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Unravelling Biofilms: Biocultural Surfaces - Crafting, Community and Communication

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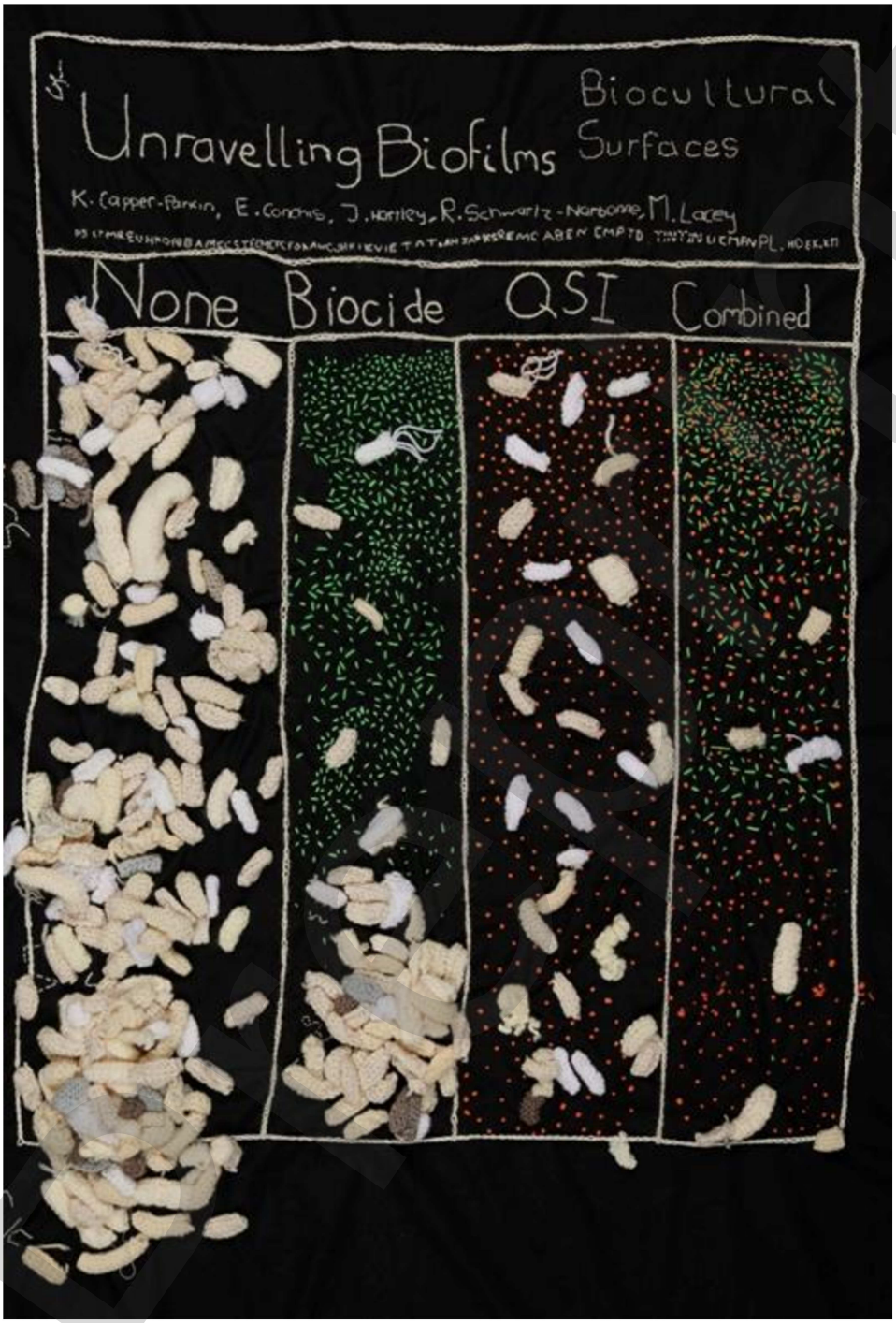
Abbreviations: AMR: antimicrobial resistance; STEAM: Science, Technology, Engineering, Arts, and Mathematics; QSI: quorum-sensing inhibitors

