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Puppets as engineers of the imagination: using performing objects to communicate innovative enzyme science

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Abstract

Puppetry has been utilised as an effective mechanism to facilitate conversation and communicate complex topics across a variety of disciplines. To provoke discussions, our project aimed to utilise puppets as an effective and entertaining 'bridge' to increase the confidence of young people, enabling them to question and explore scientific endeavours, and to increase the confidence of engineers to communicate their work with young people. This proof-of-concept was anchored in the research of the Centre for Enzyme Innovation at the University of Portsmouth, UK, which focuses on developing low-carbon biotechnological solutions for recycling problem plastic waste in a circular economy. The science was effectively interpreted and discussed through co-designed puppetry workshops between engineers from the University of Portsmouth and young people from the community through engagement with community partners Artswork, The Makers Guild, the company Making Theatre Gaining Skills in Bognor Regis and secondary school students at the Admiral Lord Nelson School in Portsmouth. Through this approach, we demonstrated that 86 per cent of the young people gained a deeper understanding about what engineers do, and 79 per cent about how engineering improves our

lives. The majority of engineers felt more confident and motivated in utilising arts-based techniques in their engagement practice following the project. Through this work, we demonstrated that puppetry can be used to bridge the gap between scientists/engineers and underserved communities, although this can be limited by the power dynamics that currently exist in society.

Keywords engagement; puppetry; interdisciplinary practice; community practice; science communication

Key messages

- Puppetry can be used as a co-creation method to increase aspirations in young people towards careers in engineering.
- Art–science public engagement can increase the utilisation of facilitation and participatory techniques in the sciences and engineering.
- Co-creative methods can increase the confidence of individuals to design and implement engagement programmes, with increased motivation to do more public engagement with audiences, such as those in underserved audiences.

Arts-based practice and the communication of applied research into global challenges

> A puppet made from scrap materials is in the hands of a postgraduate bioengineer. He confidently and concisely explains his use of groundbreaking enzyme experimentation to break down plastic waste to a group of teenagers who have had difficulties being part of mainstream education. His communication is confident, concise and entertaining. (A moment of practice in The Makers Guild Co-creation Workshop, Portsmouth May, 2023)

The pressing need to solve our global challenges, including plastic waste, has accelerated the need for a broad range of skills and knowledge to develop solutions to these problems. The complex concepts that underlie many new and emerging technologies are hard to communicate. In this project, we aimed to simplify and make the scientific theory more accessible to non-academic audiences in engagement activities. Methods, such as creative communication approaches and community engagement using puppetry, bridged the gap between scientific advancements and public awareness. This included participants with the aim to foster a collective effort towards a sustainable and circular approach to plastic use, exploring the adoption of the technologies.

Scientific and applied engineering research on plastic-degrading enzymes, developed by the Centre for Enzyme Innovation (CEI) at the University of Portsmouth, UK, offers a promising bio-recycling technology for the development of a circular plastic economy (https://www.youtube.com/watch?v=GPjPnVdoeGM). Enzymes, derived from microorganisms, break down plastic polymers into biodegradable components. This process allows for the conversion of plastic waste into raw materials that can be reused, contributing to a more sustainable and resource-efficient plastic life cycle. Ongoing research focuses on optimising these enzyme-based bio-recycling methods, aiming for scalable and economically viable solutions to address the global plastic pollution challenge (Singh et al., 2021).

Mixed with this cutting-edge research, we brought skills in artistic practice inspired by an ecological imperative. Eco-art, as developed in this project, is a way to approach the object world and the environment, positively acknowledging how we are part of a system of objects. Forms of eco-art

emphasise the need to relate to objects and hyper-objects in a more considered, attuned and appreciative way (Morton, 2021). Tim Morton (2021: 57), an important voice in eco-philosophy and culture, argues: 'Art is important to understanding our relationship to non-humans, to grasping an object-oriented ontological sense of our existence. Art fails in this regard when it tries to mimic the transmission of sheer quantities of data; it's not artful enough.' In our approach, we believed that the objects could enable art making, but that they could also encourage in participants an ecological approach and ambition to the material world around us.

Our intention was to develop an art–science approach (Sormani et al., 2019) that both developed the science communication abilities of a group of engineers and also enabled the increased aspirations of young people from underserved communities. Dorothy Heathcote, in her practice in education, and in her pioneering method the 'mantle of the expert', argues for spaces of learning where 'the teacher endows the class with the expertise of the field of knowledge that is being pursued. By this endowment, the power is also placed with the group' (Heathcote and Herbert, 1985: 174). This equitable space of knowledge opens up the participants because of the shifts in power and the dialogical way in which the practice is presented and conducted: 'The participants create possibility, while the spectator within each participant creates and owns the knowledge arising from the combination of possibility, action, and outcome' (Heathcote and Herbert, 1985: 180). The intention in our project was to impart this shifting of power from positions where experts are not just giving knowledge, but are also involved in a process whereby they become facilitators of knowledge through creatively sharing with groups who are met within a creative, flexible and equitable space – usually a workshop. In the practice of Welfare State International 1968–2008 (Fox, 2009), collective experiences were created using visual performances to engage communities in events. Objects were created to provoke reactions in communities in a very open, democratised space of creativity. Some of their work used puppets to create community narratives, and to visually capture the imaginations of everyday people. Their principals for an inclusive way to engage people through 'wonder' in creative practice were a key influence on our project.

The communication of science using puppetry has been documented by a number of practitioners and scholars, and this form of performance has been acknowledged as an effective tool in learning environments (Brits et al., 2016; Hannigan and Ferguson 2022; Simon et al., 2008). The puppet as a performing object seems to make tangible the information and the processes of science. Puppets capture the attention of audiences, even when the puppets or the performances are not used by trained animators. Puppetry in this guise, as an information-giving form, is robust and relevant to contemporary audiences and workshop participants. In their project using puppetry to promote science talk, Simon et al. (2008: 1247) found that 'the use of puppets may help to build classroom discourse that is more collective, reciprocal, supportive and purposeful'. De Beer et al. (2018: 180) similarly offer conclusions about how puppetry is useful in science communication: 'Puppetry as a pedagogy holds much promise in the biology classroom to address affective learning outcomes. It can cross various ethical scientific boundaries and provoke discussions that lead to the development of scientific communication skills.' An Australian research project using puppetry to develop discussions of science found that there were some issues with teachers confidently using puppets, but that there was 'increased student engagement, especially for the students who have learning difficulties' (Hackling et al., 2011: 23).

