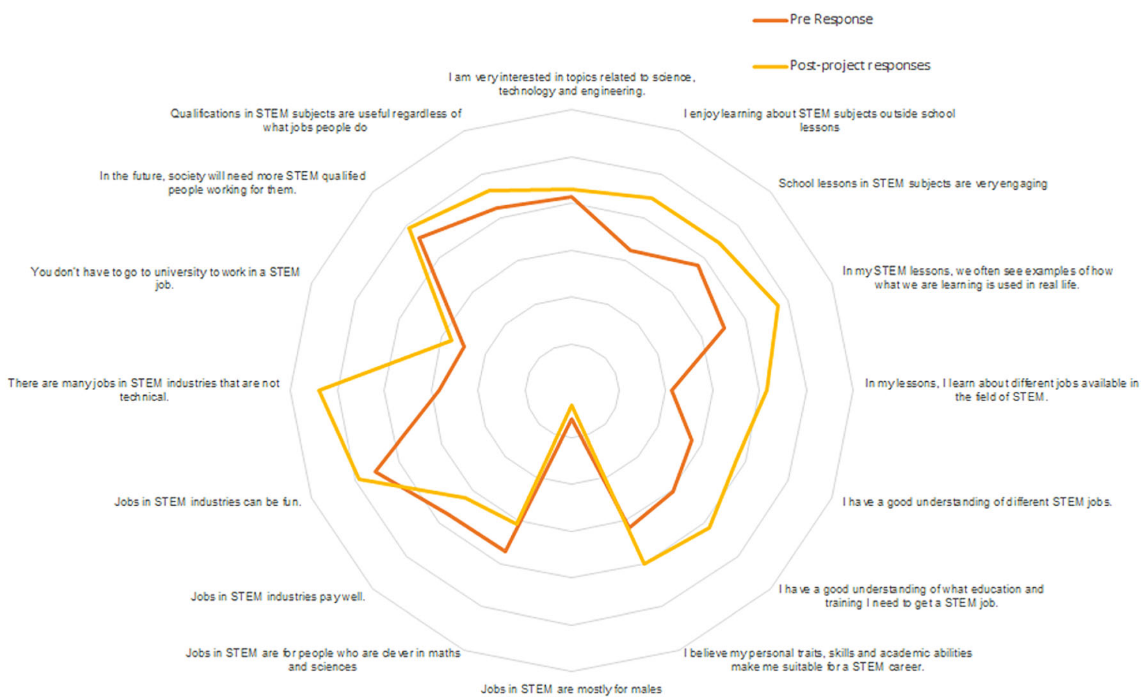


**FIGURE 1** A radar plot showing how students' attitudes towards STEM changed before and after taking part in the Jersey Daffodil Project. The farther the plot from the centre, the higher the degree of agreement. The closer to the centre of the plot indicates that all students strongly disagree. Responses were obtained via a 4-point Likert scale using surveys found in Notes S1 and S2.

on raising the profile of biosciences, but this was not shared by students through informal discussions. Historically, around 85% of students studying biology at the school would go onto higher education, with the majority wishing to study healthcare aligned subjects such as medicine, dentistry and midwifery. A number generally pursue non-biological or healthcare-aligned subjects such as law, journalism or finance.

### 3.2 | Examination performance

Figure 2 shows the positive impact that the project has had on the learning of genetics and gene technologies within the cohort, seemingly having more of an impact on the more able students. The mean Cognitive Ability Test scores of the 2019 cohort (110.0 ± 5.48) and 2021 cohort (111.2 ± 18.43) were comparable; however, the latter group showed a much greater range in prior attainment. The cohort sizes are small, and as such, a larger dataset would be needed to affirm a true relationship between the project and academic outcomes.

### 3.3 | Outreach

Participating students have been keen to share their science beyond the walls of our school. In addition to the poster they have submitted to Plant Biology 2021, they have been interviewed by Heredity Journal, presented a poster to Fellows of the Royal Society, as well as taking part in virtual conferences (Institute of Research in Schools & RHUL Biology Masterclass) sharing the entirety of the project. These students also produced a short film for the Royal Society's Tomorrow's Climate Scientists programme. Following participation, those who had participated in these outreach activities had reported a greater identity as scientists through informal discussions.