Abstract

Biofilms are complex, surface-associated microbial communities that contribute significantly to antimicrobial resistance and healthcare-associated infections. Communicating these concepts to the public is essential for improving understanding of microbial processes and promoting responsible antibiotic use. *Unravelling Biofilms: Biocultural Surfaces* is a STEAM-based public engagement project that integrates microbiology with textile crafts to facilitate multimodal learning and dialogue. Across five workshops delivered to community groups and at a city-centre public engagement event, participants engaged in knitting and crocheting to construct a collaborative biofilm artwork while discussing bacteria, biofilms, antibiotics, and antimicrobial resistance. Fifty-one participants completed exit questionnaires assessing perceived knowledge, attitudes toward science, and intended future actions. Significant increases were observed in self-reported knowledge of bacteria, biofilms, biocides, and antibiotics. Participants also reported greater perceptions of science as relevant and accessible, and many indicated intentions to seek further information, attend future events, or continue crafting. Open-text responses highlighted strong engagement with microbiological concepts, enthusiasm for learning new craft skills, and increased awareness of university research. Demographic patterns suggested that community-based delivery effectively engaged older adults, while city-centre events attracted younger participants. Overall, this study demonstrates that craft-based STEAM engagement can enhance understanding of microbiology, support transdisciplinary learning, and broaden participation across diverse communities. The *Unravelling Biofilms* model offers a scalable, inclusive approach for communicating complex scientific topics through creative, collaborative practice.

69 **Graphical abstract**



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Introduction

Biofilms, antimicrobial resistance and health

Most microbial life resides within biofilms. The self-secreted extracellular polymeric substances, consisting of proteins, DNA and polysaccharides, help to protect the microbial communities within, conferring protection from environmental, immune and chemical stressors [1],[2]. Although biofilms are found in all environmental niches, their presence upon medical devices is of great concern for healthcare systems across the globe [3], [4], [5], [6], where biofilm formation is associated with up to 80% of microbial infections [6].

Current research into biofilms has highlighted the importance of biofilms in the transfer of antimicrobial resistance (AMR) [7]. The combination of different microbes within a biofilm can lead to the close interaction of different species together with different histories and therefore different antimicrobial susceptibility profiles. Gene transfer between different species is a common occurrence in biofilms by horizontal gene transfer due to the close proximity of the species [8].

Biofilms are the leading cause of healthcare-associated infections, the ability to form on abiotic surfaces and resist antimicrobial therapy makes them challenging to eradicate [9]. One key area which the authors have focused on is the use of combined use of biocides and quorum-sensing inhibitors (QSI) to be used within antimicrobial coatings of urinary catheters [10], [11]. The combined use of biocides, with the broad mechanisms of action against microbes but potential cytotoxicity, with QSI, which interrupts the microbial communication mechanisms, has the potential to reduce the concentrations of each agent needed to eradicate the microbes [12].

Engaging the public

Microbiology, and science more widely, can vastly improve the quality and length of human lives; however, these interventions cannot succeed without the support of the public they are designed to benefit [13]. Antibiotic resistance has a lack of public understanding, which underdetermines following best scientific practice. The resulting well-established overconsumption and misuse of antibiotics leads to increased antibiotic resistance [14]. Microbiological public engagement can increase knowledge and understanding as well as alter perceptions and behaviours around antibiotic usage [15]. Increased knowledge about the ongoing risks of antibiotic resistance and the ability of individuals, working as part of their wider communities, to play a role in preventing further development of AMR [16]. Science communication, therefore, has the potential to confer wider societal benefits through positive behavioural changes [17].

There are a plethora of ways in which science public engagement and outreach take place and can lead to enhancement of knowledge and science capital, including, but not limited to, collaboration with museums [18], [19], events on university campuses [20], science in the pub [21], science festivals [22], theatre productions [23], bacterial art [24] and school-based projects [25]. By utilising a model which is developmental and evaluative, scientific engagement activities open a two-way dialogue by extending trust from scientists to the public and empowering them to assess the data for themselves [26].