Our project exploring enzymes aimed to develop a proof-of-concept to enhance the approach for the communication of novel science through an initial focus on plastic-degrading enzymes and their role in promoting a circular recycling plastic economy. This case study was selected due to its prominence in national and international media, in addition to regionally concentrated activity through the launch of the Centre for Enzyme Innovation and emotive reactions to problematic plastic waste among the general public. The innovative approach involved the use of puppets and creative methods to make the complex scientific concepts more accessible to the community. Science communication is greatly enhanced by these artistic methods, combined with a flexible approach to community participants. In this way, the arts

engage participants in affective relationships with science, whereby they feel, and creatively interpret, scientific ideas and facts.

The general finding in our practice research is that puppets elicit more engaged and lively discussions in the learning space because they open up groups' thoughts and opinions with regard to science. This idea that puppets can effect changes in a group's confidence to discuss science was an initial assumption. Our overarching aim in this project was to utilise puppets as an effective and entertaining 'bridge' to increase the confidence of young people, enabling them to question and explore scientific endeavours, and to increase the confidence of engineers to communicate their work with young people.

Empowering co-creation across engineers, young people and community groups

Matt Smith (2009, 2012, 2015, 2018, 2022), as a puppeteer and principal investigator, imparted knowledge about puppetry, and co-developed a series of workshops with the scientists from the CEI. These included six co-creation workshops with 13 engineers. The workshops focused on enabling co-creation in the whole activity to accurately and clearly communicate work on bio-recycling enzymes. For example, initially the idea of looking at chimera enzymes was offered by Smith as an artistic image that conjured thoughts of mythology. However, this was challenged by the postgraduate students as being too complex a process, which would obscure the most important messages about enzymes in the recycling process. Although a challenging part of the process, the fact that the scientists were in control of the messages to be imparted was clear. This control of the message gave them a strong sense of autonomy and responsibility in the project. The workshops utilised shadow puppetry, scrap puppet-making and collage techniques that could be adopted by the science engineers in workshops in the community. These sessions involved using games and making exercises to open up the creative and artistic parts of the scientists' thinking. We produced junk puppets from waste, using objects to describe science processes, playing the 'exquisite corpse' game favoured by surrealist artists made collectively using chance methods (Kochhar-Lindgren et al., 2009), used scrap clear Perspex to make shadow-puppet enzymes, and made collages to produce chimeras with 'animal' parts. Smith also gave each scientist a sketchbook to draw and play with ideas for community workshops, as this provided an individual space for creativity away from lab work. More specific skills-based sessions focused on how to facilitate community groups, as a way to play with knowledge and to elicit effective engagement with groups. Smith drew on his experience of community practice, as well as on his teaching methods drawn from classes in community and applied theatre.

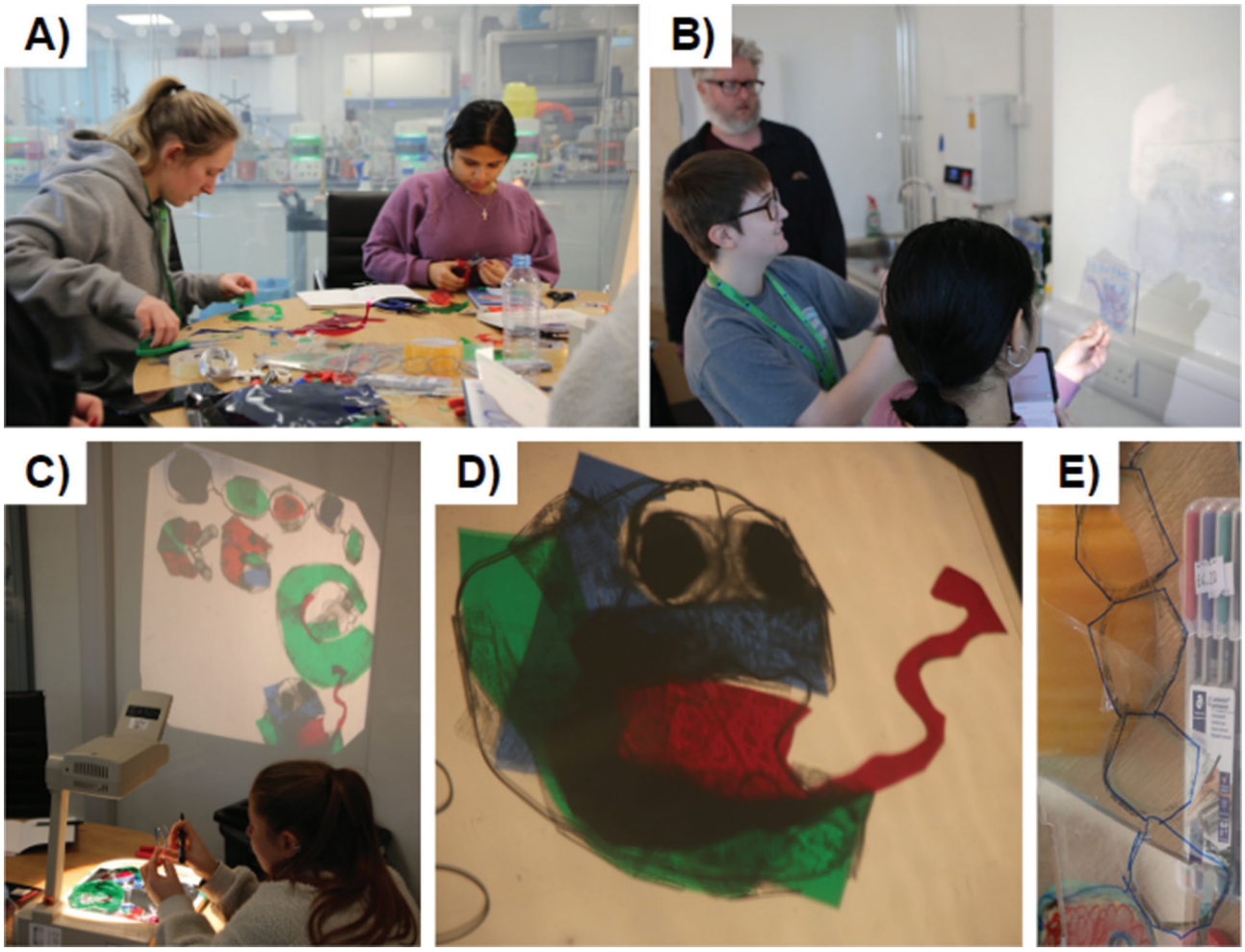
Following the engagement with the engineering cohort (Figure 1), we established a series of workshops through our community of partners with young people between 14 and 18 years old (Figure 2).

