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Oceans of Inspiration: A Marine Based STEAM Project

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ABSTRACT

This paper describes a set of project-based learning activities focused on a theme of the oceans and marine life. Whilst still providing a clear link to existing physics curricula, the STEAM (Science, Technology, Engineering, Art and Mathematics) design tasks embrace oceanography's interdisciplinary nature and its scope for allowing students to appreciate the complexity of the real world, affording connections to be made between science and art. By encouraging such links to be made, we exemplify how to effectively communicate to students that imagination and creativity is essential to successful scientific research and we highlight activities that can make physics more accessible, relevant, and interesting to a broader range of students. We also analyse the activities' effects upon the students' attitudes to physics and their spatial ability, manual dexterity, grit, patience and creativity.

Keywords: oceanography, biomimicry, e-textiles, STEAM, smart materials

INTRODUCTION AND BACKGROUND

In 1959, the physicist and novelist CP Snow famously argued that the two cultures of the sciences and the arts were dangerously divided and that better communication between them would be required to successfully address the world's interconnected problems (Snow, 1959). Snow's lecture discussed the way in which physics and the arts are pigeonholed as markedly disparate fields and that this is perpetuated by an education system that does not encourage individuals to embrace them both. Most people are aware the polymath Leonardo da Vinci provided significant contributions within physics and art, but historically there have been more individuals bridging the two fields than some may initially think. Whilst studying the polarisation of light, the Scottish physicist Sir David Brewster invented the kaleidoscope. Similarly, whilst trying to copy his calculations and notes, the English astronomer Sir John Herschel invented the cyanotype process. His strikingly beautiful cyan-blue prints became incredibly influential in the art of photography. Indeed, Einstein was known to have said 'The greatest scientists are artists as well' (Calaprice, 2000). Now, with the advent of digital technologies such as 3D printers and pens as well as smart materials, the borders between physics and art are arguably becoming increasingly blurred. For instance, the appropriate selection of materials for use with a 3D printer requires an understanding of pressure, tensile strength and elastic moduli. To comprehend how metamaterials function relies upon a grasp of electromagnetic waves and refractive indices. To follow how magnetorheological materials and piezoelectric materials work needs an understanding of the physics of magnetic and electric fields.

One of the present-day physicists making art is Dr Robert J. Lang who used to work for NASA and is also one of the foremost origami artists. He has highlighted how the mathematics of origami has led to safer airbags and Brobdingnagian space telescopes. In reverse, examples of contemporary artists using physics in their work include Fabian Oefner who places paint on rotating platforms to create spectacular visualisations of the relationship between centripetal acceleration and tangential velocity. The fashion designer Iris van Herpen's haute-couture collections have become renowned for combining the most up to date science and technology with artisanal craftmanship, to the extent that her work is no longer simply found in ladies' wardrobes but is now exhibited in numerous international art museums. Such pieces are often heavily steeped in physics, including transparent organza sewn to display moiré fringes and garments composed of various shapes found in cymatics. She used magnetic fields to manipulate material made from resin impregnated with iron filings and she attributed the ideas behind her collection titled Magnetic Motion to her visits to CERN (van Stel, 2019).

Various new research establishments, such as the MIT Media Lab, have formed in recent years to reflect the fact that many projects increasingly cut across disciplines and require a broader range of skill sets to develop solutions. Formal collaborations between artists and laboratories like CERN and Fermilab have further melded physics with art (Loek, 2019). Soft-matter physicist Tom McLeish has noted the similarities between scientists and artists and challenged the commonly held belief that scientists use less imagination and creativity (McLeish, 2019). This argument is supported by Root Bernstein's finding that

> "Nobel laureates were significantly more likely to engage in arts and crafts avocations than Royal Society and National Academy of Sciences members, who were in turn significantly more likely than Sigma Xi members and the US public" (Root-Bernstein, 2008).

This suggests that not only does science require a form of creativity, but that there is a connection between scientific and non-scientific creativity (Root-Bernstein et al., 2019; Root-Bernstein and Root-Bernstein, 2013; Root-Bernstein, 2015). According to the World Economic Forum (2016), creativity and cognitive flexibility are becoming increasingly important and felt to by employers to be among the most sought-after skills. A greater emphasis has also recently been placed upon a student's ability to adapt and to be resilient (Sant, 2013) and interdisciplinary skills are being viewed as vital for innovation (Paletz, et al., 2011). Projects showcasing the intersection of science and art are being touted as addressing such concerns and as promoting teamwork and aiding problem-solving and communication skills. As Shlain (1991) said:

> "Integrating art and physics will kindle a more synthesized awareness which begins in wonder and ends with wisdom".

It has been increasingly acknowledged within recent decades that science as well as art possesses an aesthetic element. However, it is worth noting that the movement towards including the arts within STEM education has rarely focused on secondary physics, though the benefits of such integration within physics at university level (van der Veen, 2007) has been explored. Indeed, a report on STEAM education from the BERA Research Commissions (Colucci-Gray et al., 2017) summarised some examples of school science projects that successfully integrate the arts, but none of them were physics based. Instead, they tended to be predominantly based in younger primary school years and focused on mathematics and biology, such as puppets being used to encourage discussions (Simon et al., 2008), dance being used as a mathematical teaching tool (Helsa and Hartono, 2011) or poetry being used to communicate neuroscience (Brown, 2015). In Ireland, McGlynn et al. (2019) have outlined a marine science and art project involving papier-mâché activities based around the theme of hydrothermal vents, but once more this was aimed at primary children and showcased how links can be made between pupils' understanding from biology. Again, it did not encompass physics.

Much attention has been paid to the relatively low number of females entering post-secondary courses in physical science and engineering (Mack and Walsh 2013). Logically, this has been associated with the low number of girls taking physics at A level (Silim and Crosse, 2014). Donnelly (2014) explored gender differences amongst undergraduate physics students at the Universities of Edinburgh, Hull and Manchester and found 'no overarching differences in the approach or reasoning of male and female students' nor differences in their reasons for choosing physics. Donnelly concluded that:

> "This suggests that in order to improve the gender equality of both secondary school and undergraduate populations, the gender issue needs to be targeted earlier in students' primary and secondary education, a point at which students are often influenced".

Action research has shown that girls in particular are more likely to switch off from physics if they are not convincingly shown how it fits into the bigger picture of society. Tsai (2004) commented that within secondary schools, the

> 'way science is presented, the language it uses and the examples and applications it addresses imply science to be masculine.'

Similarly, Carlone (2004) reports:

> "Recent literature in science education suggests that, to transform girls' participation, learning, and identities within school science, we must think about ways to engage girls in different kinds of educational activities that promote broader meanings of science and scientist."

Carlone (2004) highlighted the need for:

> 'a response to the traditional physics curriculum to make physics more accessible, relevant, and interesting to a broader range of students.'

OCEAN THEMED PROJECT-BASED LEARNING

The oceans have historically been a popular theme for science and art collaboration, with Captain James Cook taking the painter William Hodges with him to capture Antarctic seascapes. Ocean science is ideal in its ability to demonstrate the application of physical principles within an interdisciplinary context and the oceans provide the power to inspire students to a greater awareness of environmental conservation. Education research has shown that the most successful initiatives in improving students' attitudes towards science and mathematics are the ones that show the connection to real-life experiences, are hands on and relevant to the student's own life (Mosatche et al., 2013). Perhaps testimony to this is the attention generated by hyperbolic crochet, which was discovered by Cornell mathematician Dr Daina Taimina. This has now been developed by the Institute for Figuring to create the Hyperbolic Crochet Coral Reef project; a taxonomy of reef lifeforms bursting with vibrant hues, such as kelps, anemones and coral (Wertheim and Wertheim, 2015). This celebration of non-Euclidean mathematics is now one of the biggest art/ science/ environmental projects in the world, having been viewed by more than three million people and skilfully crafted by in excess of seven thousand individuals.