The STEAM approach

Science, Technology, Engineering, Arts, and Mathematics (STEAM) is an educational concept where "art" or "the arts" are included alongside the traditional STEM subjects [27], [28]. The interpretation of the term "STEAM" varies with context, as it is discussed as a method for economic growth, for knowledge production and as a pedagogical tool. Within it, "art" can refer to specific techniques, such as design, photography, sculpture, craft-based art, alongside drawing and painting, or to "the arts", referring to the humanities more generally [27]. By integrating arts-based approaches such as agar art, STEAM has been applied in microbiology laboratory teaching, increasing students' science self-identification and self-efficacy [29] and confidence in their aseptic technique [30]. STEAM can also be applied for scientific outreach, as it has the potential to appeal to audiences beyond those already engaged with STEM [28], for example, agar art was used to teach art students about microbiological techniques [31].

STEAM methodologies have the potential to support scientific learning; this lies in the *mutually instrumental* approach, where disciplines are brought in as "equal and in dialogic conversation, making the motivation for STEAM one based on transdisciplinary" [32]. Transdisciplinary approaches work across and beyond disciplinary boundaries, bringing together collaborators from different academic fields alongside non-academic participants to develop shared goals, methods, and conceptual frameworks [33].

STEAM approaches have been successfully utilised to share biofilm and AMR research with the public. Biofilm public engagement lends itself to model making, with LEGO modelling having been used to successfully teach school children about biofilm formation and treating biofilm-based infection [34] and mixed-methods used to model biofilms at schools and public engagement events [35]. Education theatre explored AMR at an established science festival, with participants reporting intended changes in attitude and behaviour around their use of antibiotics [23]. The STEM approach was clearly articulated in the "Hands On Biofilm" activities, where the biofilm from kombucha tea (the pecille) was dried and explored as fabric in fashion design, all of which was disseminated to the public during an established science festival [36].

Unravelling Biofilms

Unravelling Biofilms is a series of STEAM projects with the aim of communicating the importance of biofilms. The project started with submissions to the National Biofilms Innovation Centre Biofilm Create! Competition with the success of the Life and Death in Thread piece and the Biofilms Unravelled piece [37]. The project presented here is a subsequent project, *Unravelling Biofilms: Biocultural Surfaces*.

Within *Unravelling Biofilms: Biocultural Surfaces*. we set to employ a *hands-on* workshop format to facilitate a semi-structured conversation to exchange with participants on the topics of bacteria, biofilms, antibiotics and AMR. In the context of scientific engagement activities, workshops can be defined as learning events that take place in a delimited space and time with a *hands-on* approach to sharing experiences, learning from each other, and approaching learning in a collective manner [38]. Facilitating a hands-on activity such as crafting allows ways of learning that do not rely solely on written and verbal language [39], [40].

Through the series o*f Unravelling Biofilms: Biocultural Surfaces* workshops, we propose to use crochet and knitting as craft activities that allow a material engagement with the scientific topic. We use real research topics as the basis of the crafting activities and the discussion, through which the issues surrounding medical device use, biofilm formation and antimicrobial resistance could all be addressed within one area [41].

The *Unravelling Biofilms* project situates itself within the evolving field of STEAM by intentionally coordinating the "epistemic subcultures" [32] of microbiology and arts such as textile craft to promote multimodal learning. Here, we employ fibre craft as a form of artistic expression that is grounded in material engagement and practical skills that allows participants to 'think through their hands' [42]. In this sense, *Unravelling Biofilms: Biocultural Surfaces* can be understood as a STEAM initiative, where scientific knowledge and creative practices are collaboratively mobilised to support both knowledge exchange and public engagement.