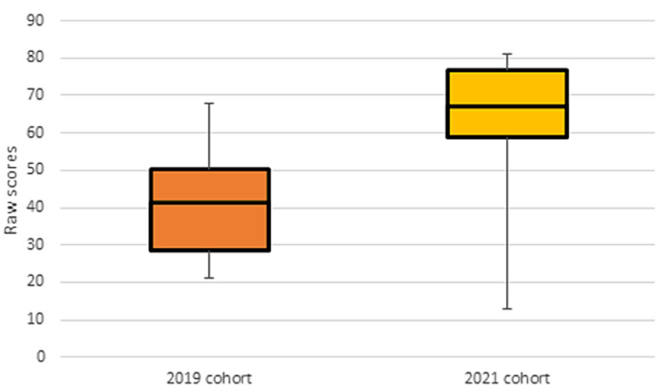


**FIGURE 2** Analysis of the pre-COVID-19 cohort (examined in 2019) and the 2021 cohort OCR Biology A (H420/02) performance showing the range of marks obtained, along with the interquartile range around the mean. The 2019 cohort did not undertake the Jersey Daffodil Project, whereas the 2021 cohort had taken part in the project. Both cohort sizes were small, but they were closely matched in mean cognitive ability.

### 3.4 | Scientific findings

Although the data produced from sequencing the OQ785886 *Narcissus* Division 4 W-Y cultivar and the OQ785887 *N. tazetta* Division 8 W-O cultivar was far from complete, the referenced-based assemblies were 'good enough' for students to produce their own phylogenetic tree (Figure 3).

### 3.5 | Nature connectedness

During the course of the project, students and their families made over 1500 observations of daffodils. The impact of this time spent in nature was assessed by calculating the nature connectedness index. We found that the mean nature connectedness index of the respondents was 72.9. This is markedly higher than the national average for 16–18-year olds (47.64) (Richardson et al., 2019). It was also worth noting that pro-nature behaviours were also positive: 100% of survey respondents travelled by foot or bicycle when surveying daffodils; 42.9% picked up litter; and 100% spent time listening to nature. When observing daffodils, each respondent noted that they saw other plants, 92.9% reported seeing insects, with even soil and rocks being actively observed by 42.9% and 57.1%, respectively.

## 4 | DISCUSSION

Providing students with the opportunity to engage in genuine, advanced research has to be a key driver for secondary education to maintain the pipeline of scientists. As educators, we must ensure that traditionally underrepresented facets of science are overtly visible, especially plant science (Stroud et al., 2022), at a time when funding for taxonomy and plant science research is scarce and even worse for non-crop species.

When considering the value of such activities as the Jersey Daffodil Project, it is important to critically assess what impact it has had on the students' learning as well as their aspirations. Although the sample size is limited, there was a clear benefit to these students' learning following the project, especially for those who were previously higher-attaining students. This may be attributed to the narrative of the investigation drawing upon many facets of their studies and thereby driving meaningful learning that builds robust connections rather than compartmentalised approaches to their learning. Therefore, students were supported in making the next step into a scientific career by providing them with the gateway grades for their aspirations.

As shown in Figure 1, students' views towards STEM careers did change. It may be that their repeated exposure to generating meaningful data, rather than attempting to observe the same results of iconic practicals as every previous generation, has increased their identity as scientists. It may have helped them understand the role of a scientist in research and provided them with the confidence that they could learn the skills to use cutting-edge technology.