Marine life has long since featured in the world of high fashion, with Coco Chanel being so enthralled with pearls that they became a key feature of her fashion house. Alexander McQueen's devotion to marine life often featured in his work, which included digitally enhanced prints featuring manta rays as well as outfits crafted out of mussels, oyster shells and razor clams. With the recent sea shell jewellery trend and Disney's remake of the Little Mermaid currently set for release, the ocean theme has certainly grabbed the public's attention.

All of this, along with their mesmerising beauty, meant the oceans were felt by those involved in this study to be an ideal way to fuse the teaching of art with physics. This paper's study focuses on exemplifying how this extracurricular theme can form the basis for STEAM activities aimed at eleven to twelve-year olds. It was felt that the activities and subject matter may perhaps particularly appeal to girls and therefore perhaps attract a more diverse demographic than more traditional STEM clubs. This age group was selected as it has been shown that a decline in attitude towards science amongst girls generally begins in the final year of primary and early secondary (Murphy and Whitelegg, 2006).

RATIONALE OF CURRENT STUDY AND RESEARCH QUESTIONS

Spatial ability is aptly defined as 'the ability to generate, retain, retrieve, and transform well-structured visual images' (Lohman 1996, p. 112). Regrettably, this important dimension of nonverbal ideation has often been largely ignored within the traditional school physics laboratory, particularly as it has been shown to be critical in terms of determining both continuance and success within the subject.

Shea, Lubinski, and Benbow (2001) tracked the progress of 563 individuals identified at age 13 as being within the top 0.5% of the population in general intelligence. At the point at which they were identified as being academically talented, their spatial skills were assessed. Those who subsequently earned STEM degrees and were still following STEM careers 20 years later were shown to have typically displayed higher levels of spatial ability as young adolescents. Similarly, Webb, Lubinski, and Benbow (2007) found that amongst 1,060 adolescents identified as being within the top 3% of the population in academic ability at age 13, those who possessed higher levels of spatial ability proceeded to follow STEM careers. Heyer's PhD thesis (2012) established an empirical relationship between the spatial thinking skills of university students studying non-science subjects and their conceptual understanding of astronomy.

Spatial skills have been identified as key to success in the sciences, mathematics and engineering (Pallrand and Seeber, 1984; Kozhevnikov, Motes and Hegarty, 2007; Uttal, Miller and Newcombe, 2013, Mac Raighne, 2015). To problem solve in physics, students need to be able to visualise complex situations and imagine the effect a change of variable would have upon a graph. Spatial skills can act as an effective predictor for both future performance and the likelihood that an individual will follow STEM career pathways (Wai, Lubinski and Benbow, 2009; Hegarty, 2014). It has been shown that there is a stronger correlation between an individuals' future propensity for innovative thinking and their spatial skills than their scores in mathematics exams. One only has to think about chirality, the double-helix structure of DNA or planetary motion to appreciate how it is an inherent cognitive requirement for all of the sciences.

Research has documented a clear relationship between spatial ability and motor skills (Voyer and Jansen, 2017). Therefore, it is not surprising that various studies have shown a correlation between motor proficiency and scholastic performance (Baedke, 1980; Beilei et al., 2002; Haapala et al., 2014; Geertsen et al., 2016), and more specifically that of motor proficiency and mathematical achievement (Luo et al., 2007; Kim et al., 2018). Of note, fine motor skills, such as manual dexterity, have been shown to be a better predictor of mathematical performance than gross motor skills (Fernández-Méndez et al., 2020). Fine motor skills are clearly necessary to perform most manufacturing engineering duties and many tasks within a physics laboratory. Indeed, Brychta et al. (2017) showed the influence of fine motor skill level (finger dexterity) upon the ability to make accurate measurements and Ackerman (1987) found that in pilots' later learning phases, their motor skills are the best predictors of their achievement. There is existing research showing the effects of origami (Bae, 2013) and fidget spinners (Cohen et al., 2018) on hand dexterity.

Knitting and crochet clearly require mathematical thought and can be used to convey complicated topological concepts (Henderson and Taimina, 2001; Kucukoglu, J. G and Colakoglu, 2013; Osinga and Krauskopf, 2004). There is also growing attention being paid to the use of knitting to teach basic maths skills to young children (Gresalfi and Chapman, 2017). Mathematical thought is inherently essential to the study of physics. The process of learning to crochet and knit does not lead to instant gratification. One would assume their fiddly and complicated nature means that to develop these skills an individual would need to possess grit and patience. Similarly, success in physics generally requires hard work and discipline, since students need to acquire a vast body of unequivocal knowledge and to memorise many formulae, protocols and rules. One could say that to continue with physics an individual requires grit and patience. Grit and patience have been previously shown to have a positive impact upon students' academic achievement (Duckworth et al., 2007; Strayhorn, 2014; Kallick and Costa, 2008; Costa, 2008; Costa, 2009) and their retention within the subject. Interpreting crochet patterns requires a degree of spatial ability and the use of hooks demands manual dexterity. To design and personalise woollen creations also presumably requires a certain degree of creativity. School level physics provides the pathway towards careers that require a high level of spatial ability, manual dexterity and creativity. Stathis and Eva (2018) called for

> 'more empirical evidence for the potential of the arts to foster in students a change of outlook as a result of learning science'.

This interplay between spatial skills, fine motor skills and STEM led to the following research question being proposed:

Research Question 1: Can STEAM activities focused around the making of marine life textile artforms help develop spatial ability, manual dexterity, grit, patience and creativity?

In agreement with previous studies (Guay, 1978; Voyer et al. 1995; Linn and Petersen, 1985.), Maeda and Yoon (2013) found after measuring individuals' 3-D mental rotation ability using the Purdue Spatial Visualization Tests: Visualization of Rotations (PSVT:R) that there was evidence of apparent male superiority. However, suggestion has been made that part of the reason males in general perform better than females in spatial ability tests may be due to a lack of confidence amongst the girls stemming from gender stereotypes (Cooke-Simpson and Voyer. 2007; Moè. 2009; Moè and Pazzaglia 2006; Ortner and Sieverding. 2008). Another factor thought to be contributing to this heterogeneity is the fact girls are more likely to be deprived of spatially rich activities in childhood (Reilly, Neumann and Andrews, 2017). Spatial toys are currently still being marketed to boys, much like computers were in the 1980s. With the strongly held belief that this gendered-marketing is a significant contributory factor to the current male dominance in the IT sector (Henn, 2014), researchers believe it is beneficial to provide girls with learning experiences that develop their confidence in performing spatial tasks.

Research shows spatial competence is not immutable and that practice can yield substantial improvement (Uttal and Cohen, 2012; Sorby, 2009a,b; Brus and Boyle, 2009; Allam, 2009; Hamlin, Veurink and Sorby (2009); Schmidt, 2015). Halpern et al. (2007) recommend teaching this to girls and advise that they should be provided with spatial skills training. Miller and Halpern (2012) looked at the effect of 12 hours of spatial training among a mixed sex sample of highly gifted STEM undergraduates. They found that although the training initially narrowed gender differences and improved examination scores in physics for a short time after the training, the effects had worn off after eight months. They concluded that the

> 'results suggest that sustained exposure to spatially enriching activities over several semesters or years may be necessary to address gender gaps in spatial skills'.