Aims

The overarching aim of the *Unravelling Biofilms*: *Biocultural Surfaces* workshops was to evaluate the effectiveness of using a craft-based project as a medium through which to engage the public in novel biofilm and AMR research. This can be addressed through the following research questions (RQ):

RQ1: Does *Unravelling Biofilms: Biocultural Surfaces* increase participants' knowledge of bacteria, biofilms, antibiotics and antibiotic resistance and research undertaken at Sheffield Hallam University?

RQ2: Does *Unravelling Biofilms: Biocultural Surfaces* impact participants' perceptions of sciences and the actions participants intend to undertake in the future?

RQ3: Is *Unravelling Biofilms: Biocultural Surfaces* an effective method of STEAM public engagement?

Method

Participants

Community groups were approached with the offer of an *Unravelling Biofilms: Biocultural Surface* workshop. Four community workshops were completed, and one workshop was hosted at the annual *LiveLate* outreach event within Sheffield, run in collaboration with Sheffield Museums Trust, extending the transdisciplinary collaboration to include public-facing institutions [18], [19].

Workshop

All workshops were free to attend and had no charge to the hosting community groups. Workshops were hosted by at least two team members, one acting as the scientist and the other as a facilitator, reflecting the collaboration between microbiology and craft perspectives that informed the project development.

Following introductions, as crochet hooks and knitting needles were handed out, participants were encouraged to discuss their relationship to crafting. As the knitting and crocheting of the bacteria began, the conversation was steered towards the topic of what bacteria are and what participants knew about them. Once bacteria were made, they were attached to the piece, and the conversation was moved towards the topic of antibiotics, the use and resistance.

Participants were also encouraged to discuss what impacts where they live may have on their health and what would improve health in the future, bringing the scientific themes together with the participants' experiences. Within each session, a loose script was followed (Supplementary Data 1) to structure the discussion along shared themes developed across the team, and an element of the crafting process was completed at each question.

Data collection

Following the session, participants were invited to fill in an exit questionnaire (supplementary material 2), which collected demographic information, Likert scale

evaluations of knowledge and impact and open text boxes for comments about what was interesting and what they found out.

Ethics

Before starting the workshops, the ethics and data collection of the project were discussed, and any questions were answered. Ethics oversight was given by Sheffield Hallam University, under ethical approval ER62207745.

Photography

The photographs of the *Unravelling Biofilms: Biocultural Surfaces piece* were taken at regular intervals over the duration of the project. They were shot in the photo studio at Sheffield Hallam University using flash lighting and a high-resolution digital medium format camera to capture fine details.

Data analysis

Exit-questionnaire data from each workshop were entered into an Excel document. Only participants who provided both a “before” and an “after” response to a given question were included in that comparison. Changes in perceived knowledge and impact were assessed using two-sided Wilcoxon signed-rank tests [43], implemented in SciPy [44]. A two-sided alternative was used because no direction of change was assumed a priori; this provides a more conservative test of whether scores changed following the workshop and is the recommended default in the absence of a strong directional rationale [45]. Because Likert responses are restricted to a small set of integer values, a substantial proportion of participants gave identical “before” and “after” scores (zero differences); for example, 27 of 47 pairs for "Bacteria" and 31 of 42 for "science helps improve my life". These tied pairs were handled using Pratt's method, which retains zero differences during ranking before excluding them from the test statistic, rather than discarding them before ranking [46]. Pratt's approach was preferred because excluding zeros at the outset can substantially reduce the effective sample size and may yield inconsistent results when ties are common [46]. Statistical significance is denoted throughout as: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, **** $p < 0.0001$.

Open coding was used to categorise open text box answers to the questions of “Tell us something from today you have found particularly interesting” and “Has this event impacted what you might do in the next week/month/year, if so how?” using thematic content analysis [47].

Throughout the results, different n numbers are given; this is due to the presence of blank responses or in the case of open coding, there are multiple categories of responses within which the response could fit.

Maps of participant locations and event locations were processed on a workshop-to-workshop basis. Maps of participant and workshop locations were created with the use of shape files [48].