We again sought to instigate co-creation and participatory methods with our community partners, as a means to achieve the objectives of the project in a way that was adapted for communities. One of the key creatives who imparted knowledge in the project was Matt Rudkin, an artist who worked for Making Theatre Gaining Skills in Bognor Regis (Figure 3). In his summary of his activity, he offered some very useful forms of advice about doing engagement activities with young people:

> When I go in to lead a workshop, I like to have a list of ideas in mind jotted down in a provisional order, and then be prepared to diverge from this plan should circumstances call for it. My list usually contains more activities than I can actually do, partly to avoid the prospect of running out of activities. Like a DJ with a large selection of records, I monitor individual participants and the general vibe of the room, ready to choose activities that engage them. (Personal communication, 1 March 2023)

Rudkin modelled this way of working for the scientists when they participated with young people in his sessions. In his opening of the workshop, Rudkin used a series of games, and this vibrantly opened up

Figure 1. The engineers' engagement workshops. Photographs taken at the engagement training workshops. (A–C) The engineers brainstorming creative methods of communicating their science. (D) An example of a creative interpretation of an enzyme. (E) An example of a creative representation of a polymer chain (Photographs: Brooke Wain)



the young people and generated a good energy in the space. Rudkin explains his approach to games thus:

> The usefulness of a competitive element has been perhaps most evident to me with children – even the shyest child can be transformed into an excited, focused and motivated participant by the prospect of notionally 'winning' and a clear structure of rules and goals. For adults, even when they understand they are only 'playing' at competing, framing the activity in this way seems to trick their apparently innate psychology into energised motivation. I understand there can be benefits to more 'open-ended' play, where activities are less rule-bound and goals less defined, but for less experienced or motivated 'players', immersion in playful improvisation is most likely to occur within the confines of specified rules and goals. (Personal communication, 1 March 2023)

After leading games, Rudkin imparted science knowledge through a version of the game Pictionary, exploring enzyme science elements, introducing these elements in the game as it went along. The puppet element that he developed next involved sock scientists and inflatable puppet enzymes. These

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Figure 2. The Makers Guild workshops. (A–C) Participants making enzyme puppet figures and brainstorming ideas for workshop activities. (D–E) The beginnings of the creation of a board game explaining the breakdown of a polymer chain using an enzyme (Photographs: Greg Smith)

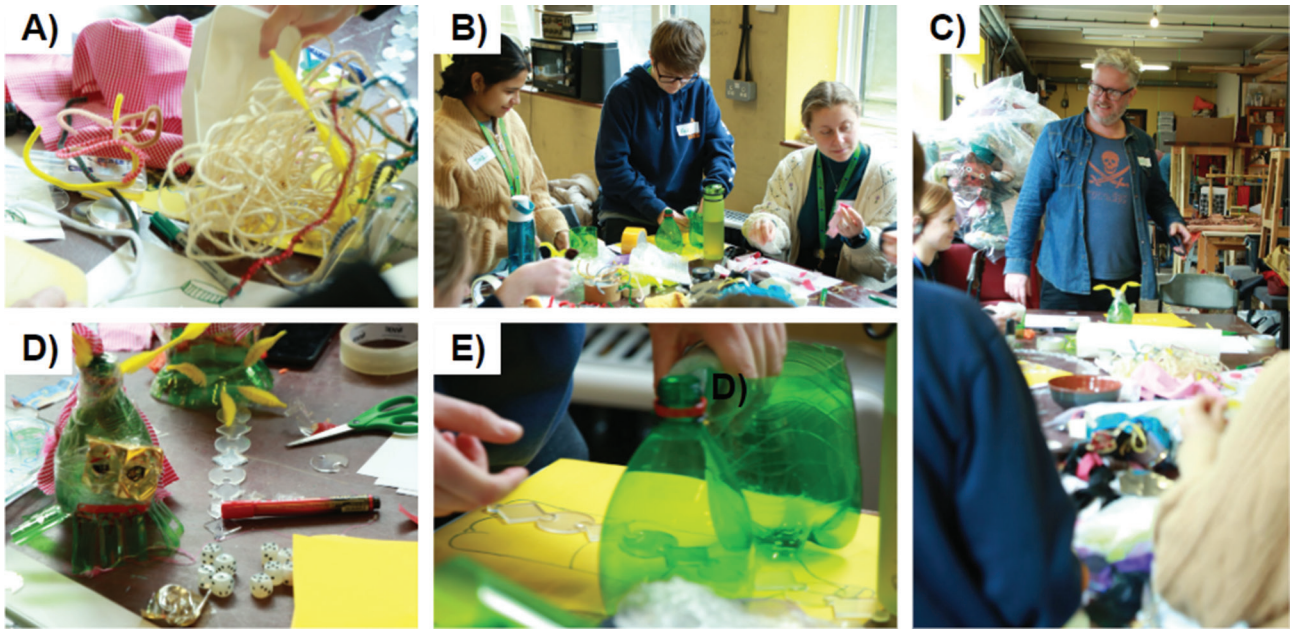
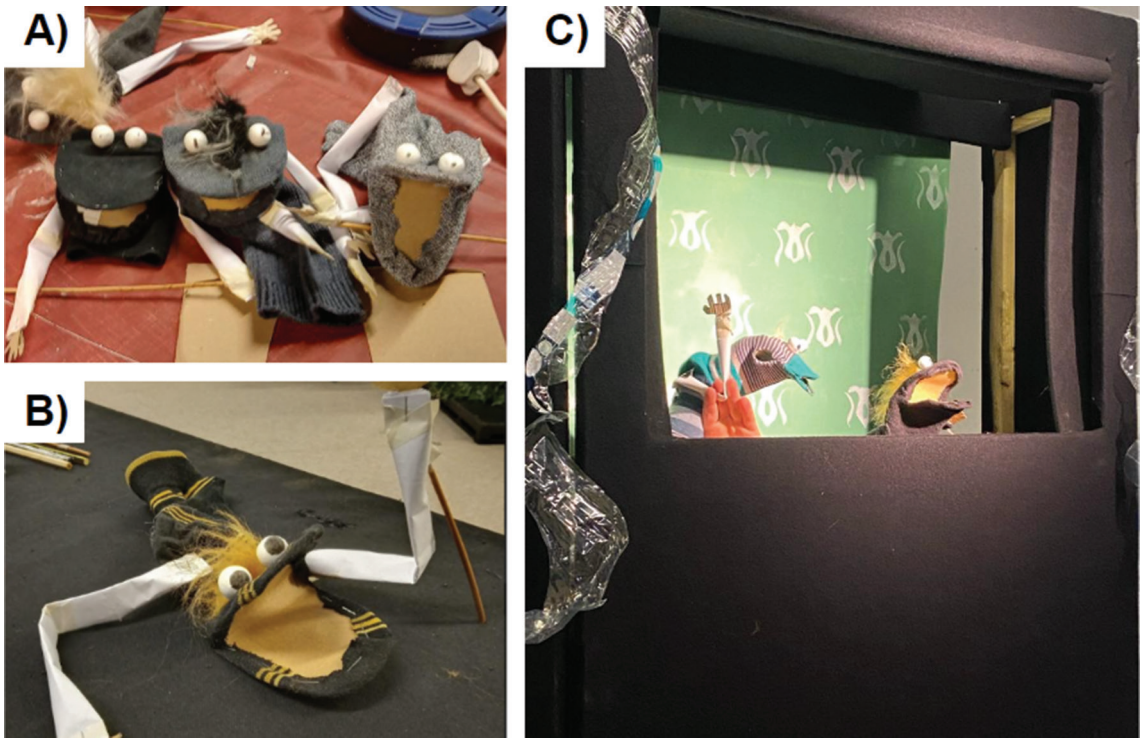