Therefore, it was felt that this study could also answer a secondary aim of establishing whether e-textiles can provide an effective means for increasing the level of participation of girls within physics. That is, we sought to answer:

Research Question 2: Can integrating textile art into a science club widen the appeal of STEM and more specifically help address the gender imbalance within physics?

METHODOLOGY

Learning Activities

The activities were designed and delivered by the author of this paper. They were trialled by seven students within the youngest year of a Scottish secondary school (aged eleven); six of whom were girls. As this research attempts to explore avenues to address the existing gender imbalance within Physics, it could be argued that it would have been more appropriate to have selected a sample group that was more balanced in terms gender, so that a comparison could have been made between attitudinal change amongst the boys and girls. However, it was felt unethical, inappropriate and unfair to choose who could attend an extracurricular club based solely upon gender and so the club was instead offered to everyone within the youngest year of this school. The very fact six of the seven students electing to attend were female does in itself confirm that the ocean-based textile activities were successful in their attempt to appeal to a higher proportion of girls than more traditional STEM clubs. In terms of validity of data, it clearly would have been better to have opted for a larger sample size. However, the practicalities of conducting the project with children and the fiddly nature of the activities, including the use of crochet hooks and needle work, led the author to deem it beneficial to limit the club to only this year group as otherwise the size of the practical group would have been less manageable. Had there been more facilitators available, then a wider sample size in this study could have been an option. For each of the studies, the control groups comprised of pupils within the same year of the school who did not take part in this STEAM club. The control groups had an equal balance of boys and girls. One may conjecture that it might have been best to compare the girls in the STEAM group to girls in the control-group. However, as the sample size of seven was already so small, it was felt best to consider the STEAM group as a collective whole, rather than then subdivide it further into boys and girls.

The first session showcasing the nexus of physics and art involved students making jellyfish cartesian divers using hex nuts, plastic pipettes, disposable gloves and drinks bottles. The second activity involved making artwork based on the layers of the ocean. The iridescent effect of the pearlescent particles made it look akin to mother of pearl, which sparked discussion on the interference of light and the work by physicists at the Cavendish lab to recreate the steps of molluscs to form nacre-inspired bioactive materials (Finnemore et al., 2012). The students then made their own 'ocean in a bottle' with cooking oil, water and blue food colouring (**Figure 1**).

Figure 1. Ocean in a bottle showing stratification of water columns

The simple zoetrope perfected by James Clark Maxwell has been experiencing a resurgence, having gained recent attention with the likes of Veerle Coppoolse's 3D version depicting the lifecycle of a butterfly and Jiří Zemánek's use of the EggBot Pro to robotically etch mathematically generated patterns onto Christmas ornaments (Zemánek, 2018). The trend extends to food art with cake zoetropes featuring in a prominent supermarket's advertisement campaign. The basic physics principle behind these contemporary reworkings was explored with the students making thaumatropes and replicas of the classic leaping whale zoetropes (**Figure 2**).

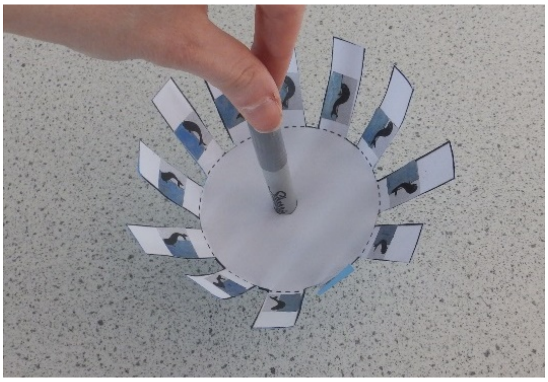

Figure 2. Ocean thaumatrope and whale zoetrope

Since delicate corals are destroyed by sea temperatures increasing, it was felt that painting coral patterns with thermochromic pigments would be a captivating visual way of demonstrating the deleterious effects on ocean ecosystems and the effects of coral bleaching (**Figure 3**). During this time, the students had access to prints from Ernst Haeckel's Art Forms in Nature. Haeckel was a German zoologist who is particularly remembered for his work on marine organisms such as cnidarians (jellyfish, anemones and corals) (Haeckel, 2000).

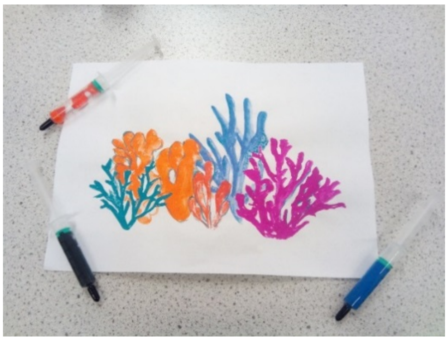

Figure 3. A painting of delicate corals made using thermochromic pigments, highlighting the damage of rising sea temperatures

The next activity took its inspiration from the work of Sachiko Kodama, a sculptor with a degree in physics and a PhD in art. She makes 3D liquid sculptures by controlling ferrofluid with magnetic fields (Kodama, 2008). The students poured ferrofluid onto a glass plate placed on top of a magnet and found the ferrofluid quickly assumed the shape of a sea urchin (**Figure 4**). Interestingly, a new space exploration tool has been modelled on a sea urchin's teeth and their spines have inspired crack resistant cement. Furthermore, the ability of a sea urchin to rapidly change the elasticity of the collagen in its skin could provide novel applications such as bio-inspired brain implants for patients with Parkinsonism, implantable biosensors and treatments for skin aging (Mo et al., 2016).

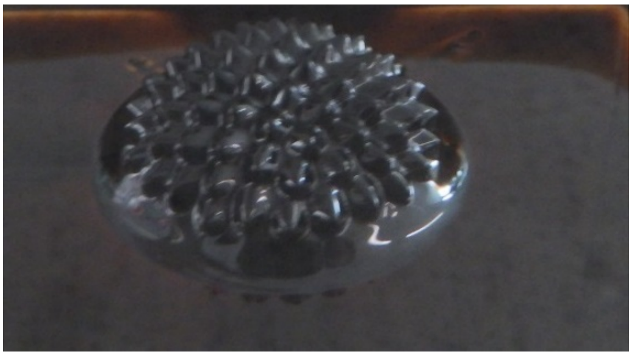

Figure 4. A ferrofluid sea urchin

Squishy circuits (Johnson and Thomas, 2011) were then introduced with the students making conductive and insulating play dough as outlined in Boyle (2019), which they then fashioned into bioluminescent octopuses, jellyfish and seahorses and sea turtles (**Figure 5**).