Results

Unravelling Biofilms: Biocultural Surfaces

Unravelling Biofilms is an ongoing STEAM project to communicate the fascinating world of biofilms to the community. Each piece in the *Unravelling Biofilms* series takes a different environment where biofilms exist and uses this to communicate related themes through structured dialogue and simultaneous craft activities. The *Unravelling Biofilms: Biocultural Surfaces* project was created over time, mirroring the growth of a biofilm.

In the style of an academic poster, participants knitted or crocheted the individual "bacteria" to add to the biofilm. The concept of the poster is based upon work evaluating the use of biocides and quorum-sensing inhibitors to inhibit uropathogenic *Escherichia coli* growth [41] and the near-completed *Unravelling Biofilms: Biocultural Surfaces* piece won the Access Microbiology Poster prize at the Microbiology Society's Annual Conference [49] (Figure 1).

Participant Demographics

A total of 5 workshops were completed. The four community group workshops saw 24 participants from 30 attendees (5, 3, 4 and 12 participants respectively) opt into the study. The workshop held at the public engagement event had 27 participants from 38 attendees opt into the study. Together, 51 questionnaire responses were collected from 68 attendees, giving a 75% overall opt-in to the study.

Across the series of workshops, 31% of participants were 65 years old or more, 29% aged 45 to 64, 19% aged 26 to 44 and 21% 16 to 25 (n = 48). Most participants were female (88%), with 12% male (n = 43). Participants were predominantly White/White British (79%), mirroring the overall Sheffield population. 6% of participants were Asian/Asian British, less than the Sheffield population of 10%. Only 2% of participants were Black/Black British, compared to 5% of the Sheffield population. 10% of participants described themselves as Mixed ethnicity or Other, compared to 7% of the Sheffield population (n = 48, [50]).

The community group workshops saw proportionally older participants, with 48% being over 65 years old, compared to 17% at the public engagement event workshop. Conversely, 39% of participants were 16–25-year-olds at the public engagement event workshop, compared to 4% at the community group workshops. There was no difference in the gender or ethnicity of participants between the community group and public engagement event workshops (data not shown).

To determine where participants resided, they were asked to provide their postcode in the exit questionnaire. The resulting postcodes were then mapped (Figure 2). Unsurprisingly, most participants were from the Sheffield area, with participants being in a similar geographic area to the community groups and events they attend.