Figure 3. Sock puppet scientists. Photographs taken at the Bognor Regis Workshops during the afternoon of the puppet show. (A–B) Example of the sock scientists. Both sock scientists and interviewers were created. (C) The sock puppets being used by the participants in explaining the research through using an interviewer sock puppet to ask questions of the scientist working on the plastic-degrading enzymes (Photographs: Brooke Wain)



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performing objects were animated, and they were then developed into short skits videoed in the style of rough news reports commenting on cutting-edge enzyme science. These performances were played within a Punch-and-Judy-style puppet booth in the workshop space. Rudkin's methods and workshop techniques became an exemplar for the scientists to follow when engaging groups in workshop activities. Rudkin's account and list of exercises became an important element in the final kit for further use in engagement after the project.

We also utilised this approach in the context of secondary school students at Admiral Lord Nelson School in Portsmouth (Figure 4). Due to the number of participants, we sought to scale the approach with a distinct workshop model. The workshop kicked off with a brief explanation of the main aim of enzymes regarding plastic waste, and then encouraged the young people to produce representations of the enzymes as little monster characters. It was not important for the participants to realistically represent the enzymes, so we encouraged them just to give the puppets characteristics of the enzymes. For example, giving mouths to the puppets was important to represent the area known as the active site, where the bonds within the polymer are broken down. Also, eyes anthropomorphised the enzyme puppets, making them more characterful, and encouraging humour with regard to what was made.

A co-creative offshoot of the project occurred through the engineers' enthusiasm for the development of a board game to better communicate and represent the mechanism of the enzymes' activity. In this game, the chains of polymers were broken down by throws of dice until there were singular monomers left after the game. This activity took a little time, and it emphasised the need to find processes to allow for the breakdown of the plastics. This game roughly approximated the aim of enzyme science, and it offered a tangible way to impart this knowledge about the scientists' need to find solutions to problems in the lab. At the end of this process, the young people were asked to imagine what they could make with the chemicals, once they were broken down and recycled in a new product or object. The final part of the workshop was a Q&A with the engineers about 'a day in the life of their role'. It was felt that by this point in the workshop, the participants were more relaxed, and they were willing to ask questions and discuss science with the bioengineers in the room. The participants were free to ask any science-related questions they liked, and this was a lively and fun conversation, including unprepared details and unpredictable humour. These were lively workshops conducted in a school science class and in workshops with Artswork, who work with vulnerable young people.

To evaluate the engineers' experience, an online survey (using Google Forms) was provided to the cohort. This focused on assessing their experience and confidence in participating in public engagement activities, with a particular focus on art–science/STEAM (science, technology, engineering, arts and mathematics). A member of the science engineer community (Wain) also joined the project governance group, enabling the tailoring of the project to the requirements of the cohort during project delivery.

For our public audiences in schools and community groups, data were collected from quiz questions from the groups during the workshops. We also provided a graffiti board for students to highlight what they found out about engineering, what they enjoyed about the workshop, and how the workshop could be improved. Some community group leaders also provided feedback about experiences in the governance group and through unstructured written feedback after the events. For adult public audiences, data was collected on registration for the final showcase through Eventbrite. For feedback about the change in perceptions during the event, a graffiti board was provided at the exit to the studio.

To conclude the engagement in the project, we hosted a showcase event with a giant enzyme puppet (Figure 5) as the focal point, and the other puppets made in workshops, as an interactive exhibition. This exhibition celebrated the community practice, and it was a space of lively discussions and networking. The intention for the showcase was to expand the impact of the project for the wider public. The showcase celebrated the participants, and it further promoted the cutting-edge science of the bioengineers involved.

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Figure 4. Puppets made in a secondary school science class with the workshop team (Photograph: Brooke Wain)

The experience of engineers in arts–science practice

Brooke Wain, Engineer Co-lead, 2024, said:

> Before the workshops, our attempts to engage with creative methods in communicating our scientific research were limited. Conveying complex topics, especially to non-academic audiences and young minds, posed a significant challenge. This project marked a turning point, first, by introducing us to creative workshops where we explored innovative ways to bridge the communication gap.
>
> Stepping away from our familiar laboratory setting, we spent afternoons engaging in discussions on how to effectively communicate our research. Using resources like pipe cleaners, wire and tissue paper, we crafted representations of enzymes, bringing them to life through puppetry. Each puppet had its unique identity, serving as a tangible narrative to explain the journey enzymes undergo when encountering plastic.
>
> Once we had a list of engaging activities, we delivered them in external workshops to diverse audiences. Witnessing my colleagues step out of their comfort zones to simplify scientific concepts pitched at varying levels was genuinely remarkable. The workshops became a space for collaboration, where the scientific field used experiences and techniques from the creative field to help communicate their knowledge.