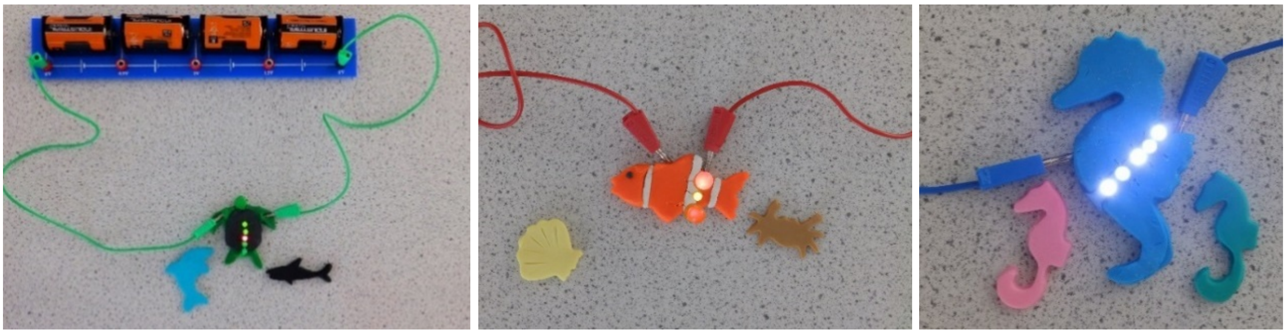

Figure 5. Squishy circuits made from conductive and non-conductive dough: a bioluminescent seahorse

The following week commenced with the students making pop-up cards from origami marine life (**Figure 6**). They then formed paper-circuits by using copper foil tape and conductive ink pens to add LEDs to their cards (**Figure 7**). As certain sea turtles have recently been discovered to exhibit bioluminescence, perhaps the turtles festooned with red and green LEDs were more scientifically accurate than some of the other creations. During the next few sessions, the students progressed on to making memory wire origami cranes and herons. They used shape-memory alloy to actuate paper (**Figure 8**) by following a set of instructions and pattern from MIT Media Lab's simple beginner's project (MIT Media Lab, n.d).

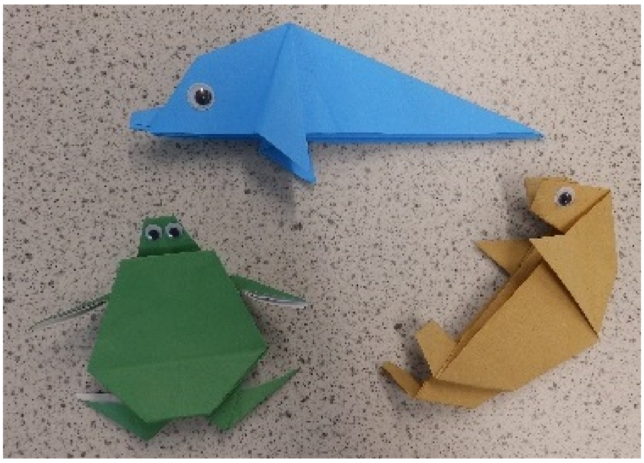

Figure 6. Origami otter, dolphin and sea turtle

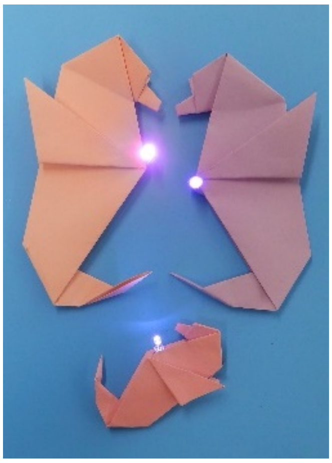

Figure 7. A paper circuit whose design was based upon bioluminescent seahorses

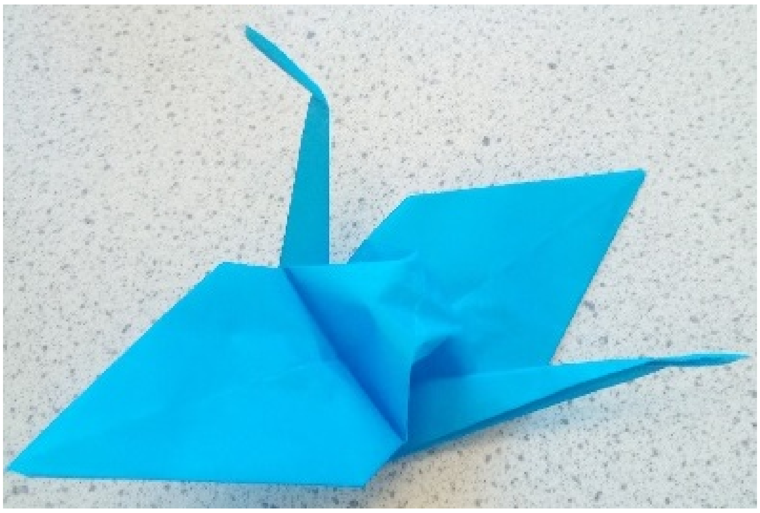

Figure 8. An origami crane with memory wire placed inside to make the wings flap

The squishy and paper circuits consolidated the students' understanding of basic circuitry and electronics, such as charge, polarity, current, voltage, resistance, short circuits and open and closed circuits. By then they were equipped to start working with e-textiles. They took their inspiration from those working in wearable technology industry, such as the likes of Kitty Yeung who has been using her physics background to harmonise science with fashion, creating garments embroidered with LEDs that blink according to the wearer's heart rate (Yeung, 2017). Using conductive thread, they each stitched a cell holder, LEDs and a push switch inside either a felt jellyfish, seahorse or sea turtle (**Figure 9**). A more complicated circuit was then attempted, with students sewing a magnetic switch and LEDs inside a felt penguin, narwhal or seal. They then stitched a magnet inside a felt fish and adorned it with sequins resembling scales. When they placed the fish on their felt bird or mammal, it activated the circuit with the LEDs, making the animal's face light up (**Figure 10**).

Figure 9. A felt circuit jellyfish and seahorse

Figure 10. Circuits involving magnets sewn into felt fish and magnetic switches sewn into felt narwhals, seals and penguins

Before introducing hyperbolic structures, the students were first taught crochet skills through making amigurumi animals. They began with either the simple jellyfish or octopus (**Figure 11**) and they were interested to know that such creations are thought to benefit premature babies as their tentacles resemble the umbilical cord and reduce the amount the infants pull at incubator monitor cords (Smith et al., 2018). They then progressed onto more complicated projects such as seahorses (**Figure 12**), sea urchins (**Figure 13**) and sea turtles (**Figure 14**). Some opted to use a pompom maker to create the anemones used by boxer crabs (**Figure 15**). Others chose to make starfish and added electroluminescent wire (Adafruit, 2012) to replicate their bioluminescence (**Figure 16**). Crocheting the electroluminescent wire itself resulted in something resembling Singapore's 'the urchins' art installation. A few at this stage chose to focus on creatures affected by climate change (**Figure 17**).

Figure 11. Crocheted jellyfish

Figure 12. Amigurumi seahorses

Figure 13. Amigurumi sea urchins

Figure 14. Amigurumi porpoise, sea turtle, lobster and clam

Figure 15. Amigurumi boxing crabs with pompom sea anemones

Figure 16. Crocheted sea urchin and bioluminescent starfish formed using electroluminescent wire

Figure 17. Amigurumi animals affected by climate change

From there, they continued on to make crocheted plankton (**Figure 18**), adding LEDs to dinoflagellates to make them appear bioluminescent (Instructables Craft, n.d.).

Figure 18. Crocheted plankton: coccolithophore, bioluminescent dinoflagellate, radiolarian and a circular diatom

To crochet their hyperbolic coral structures, the students progressively increased the number of stitches in each row (**Figure 19**). Some decided to modify their design to form a coral reef scrunchie for their hair.

Figure 19. Hyperbolic crochet coral including hyperbolic plane, pseudosphere, seed-pod and double hyperbolic plane

The next design task was based around the Venus' flower basket, a living embodiment of the fusion of science and art, with its distinctive lattice-like structure being mimicked in architectural design, such as the Gherkin building, and its silica fibres being studied to help make better optical fibres. They even contain a uniquely romantic story by housing a male and female shrimp. Young shrimps enter the sponge when they are small but as they grow, they become trapped inside, remaining with the same mate for life. They are offered as wedding presents in Japan as they symbolise eternal love. After this introduction, the students then crocheted their own Venus' flower basket (**Figure 20**) and adorned it with optical fibres connected to LEDs.