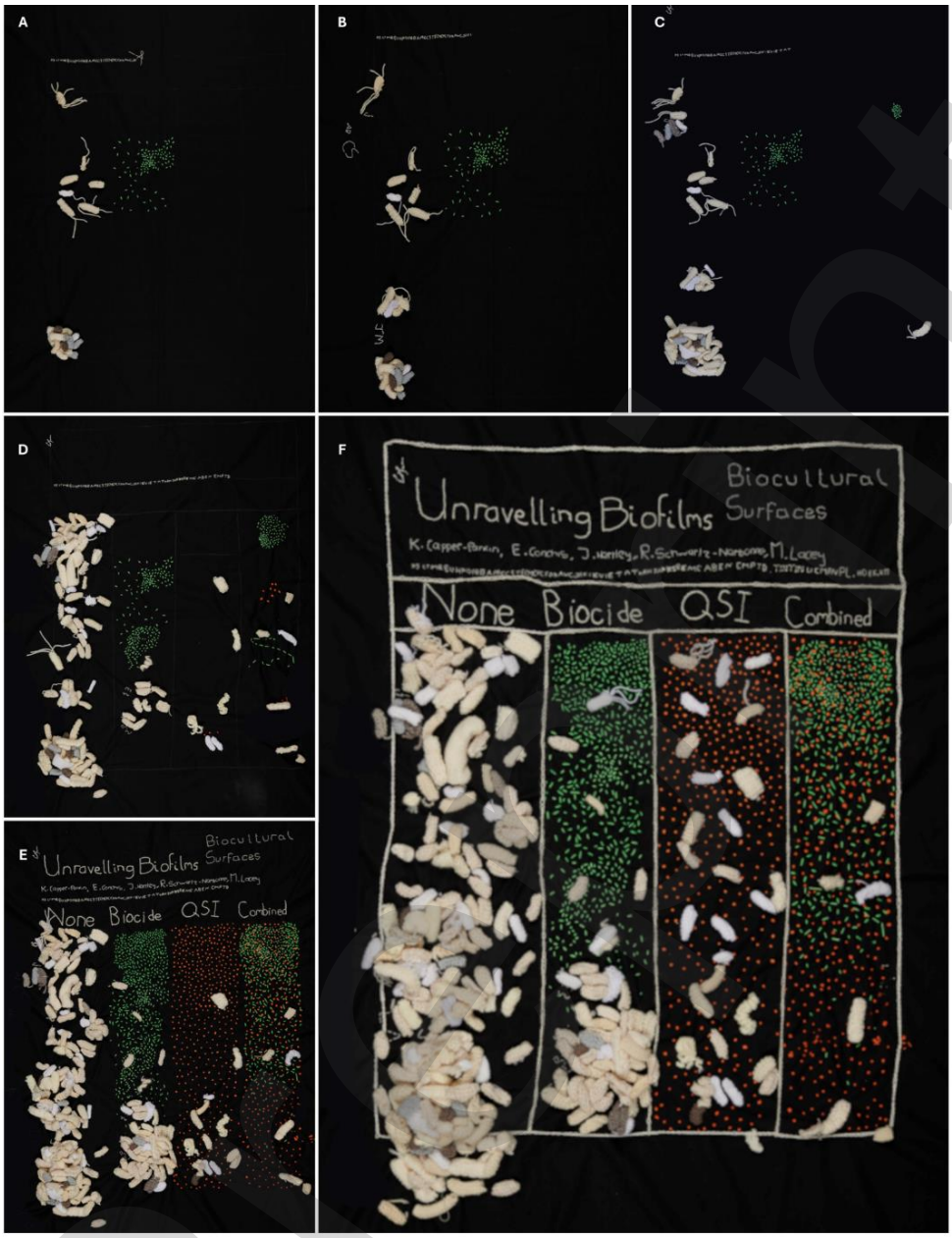

Figure 1. Unravelling Biofilms Biocultural Surfaces. Photograph series showing the progression of the *Unravelling Biofilms: Biocultural Surfaces* after each workshop to the final piece. A: after workshop 1, B: after workshop 2, C: after workshop 3, D: after workshop 4, E: after workshop 5, F: final piece. Growth of biofilm on a surface over time is shown vertically down the first column. The impact of biocides (green) and QSIs (red) on biofilm growth is shown in the 2nd and 3rd columns and in combination in the final column.