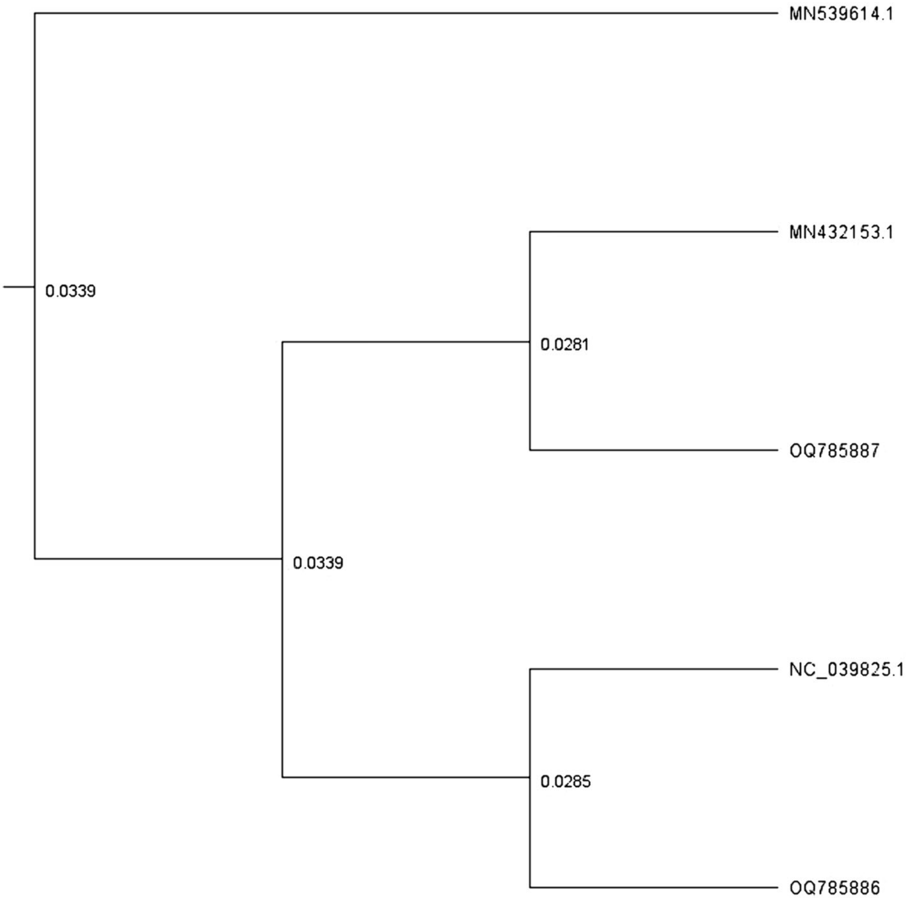


**FIGURE 3** Phylogenetic tree produced using Geneious Prime (2021.1) using data from GenBank. The phylogenetic tree illustrates how similar the DNA sequences are within each specimen. The MN539614.1 *Pancratium maritimum* was used as the outgroup. Students had created assemblies from the sequencing OQ785886 *Narcissus* Division 4 W-Y cultivar and OQ785887 *Narcissus tazetta* Division 8 W-O cultivar.

It may also be that many of these views changed as a result of interactions with other scientists and those involved in communicating science (Dewitt, 2019). By discussing their thoughts and goals with a diverse group of people, many students have been able to see how they could fit into a scientific career after completing their secondary education. It was important that these encounters were true reflections of individual experiences to truly inform students of what a scientific career looks like from their perspectives rather than a 'whizz-bang' demonstration memory. Unexpectedly, this led to an entire cohort pursuing tertiary education in biological science in 2021. This may show evidence of the role of belonging and connectedness in psychological energy (Bevins & Price, 2016) and their impact on aspirations.

It remains a challenge to demonstrate the value of sustained research within the curriculum, mostly due to the time demands on staff and finances. As this project has remained an extra-curricular activity, it has been seen as a beneficial addition to the curriculum rather than replacing other aspects. As students became more aware of plants and plant science through the project, their engagement in these curriculum lessons increased. The use of ONT Rapid Sequencing Kit (SQK-RAD004) and Flongle flow cells has improved both of these elements, with the entire protocol achievable within 45 min and reagent costs dropping close to £100 per run. As the costs are likely to continue to decrease, schools could work collaboratively to share the hardware and make consumable costs and time the only outlays.

## AUTHOR CONTRIBUTIONS

**Jon Hale**: Design of the research; performance of the research; data analysis, collection or interpretation; writing the manuscript. **Alex Harkess:** Data analysis and writing the manuscript. **Kálmán Könyves:** Design of the research and writing the manuscript.

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## CONFLICT OF INTEREST STATEMENT

Jon Hale was a teacher of a number of participants. Alex Harkess and Kálmán Könyves report no potential conflicts of interest.

## DATA AVAILABILITY STATEMENT

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

## ETHICS STATEMENT

Informed consent was obtained for all participants included in this study in line with Beaulieu Convent School's policy on research. Participants maintained the right to remove their data from the study without limiting their opportunity to take part in the Jersey Daffodil Project. No identifiable data was collected in order to maintain anonymity.

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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