Figure 20. Crochet baskets fashioned to resemble Venus' flower baskets

The original intention was for the students to then make a snow globe based on the concept of marine snow, the continuous shower of organic detritus that delivers energy to organisms living deep down in the ocean. They were to use magic snow as the detritus and polymorph moulded into the shape of deep sea creatures. However, the organisms living in the murky depths of the aphotic zone were quickly discounted by the students as offering little visual appeal. So, they instead followed the more endearing task of making festive penguin pipe cleaner snow globes (**Figure 21**).

Figure 21. Pipe cleaner penguins inside a snow globe, surrounded by magic snow

They then fashioned autoheal self-repairing polymer into jellyfish designs resembling Blaschka's glass models (**Figure 22**). This particularly matched the bio-inspired theme since, amongst other developments, scientists have created a polymer inspired by ocean mussels and adhesive patches for wounds based on octopuses. Moreover, jellyfish have recently led to the development of water resistant self-healing artificial skin and seaweed extract has been used by bioengineers to create a hydrogel adhesive that can bind tissues together. The students were then told about research being conducted locally into digitally fabricated biodegradable structures made from chitin, a polymer that is found in crustacean shells.

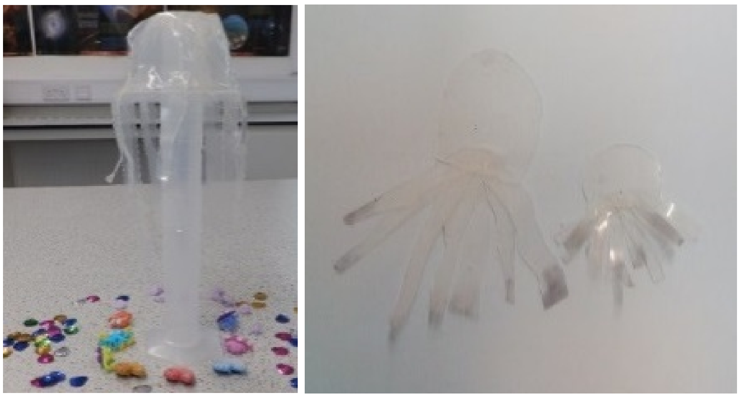

Figure 22. A jellyfish artwork constructed out of autoheal self-repairing polymer

The next activity involved the pupils making 3D ocean creatures by using ultraviolet light boxes to cure liquid resin (**Figure 23**).

Figure 23. 3D shapes made using ultraviolet light to cure liquid resin

The students then studied Anna Atkins' books of cyanotype impressions of algae (Atkins, 1843). Numerous artists and fashion designers have been resurrecting this 19th century technique with contemporary twists. In an attempt to replicate such work, the students used potassium hexacyanoferrate III solution, ammonium iron III citrate and UV light boxes to form a photochemical reaction (**Figure 24**).

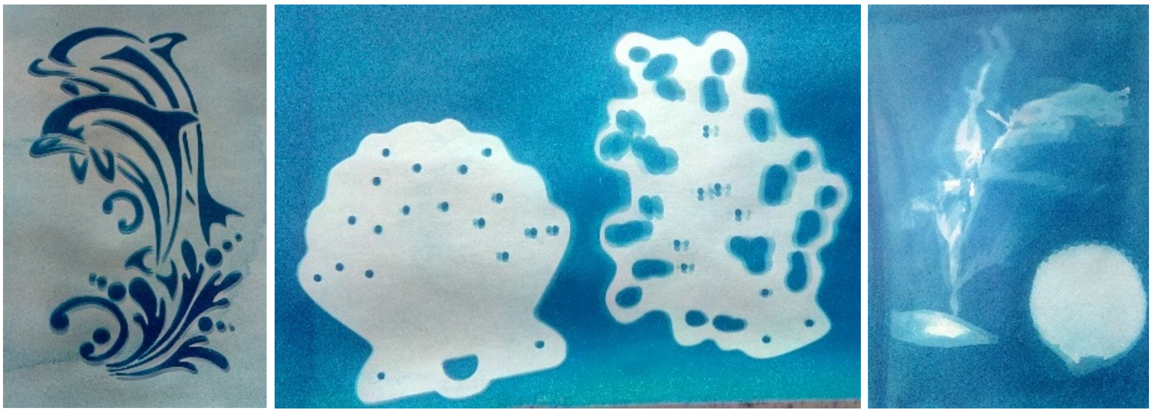

Figure 24. Cyanotype paintings of seaweed, scallop shells and dolphins

The quirky artform of diatom arrangement also dates back to Victorian times and has gained renewed interest with Klaus Kemp creating contemporary versions. There are many overlaps between algae and physics, such as the fact that researchers have discovered that algae living in low light intensity conditions can switch a quantum coherence on and off to maximise the light they collect for photosynthesis. Moreover, the psychedelic jewel like arrangements in diatom art resemble that of a kaleidoscope. So, the next design task selected for the students involved asking them to construct their own 'diatom' kaleidoscope a cardboard tube and mirrors (**Figure 25**).

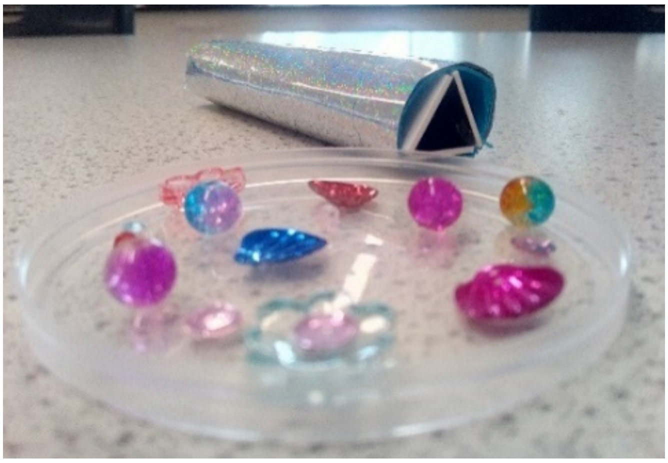

Figure 25. A 'diatom' kaleidoscope and the smart-phone kaleidoscope being used to observe an intricate pattern

The sessions and their relevance to existing curricula are summarised in **Table 1**.