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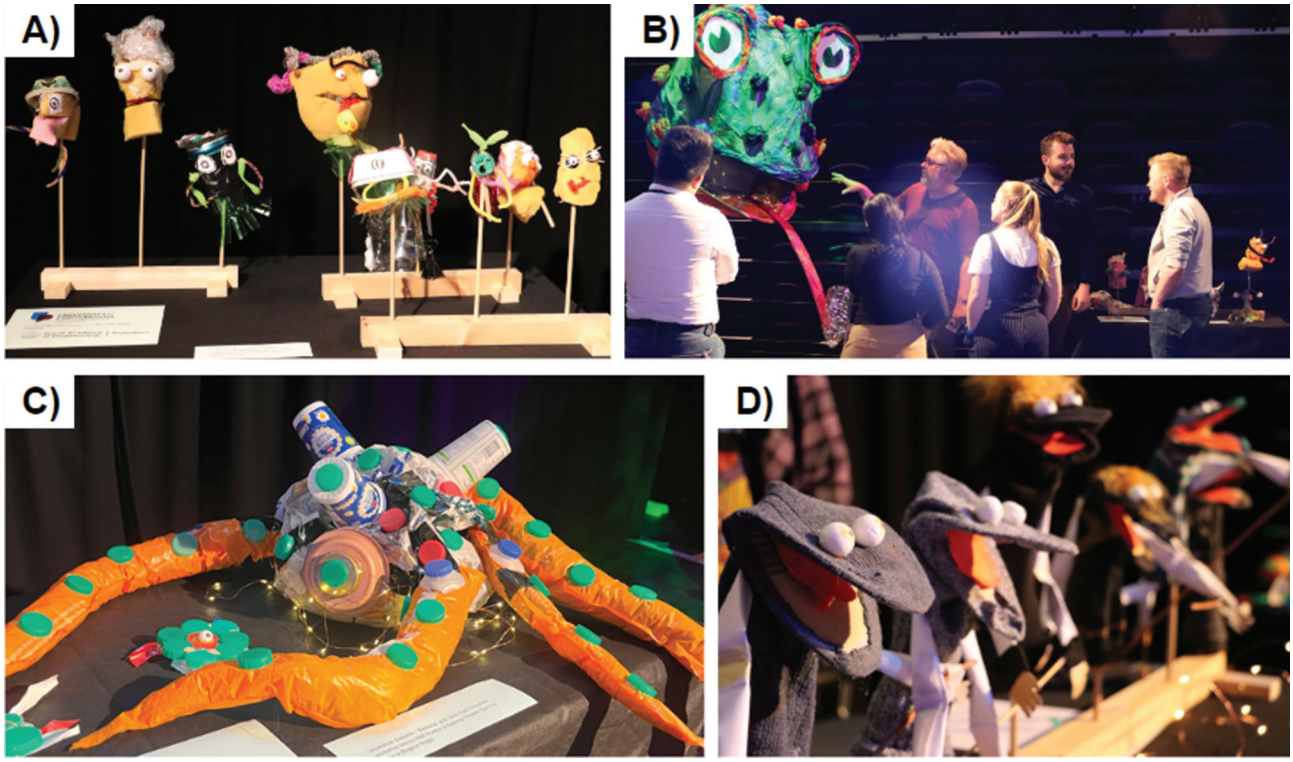
Figure 5. The showcase event. (A) The display of the enzymes made in the various school and group workshops. (B) The engineers discussing the giant puppet enzyme, which was hung from the ceiling. (C) Another representation of an enzyme from the Bognor Regis workshops following the conversation on the background of the research and discovery of the first PET-degrading enzymes. (D) The puppets from the puppet show workshop showing the puppet scientists and their puppet interviewers (Photographs: Greg Smith)



The highlights in this practice for me were the Q&A sessions. Scientists not only embraced the questions, but also discovered joy in answering them. Beyond gaining confidence in engagement, we found a unique opportunity to solidify our understanding by transforming intricate concepts into accessible narratives. Notably, the puppet show workshop stood out. We employed icebreaker activities like storyboards, charades and word games, to introduce our research, leading to the creation of sock scientist puppets (Figure 6). In rehearsals and the final puppet show, participants enthusiastically responded correctly to questions, showcasing the success of the preceding activities and the workshops' impact.

This project significantly reshaped my perception of the key role public engagement plays in the scientific field. The collaborative workshops reinforced the importance of effective communication and demonstrated that incorporating creative methods not only breaks down barriers, but also fosters a deeper appreciation for both science and the arts.

As the student co-lead, my role involved facilitating seamless communication between the scientific and creative teams, ensuring the correct theory was being conveyed in the best way. Witnessing the transformation of ideas into engaging activities that were enjoyed by all the audiences we shared them with, was really rewarding and has motivated me to continue advocating for interdisciplinary collaborations.