Table 1. Summary of the activities' links to the UK physics curricula

Figure Number	Description	Physics curriculum links
1	Ocean in a bottle	Density; convection
2	Ocean thaumatrope and whale zoetrope	Persistence of vision
3	A painting of delicate corals made using thermochromic pigments, highlighting the damage of rising sea temperatures	Temperature and heat transfer
4	Ferrofluid sea urchins	Magnetic field patterns
5	Deep sea creature squishy circuits	Conductors and insulators; electrolytes; open and complete circuits; basic electrical circuit rules; short circuits; behaviour of LEDs
6	Origami otters, octopuses, dolphins, fish and lobsters	Spatial skills development
7	A paper circuit whose design was based upon bioluminescent sea turtles	Spatial skills development; open and complete circuits; basic electrical circuit rules; short circuits; behaviour of LEDs
8	A memory wire origami crane	Spatial skills development; open and complete circuits; basic electrical circuit rules; short circuits
9	Felt circuit jellyfish and seahorses	Open and complete circuits; basic electrical circuit rules; short circuits; behaviour of LEDs
10	Circuits involving magnets sewn into felt fish and magnetic switches sewn into felt narwhals, seals and penguins	Magnetism; open and complete circuits; basic electrical circuit rules; short circuits; behaviour of LEDs
11-13	Crocheted jellyfish, amigurumi seahorses and amigurumi sea urchins	Spatial skills development
14	Amigurumi porpoise, sea turtle, lobster and clam	Spatial skills development
15	Amigurumi boxing crabs with pompom sea anemones	Spatial skills development
16	Amigurumi animals affected by climate change	Spatial skills development
17	Amigurumi bioluminescent starfish formed using electroluminescent wire	Spatial skills development
18	Crocheted plankton: coccolithophore, bioluminescent dinoflagellate, radiolarian and a circular diatom	Spatial skills development and understanding of simple circuits
19	Hyperbolic crochet coral including hyperbolic plane, pseudosphere, seed-pod and double hyperbolic plane.	Spatial skills development and basic awareness of hyperbolic geometry
20	A woven basket fashioned to resemble the Venus' flower basket	Spatial skills development; refraction; total internal reflection and optical fibres
21	Pipe cleaner penguins inside a snow globe, surrounded by magic snow	Spatial skills development; covalent bonding in polymer
22	A jellyfish artwork constructed out of autoheal self-repairing polymer	Pressure; smart materials
23	3D shapes made using ultraviolet light to cure liquid resin	Ultraviolet light
24	Cyanotype seaweed and algae	Ultraviolet light
25	'Diatom' kaleidoscopes	Reflection

Analysis Methods

To assess the project's effects upon the students, they were asked to perform each of the following tests before they started attending the sessions and upon completion eight months later. A control group of thirty pupils (fifteen girls and fifteen boys) who did not take part in any of the activities was also tested at the starting point of the club, allowing a reference point and comparison to be made. However, a larger group was sampled (N=50) for the attitudinal questionnaire as it did not demand much time to complete and therefore did not necessitate non-STEAM club pupils deviating from their normal time tabled lessons. Again, there was an even gender divide for this control sample.

Each student's spatial ability was gauged using the paper folding test from Ekstrom, French and Harman (1976). This paper folding test required students to visualise where the holes would be situated after a piece of paper is folded and a hole is punched through it. The Purdue Pegboard Test (Tiffin and Asher, 1948) was employed to investigate dexterity.

Duckworth's 8-item grit scale was used to explore their passion and perseverance (Duckworth and Quinn, 2009) and Schnitkner's 3-factor patience scale was used to investigate their patience (Schnitkner, 2012).

Mohamed (2006) summed up scientific creativity as being:

> 'the uniqueness and appropriateness of the student's responses to questions related to science'.

The impact of the club upon students' creativity was measured using the 7-item scientific creativity test developed by Hu and Adey (2002) and marked according to their instructions.

Four attitude statements were adapted from the Student Questionnaire For PISA 2006 document (OECD, 2005), one exploring each of the domains of enjoyment, self-confidence, value and motivation. The selected statements were similar to those of Muller et al. (2013):

I find learning science interesting
I think science is too hard
I think science improves people's lives
I want to become a scientist

The responses used a 5-point Likert rating scale in the form of 1-strongly disagree to 5-strongly agree.

Inevitably any improvement in the students may in part be due to them having been eight months older between the initial testing to the time at which the project was completed and the final tests were administered. It is impossible to delineate exactly how much any improvement in a STEAM club member is due to them having aged a further eight months and naturally matured from how much it can be attributed to the effects of the club itself. The club started in August 2019 and reached its completion in March 2020. Obviously, it would have been better if the control group had also been retested at the same time, but this proved impossible with the sudden, unexpected and prolonged closure of all schools within the UK as a result of covid. Retesting all the students at the end of the extensive lockdown period would have led to even more potential variables clouding the results. So, instead the STEAM club member's data from August 2019, March 2020 and the control group's data from August 2019 could only be used.

RESULTS AND DISCUSSION

For the individuals taking part in the ocean-based STEAM activities, the attitudinal questionnaire revealed the results outlined in **Figure 26**. This suggests that the club served as a positive influence upon the students' inclination towards following STEM pathways. Presumably this was in part due to the participatory, humanistic (Hadzigeorgiou, 2005, 2016; Hadzigeorgiou and Konsolas, 2001), social and interactive nature of the activities.

Figure 27 shows the STEAM club members' scores in the paper folding spatial test, both before and after completion of the project. It can be seen that the STEAM club members started out with a higher spatial awareness than their peers (the control group) and that their spatial skills strengthened whilst taking part in the club. Therefore, similar to studies discussed earlier, this data suggests that spatial skills can be improved through carefully devised intervention. This is key as it has been previously shown they can act as a potential barrier to STEM disciplines.

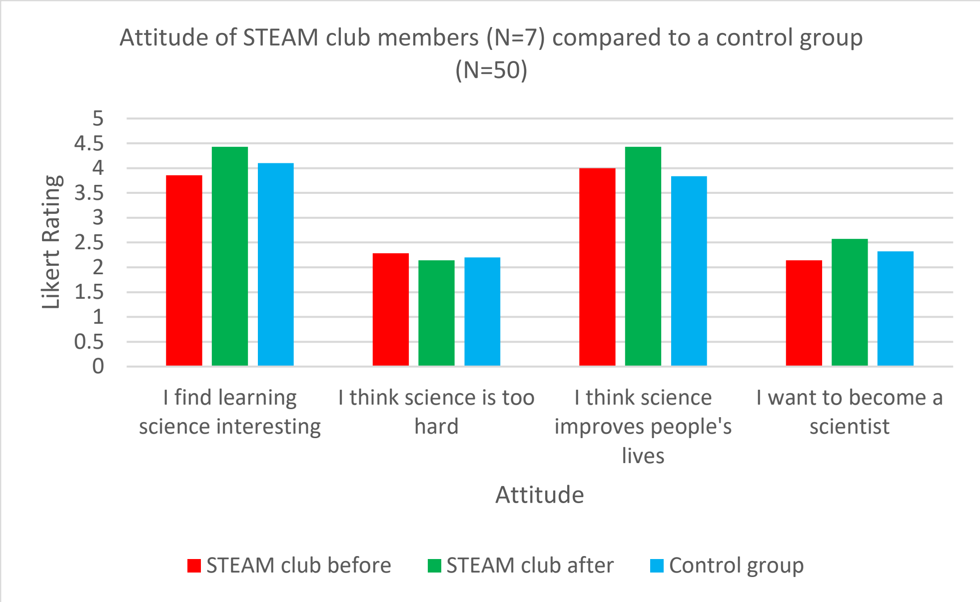

Figure 26. Students' responses to an attitudinal questionnaire before and after the ocean-based STEAM club in comparison to a control group who did not take part in the ocean-based STEAM club

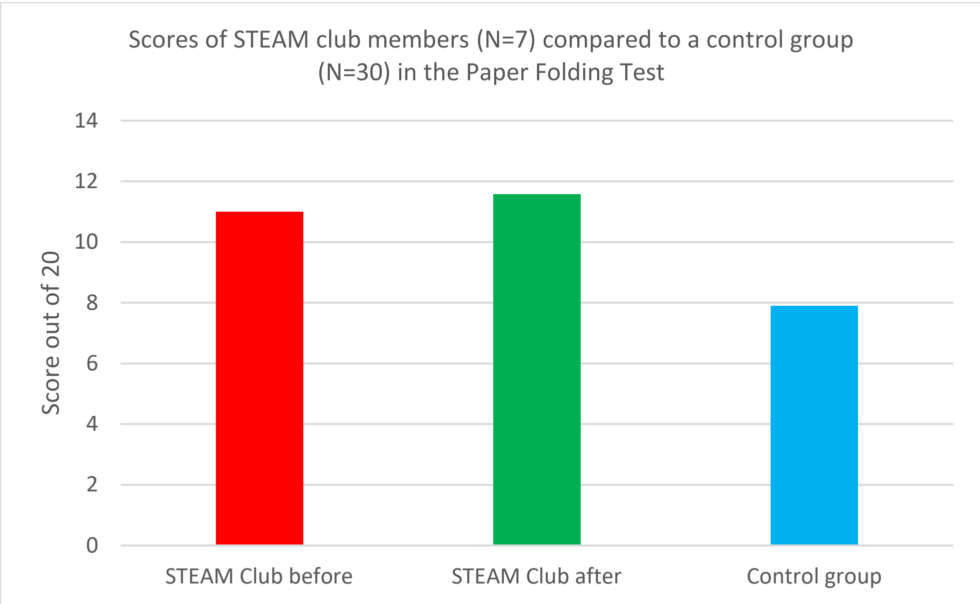

Figure 27. Ocean-based STEAM club students' paper folding test scores in comparison to their peers

The Purdue Pegboard Test involves placing as many pins as possible into slots on the board, using each hand individually over thirty second time periods. Then, over a further thirty seconds, they insert pins using both hands simultaneously. Finally, over a one minute time interval, they construct 'assemblies' comprising of a pin, a collar and two washers. The overall score for each element is the total number of pieces placed into the board. Figure 28 highlights the effect of the STEAM club activities upon the students' dexterity. It should again be noted that the club members were eight months older at the time of their second dexterity test and one may therefore initially ponder whether the gains could be attributed to them simply maturing with age, as opposed to any effect from the actual club itself. However, research from Gardner and Broman (1979) suggests that, when an eleven-year-old ages eight months, it should ordinarily have minimal impact upon this battery of tests. They found that 'assemblies' scores improve on average by less than two over this age range and that individual and bilateral hand scores show a variation of 0.1 or less between the ages of 11 and 12, with an actual decrease over this time in some elements. This finding presumably reflects typical variations between the same individual sitting a test at different times, something which could also be argued may have come in to play in our study. However, Buddenberg and Davis (2000) when exploring test-retest variability found a mean gain in one-trial administration of only 0.7 in each hand, 0.5 for both hands and 3.8 for assembly. The gains in our study compare favourably, with a gain of 1.3 for the preferred hand, 2.9 for the non-preferred hand, 2.3 for both hands and 6.0 for assembly.

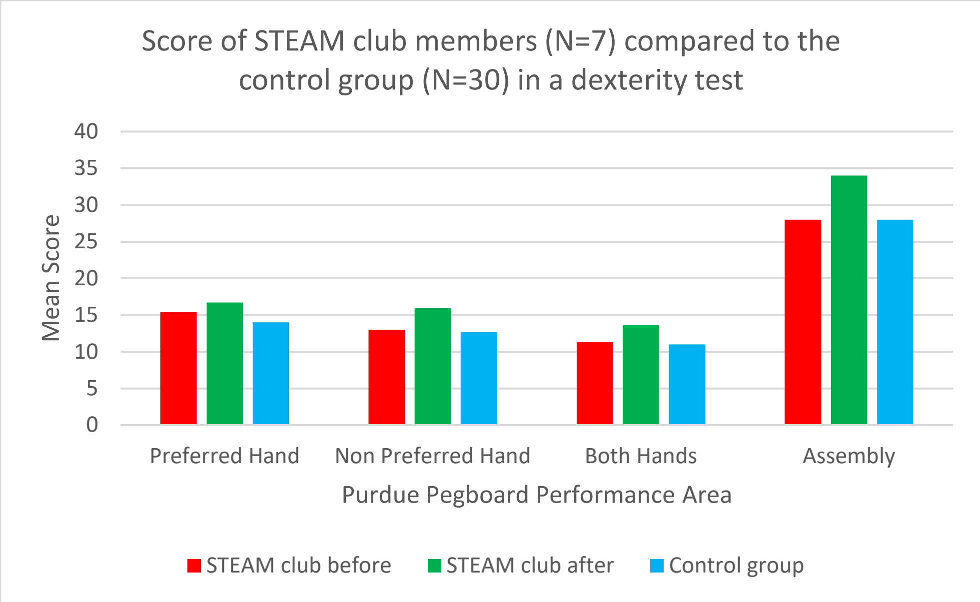

Figure 28. The effect of the ocean-based STEAM club upon students' dexterity

Figures 29 to **30** show a comparison of the STEAM club participants' grit and patience before and after completion of the project, with a control group's results displayed for comparison. On the 8 item grit scale (Duckworth and Quinn, 2009), all items were measured on a 5-point Likert scale and an overall score was assigned, with 5 being the most gritty. When using Schnitkner's 3 factor patience scale (Schnitkner, 2012), all items were measured on a 5-point Likert scale and an overall score was assigned, with 5 being the most patient. The pupils were all made fully aware that the club would require time and commitment to learn to crochet. Therefore, one may have anticipated that only those who were more gritty and patient than the norm would be inclined to join such a club in the first place. However, this does not actually appear to have been the case and this self-selecting group was found to have improved in these areas throughout the duration of the project. One may anticipate this should be the case anyway with the children having aged, but perhaps surprisingly Peña and Duckworth's (2018) longitudinal sample of students in 9th and 12th grades actually found 'absolute age has a positive effect of 0.09σ on perseverance of effort and a negative effect of -0.13σ on consistency of interest'. Therefore, the changes in the STEAM club's level of grit does seem to indicate a positive effect from the club. Bettinger and Slonim's data (2007) matches common intuition to show 'older children are more patient', but as their study involved experiments based around delayed economical gratification, it could not be determined how responses to self-report questionnaires on patience would ordinarily change over an eight month duration. Therefore, the extent of the impact of the club in this regard cannot be fully assessed.