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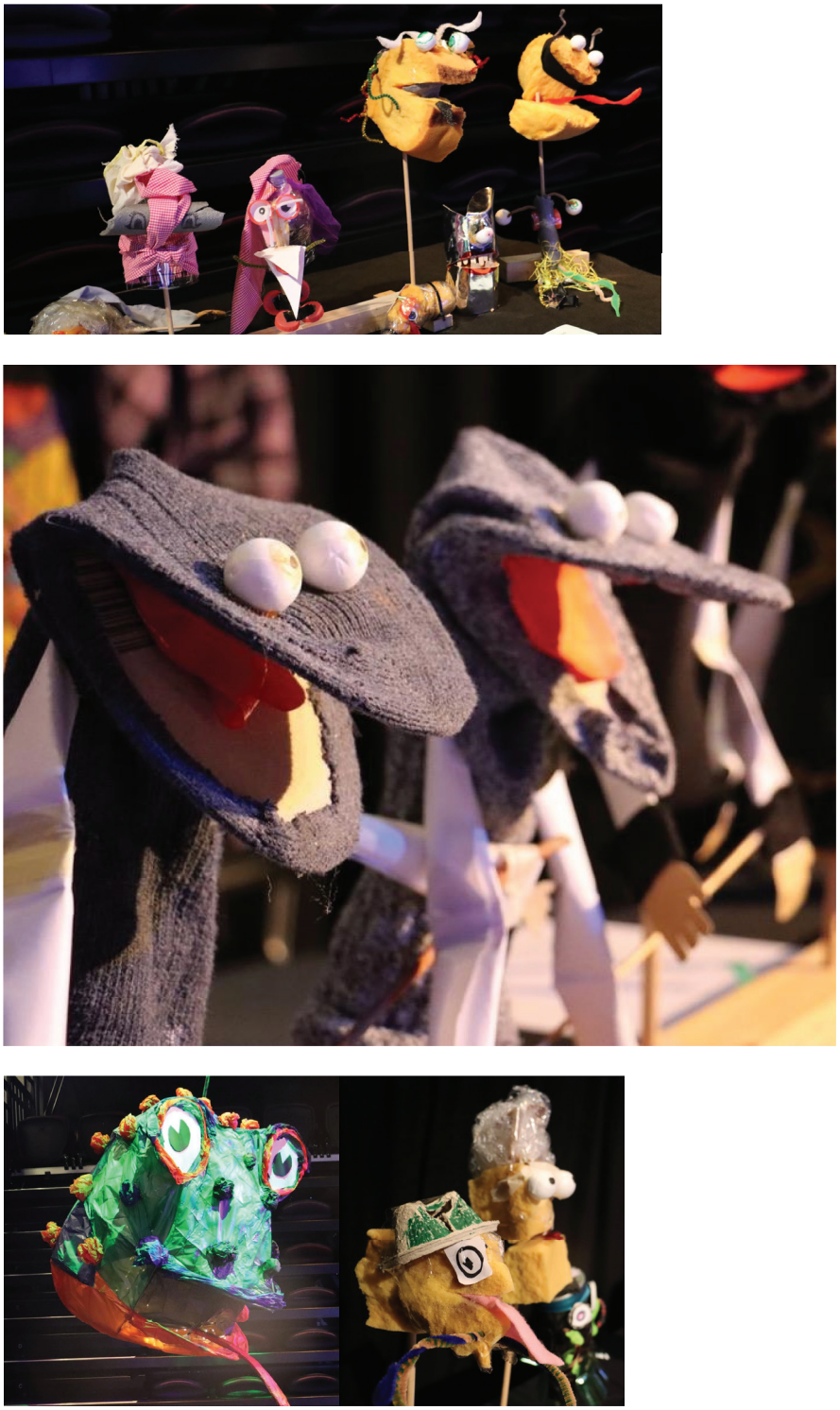
Figure 6. Puppets from workshops in the showcase event (Photographs: Greg Smith)



The whole project made me rethink how I communicate my science, where I realised that it does not have to rely solely on graphs and data tables. In fact, I feel that the more creative the activity, the more enduring and lasting the impact of the shared knowledge and information. This collaboration now influences my approach to scientific communication, emphasising the power of creativity in making complex concepts accessible and memorable.

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A focus on our feedback

A key focus of the project was on how arts activities that encourage engagement affected the science engineers. This small cohort of 11 were asked to respond in simple surveys. We received the following feedback from the scientists responding to the prompt, 'Describe why this aspect of the project was the most beneficial to you':

> Got me out of my comfort zone and helped me improve my science communication.
>
> The outreach events and engagement opportunities.
>
> It was fun to talk about science in a different way to normal – a more relaxed environment.
>
> The interaction with the audience.
>
> Nice to talk to people with the aid of the puppets.
>
> Enzymes are quite interesting. Both to learn as well as to teach. Playing with enzymes is always exciting.

This feedback emphasises the ludic potential of the project playing with ideas and puppets to relax the participants and allow spaces for discussion. We also worked to understand the experience of the engineers, through exploring the lessons learned for future engagement projects. We received the following feedback from this cohort about this point:

> I would like to have a larger audience where we can interact with students of varying ages.
>
> Which activities are more engaging and focusing on those, fine tuning the games so they are easier for people to understand the rules.
>
> Be prepared and open minded.
>
> That simple but interactive tasks can benefit the audience and improve its understanding.
>
> Props are essential.
>
> The ability to interact and communicate well.

This feedback indicated that there was a desire for the science engineers to do more engagement, but that they wanted more opportunities for this kind of activity. Then we asked them about areas that could be improved with the project:

> It would be wonderful to have more classes/workshops with the students/youth.
>
> More events and more of an initial plan.
>
> The class series should have been more coordinated with some specific enzymes, so that the tutors can have a read on it before the class and prepare well for the listeners.

This indicated that the structured nature of research made some of the elements of co-creation feel unfamiliar to the engineering cohort, in particular, the need to formulate a plan collaboratively, as opposed to having a comprehensive structure. To approach the questions more on a level of personal preference, we also asked the science engineers 'What was the one thing you liked the most?':

> The hands-on creativity was amazing
>
> Getting creative
>
> The game creation
>
> Making puppets

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> The engagement with the public and the design of various relevant bits
>
> Final showcase
>
> None other than the puppet itself!

We demonstrated increased understanding across the cohort of engineers as part of the delivery of the project. This positive outcome was confirmed through a number of additional comments:

> It has reaffirmed the importance of working with youths of all different backgrounds.
>
> It has helped me understand how to include enough detail to make people interested and help them to understand the science behind what we are doing without making it too technical/complex.
>
> My understanding regarding the careful planning on how to design a public engagement activity has been improved, as well as the communication methods to transmit the knowledge and create an interest to the audience.