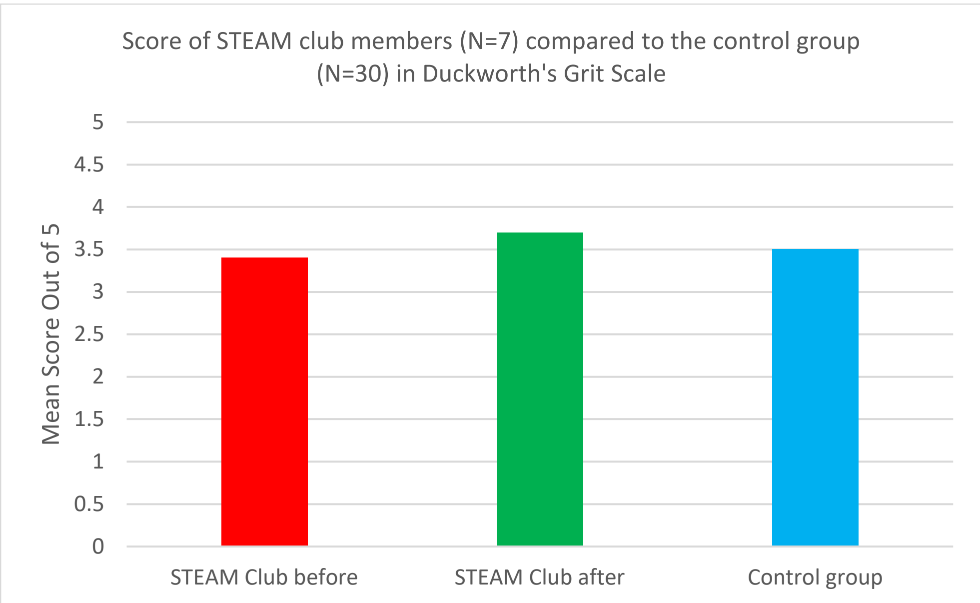

Figure 29. The effect of the ocean-based STEAM club upon students' grit

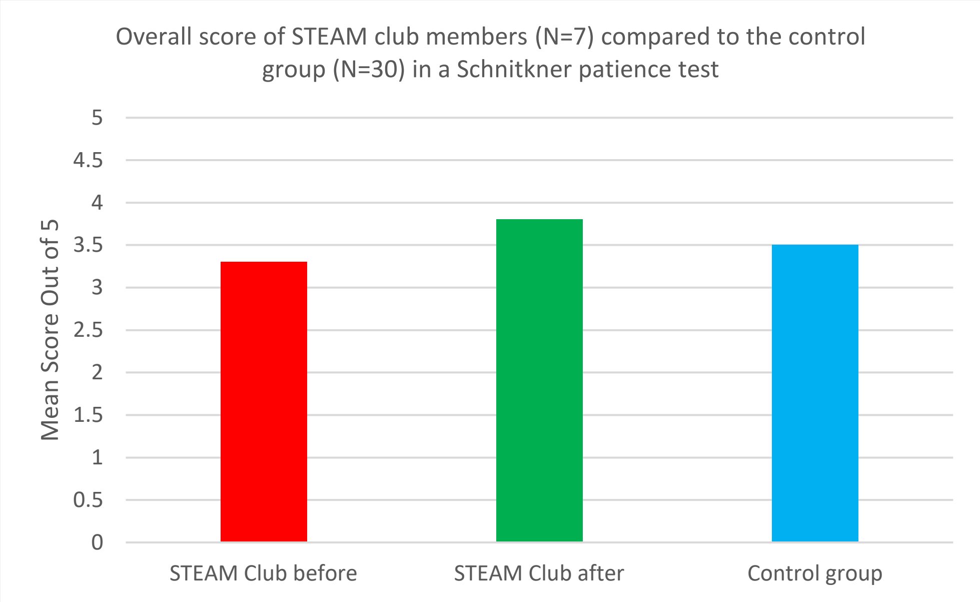

Figure 30. The effect of the ocean-based STEAM club upon students' patience

Figure 31 shows a comparison of the STEAM club participants' scientific creativity before and after completion of the project, with a control group's results displayed for comparison. It should be acknowledged that there are many different views on how best to assess creativity in general (Hocevar, 1981; Plucker and Makel, 2010; Lucas, 2016). Indeed, as noted by Hadzigeorgiou, Fokialis and Kabouropoulou (2012), any attempt to assess creativity poses inherent difficulties. They observed:

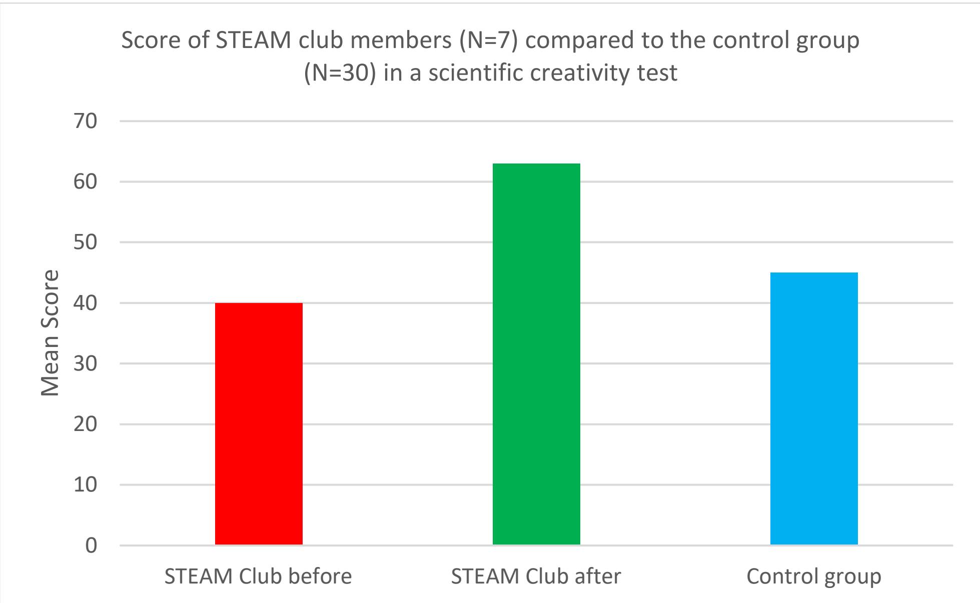

Figure 31. The effect of the ocean-based STEAM club upon students' creativity

"The problem is that, even if one teaches deliberately for creative thinking, one cannot expect to assess it when one wants to assess it, as a result or consequence of his/her teaching. The problem becomes more complicated if one considers the fact that, regardless of the opportunities students have for creative thinking, the testing situation may not provide a reliable means to assess creativity. For the test itself may be felt as a constraint on a student's freedom."

It is also worth noting that in this ocean STEAM club study, the pupils were only afforded half an hour to complete the scientific creativity paper and not the full hour as assigned by Hu and Adey (2002). This surely would have caused some suppression in the mean scores, both before and after and in the control group. Again, part of the improvement in the students' scientific creativity could potentially be attributed to them having matured by eight months. However, Hu and Adey's scientific creativity study, which was carried out with students aged 12 to 15 years old, found the mean score to be 45.36 for 12-year-olds, 56.92 for 13-year-olds and 62.52 for 15-year-olds.

Therefore, assuming a linear progression between the ages of 11 and 13, one would have anticipated a change of 23% between the ages of 11 and 11 and 8 months, whereas the club showed a gain of 58% during this time.

CONCLUSION

We have endeavoured to exemplify the connectivity between the domains of physics and art through the use of an ocean-based STEAM club which can targeted at those within either the upper primary or lower secondary. Such an arts-infused extracurricular science club option proved particularly appealing to girls, with the majority opting to attend being female. This is in contrast to other STEM clubs that have previously run in the school that have attracted mainly boys. It would be interesting to explore whether such activities have an effect upon students' views on environmentalism and sustainability. The project certainly was shown to have a positive effect upon their attitude, spatial ability, dexterity, creativity, grit and patience, albeit more pronounced in some areas than in others.

One may question whether the same gains would have been achieved had the students taken part in a more traditional STEM club without the artistic element. One would assume that a more traditional STEM club would have had minimal impact upon spatial ability and dexterity as there would be no reason for it to do so. However, the added benefit of integrating arts into STEM-projects in terms of attitude, grit, patience and creativity is less clear and cannot really be quantified from this study alone, since this STEAM-group can't be compared with a STEM-group as there was not one running concurrently in the same school with the same age group. That is to say, there is no concrete proof from this research that the integration of arts has led to more of a gain in terms of spatial ability, dexterity, attitude, grit, patience and creativity. Presumably, it would be almost impossible to prove this anyway as different children may respond more positively and in different ways to certain activities. Nevertheless, this research has provided evidence that STEAM wins over STEM in terms of attracting more girls than usual into science-based clubs and that a STEAM club can bolster students' attitudes towards science and improve the abilities that they need for success within science.

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