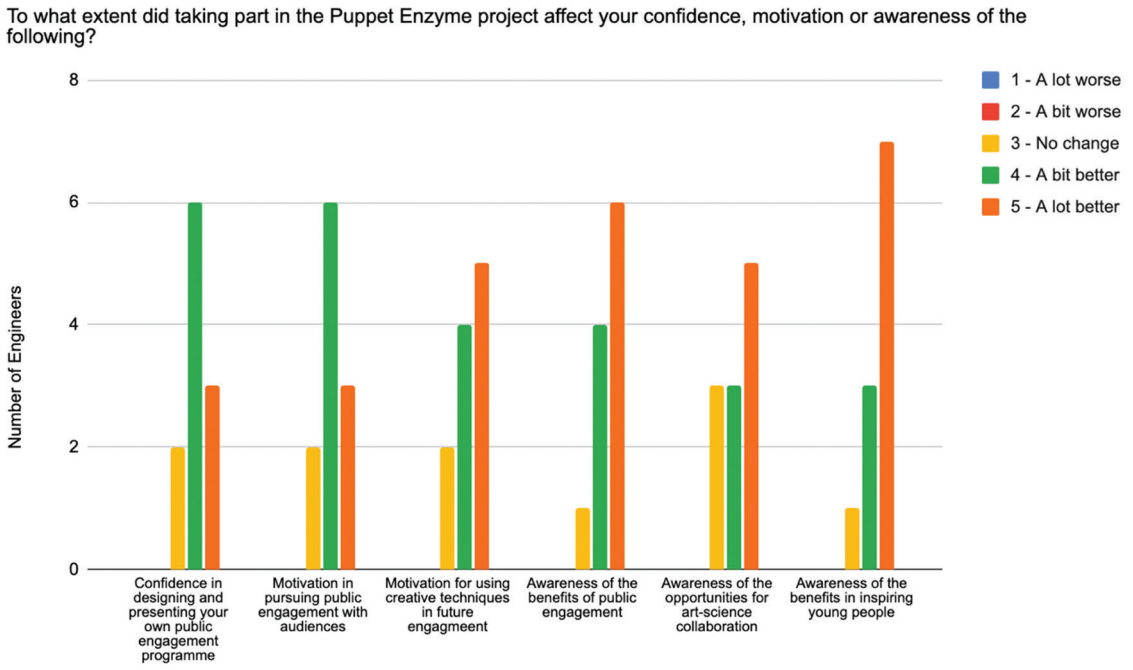
In the cohort of engineers, we also demonstrated improved confidence, motivation and awareness of public engagement across the majority of participants (Figure 7). We received the following feedback from participants with regard to this aspect:

> I am introverted, but I understand that being an introvert is not a flaw. Everyone can speak.
>
> It was wonderful to work in a collaborative space with others and just enjoy each other's company.

Public and young people's understanding of engineering communicated through puppetry

Our standard impact questions for young people demonstrated that the majority of participants (79 per cent) learnt something new about science engineering. This also applied to gaining a deeper

Figure 7. Knowledge and understanding of engineers



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understanding of what engineers do (86 per cent), and how engineering improves our lives (79 per cent). Qualitative feedback highlighted that they learnt 'why engineering is important', and they commented that it was 'educational in a fun way'.

From the adult public joining the final workshop, only 10 per cent of attendees had a lot of knowledge about engineering, with 27.59 per cent having little knowledge. Engagement was limited across most questions asked; however, we received many responses on art/science and engineering (Figure 8).

Collaborating with community groups in co-creative projects

Our work with Artswork presented a significant area of knowledge development. The small groups in the workshops were receptive, inquisitive and engaged. Comments from workers who supported these individuals involved reflecting that they were surprised how well the groups stayed focused and engaged with the activities. It was also an area of reflection for the engineers, as they were not aware of, or did not have any experience of working with, young people who were so underserved. Feedback from the key link at Artwork demonstrated the impact they had seen in the engineer cohort:

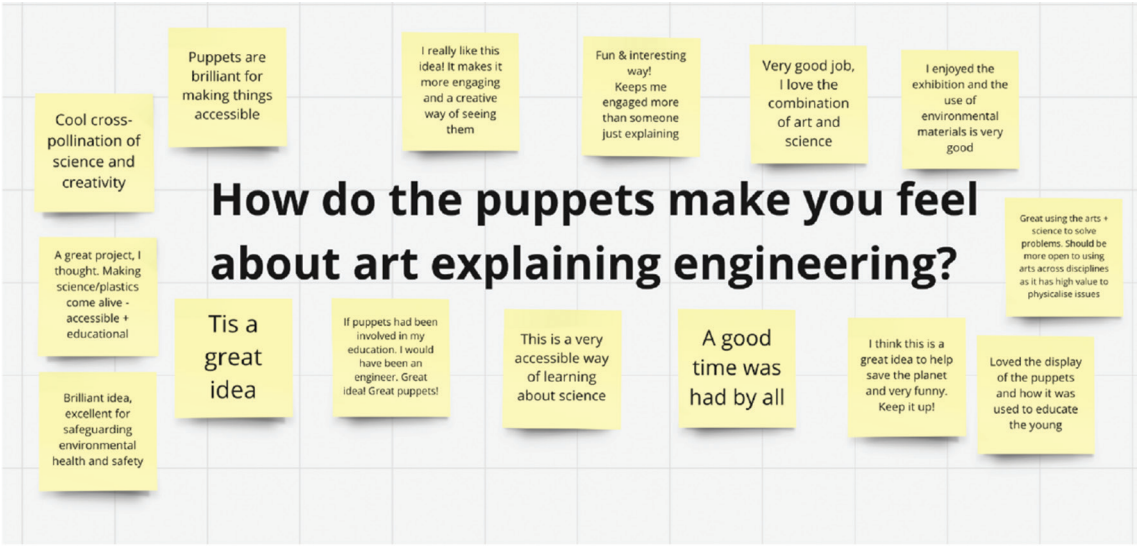
> Thanks so much for yesterday – I drove home in a very happy mood as I felt that both groups had really benefited. I could see a difference in the way those students who I had met before were able to relate to the young people and gain skills in explaining how stuff works. As for my crew, I think that was the first engagement of any kind that [name deleted] had done in the two years since being expelled from Harbour School – similar [names deleted], the joy of doing a fun activity rather than slogging in a low-paid job was very apparent.

And:

> I think it also perhaps opened the eyes a bit for some of your students as to the gulf there is between them and non-academic young people.

Within the scope of the project, we did receive feedback that, although the project was successful in increasing awareness, there was some hesitancy that it would not create long-term benefits in terms of pursuing an engineering career:

Figure 8. Feedback from community participants



> Whilst it might not have got my lot any nearer to an engineering career, I do feel it made them more linked to the university and as probable lifelong Portsmouth residents in some cases, then, that's a good thing.
>
> I also believe there might have been a really positive outcome for [engineer name removed], giving her potential links to 154 industry members of Interspill [an organisation that organises conferences and networks in reaction to marine spill issues globally – https://www.interspill.org/2025/], and whilst that won't excite my sponsors, it excites me, and hopefully the wider world.

Applied and arts-based approaches can effectively inspire and communicate on complex topics

Through this work, we demonstrated our ability to change attitudes and communicate hopeful ideas about the future of plastic waste. The project emphasised the role of plastic-degrading enzymes as a solution to address plastic waste. By focusing on innovative technologies and scientific advancements, it conveyed a sense of progress and hope for the future. Communicating the concept of a circular recycling plastic economy as a viable and sustainable model portrayed a positive vision for the future. This approach emphasised the importance of recycling and reusing materials to reduce environmental impact. When people feel that they play a role in shaping a better future, it can lead to more optimistic attitudes. Interactive and engaging educational methods, such as games or activities, made the learning experience enjoyable and memorable. Comparing the current challenges with potential future scenarios, where effective waste management is widespread, we helped convey a sense of progress and improvement.

In anchoring our project through community groups and social enterprises who are already connected to community groups (Artswork and Making Theatre: Gaining Skills), we were able to receive attendance from underserved audiences who may not have engaged with the arts or engineering before. These partnerships also enabled the project to explore innovative ways of presenting scientific information, making it accessible and engaging through theatrical elements. Working with creative partners involved incorporating drama and storytelling techniques to convey scientific concepts. This collaboration resulted in the creation of narratives, scripts and performances that made the information more memorable. This was demonstrable through the significantly increased knowledge about engineering demonstrated by attendees at the workshop. Makers Guild interactions provided insights into hands-on and tangible approaches to science communication, modelling the idea of a game with linked elements that joined to make and represent the chains of monomers which the enzymes break down.

While our final showcase was not attended by the diverse backgrounds that we hoped for, the project in itself made progress in eliminating barriers that can be seen between the city and its academic institutions. It is uncommon for specific university projects, particularly engagement work, to be featured in so many regional media outlets, for example. Through the project, we found that visual and creative representation using puppets added a dynamic element to the communication strategy. Puppets can be engaging and relatable, making it easier for the audience to connect with the information, even though they are unrealistic as representations. Incorporating visually appealing elements, such as physically made puppets and plastic waste models, helped simplify complex scientific details and make them more understandable to a broader audience. Developing storytelling and narrative structure framed the information within a form which helped create a cohesive and easily digestible storyline. This approach allowed the audience to follow a logical sequence of events and concepts through the use of the puppet figures. Using the characters (through the puppets) can also humanise the scientific process. For example, the puppets that were produced, such as the sock scientists and the junk enzymes, playfully used character types that were non-representational but acted like 'clown avatars' in live descriptions of scientific processes. One moment at the Makers Guild Co-creation

Workshop in May 2023 that highlighted this dynamic was when one of the scientists started to describe a process that he was developing in his own area of research. He naturally picked up a puppet that had been made during the workshop, and his description became both tangible and engaging. It was also a moment in which the scientist grew in confidence, enabled by the way the puppet had displaced the focus of attention of those who listened to his description.

From our experience, the co-creation workshops between the young people and the engineers were very transformational. We were able to see young people who had limited engagement at previous workshops (as advised by the group leaders) leap into building their own enzyme puppets and gain confidence in asking the engineers questions. On the bioengineer side, we noticed the growing self-confidence of the introverted engineers in communicating with schools and the public. Conversely, we saw the extroverted members of the group becoming more aware of their own communication abilities and taking a role in actively creating opportunities for other engineers to engage. So, for our project, we found that the use of arts activities enabled a general feeling of confidence-building which could positively impact knowledge exchange. This was the case even with groups who were vulnerable and failing in mainstream education. These approaches had a powerful impact on the engineering cohort, where we demonstrated a significant increase in knowledge, motivation and skills in both utilising arts-based approaches and in working with community groups in the future.

One of our core challenges in the project was balancing the needs of the engineering cohort with the connection to our community groups and art practitioners. The engineers desired the precise communication of their work, and they initially found it challenging to facilitate and enable creative interpretation. This could be seen metaphorically as telling people that there is a solution, as opposed to asking people if it is the solution that they need. Similar challenges have been found in other art–science collaborations, with notes of a risk of extractivism, through the grabbing of information and its utilisation for arts-based and scientific practice, without a contribution to the community (Errazuriz, as cited in Ostendorf-Rodríguez, 2023). We sought to mitigate this through our direct collaboration with the community through arts organisations already in our community, and through embedding their leaders within project governance.

Puppetry can be used as a co-creation method to increase aspirations in young people towards careers in science and engineering by opening up conversation between experts and non-experts in an amusing non-threatening environment. Art–science public engagement can give confidence to non-experts when asking questions, discussing and also imagining positive futures using science and creativity when approached in this way. One important principle introduced early in the project to the science engineers was the 'mantle of the expert', created by pioneering educationalist and drama practitioner Dorothy Heathcote (Heathcote and Herbert, 1985). This technique opens up knowledge by saying in workshops that anyone can assume a role of expert as a form of role play. This can demystify knowledge and give a sense of equanimity to groups, including some participants who had become very alienated from mainstream education. In some ways, the most significant achievement was that the most disadvantaged groups we worked with were being offered insights into cutting-edge science through the creative events. It was both encouraging and a great outcome of the project that the scientists gained knowledge and, in turn, through workshops, enabled groups to gain confidence in discussing science on their terms.

Conclusion

Unusual objects such as puppets open up knowledge as an interlocutor for groups in workshops, enabling confidence, and allowing spaces to imagine the possibilities of different futures in reaction to technologies and science. Puppets and objects in workshops are not just simply tools but are truly 'engineers of the imagination' (Coult and Kershaw, 1990) in the way they affect our ability to interact with each other, the world of objects and knowledge in playful ways. Co-creative methods can also increase the confidence

of individuals to design and implement engagement programmes, with increased motivation to do more public engagement with audiences, such as those in underserved audiences. This project was a proof-of-concept on a specific topic; however, we believe that it effectively builds a framework of co-creative workshops and arts–science communication tools, and a model for collaboration with community-based organisations, which could be applied to a range of topics across science and engineering disciplines. We believe that this approach shifts narratives and inspiration on solutions to global challenges to a more democratic and inclusive approach, which is more likely to engage underrepresented members of society.

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Declarations and conflicts of interest

Research ethics statement

The authors declare that research ethics approval for this article was provided by the University of Portsmouth Faculty of Science and Health ethics committee, Reference SHFEC 2022-080.

Consent for publication statement

The authors declare that research participants' informed consent to publication of findings – including photos, videos and any personal or identifiable information – was secured prior to publication.

Conflicts of interest statement

The authors declare no conflicts of interest with this work. All efforts to sufficiently anonymise the authors during peer review of this article have been made. The authors declare no further conflicts with this article.

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