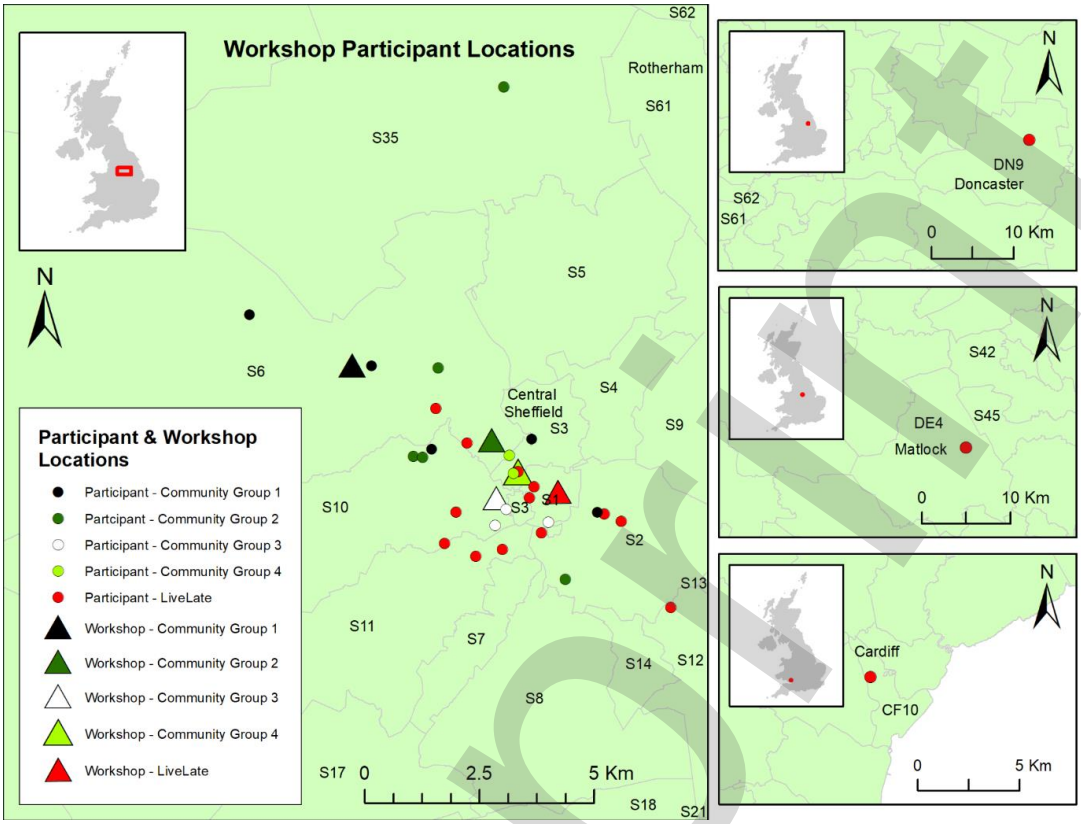

Figure 2. Map of participants and workshop locations. Locations are defined by participant postcodes provided in the exit questionnaire. Office for National Statistics licensed under the Open Government Licence v.3.0. Contains OS data © Crown copyright and database right [2022]. © GeoLytix copyright and database right 2012 Contains Ordnance Survey data. © Crown copyright and database right 2012 Contains Royal Mail data. © Royal Mail copyright and database right 2012 Contains National Statistics data. © Crown copyright and database right 2012. GIS vector data (n = 36).

Interest and Knowledge

To determine if participants had found the workshops interesting, the exit questionnaire asked: "Tell us something from today you have found particularly interesting" (Table 1). As the workshops used real ongoing research as the topic of the craft piece, the impact of using and discussing research with a lay audience was evaluated by asking "What have you learned about Sheffield Hallam University today" (Table 1).

Table 1. Themes of responses to the open questions of "Tell us something from today you have found particularly interesting" (n = 34) and "What have you learned about Sheffield Hallam University today" (n = 29). Responses were open-coded and themes identified. Note: as several responses were coded into multiple themes, the total of the frequencies may be larger than the sample size.

"Tell us something from today you have found particularly interesting"		
Theme	Frequency	Example
Bacteria / biofilm formation	12	*"Plaque is a biofilm, so is the slime on a boat"*
Learning to Knit / Crochet	9	*"Learn how to crochet"*
Antibiotics / biocides / natural biocides	8	*"Biocides are toxic"*
Using craft as a teaching medium for science	7	*"The concept of combining art with science craft"*
Learning about scientific research	6	*"Research- always interested as have medical background, interesting to learn that new ideas can impact on old problems"*
"What have you learned about Sheffield Hallam University today"		
Theme	Frequency	Example
the amount of research we do / diversity / complexity	7	*"That it is hugely diverse, complex"*
How the research can improve health	6	*"Interesting and important to improve patient health"*
Research on biofilms and microbiology	6	*"Very diverse range of microbial research going on"*
How public engagement can play a key role in research	2	*"There are fun ways to contribute to research"*

The most common theme the participants highlighted as finding particularly interesting was bacteria and biofilm formation. Most responses were related to the microbiology content and scientific research discussed in the workshops, although the use of crafts and learning new techniques was also a strong theme. Learning about Sheffield Hallam University was focused on research, specifically research around biofilms and health.

To determine if the workshops had increased participants' perceived knowledge, they were asked to rate how much they knew about a range of relevant topics before and after the session (Figure 3).

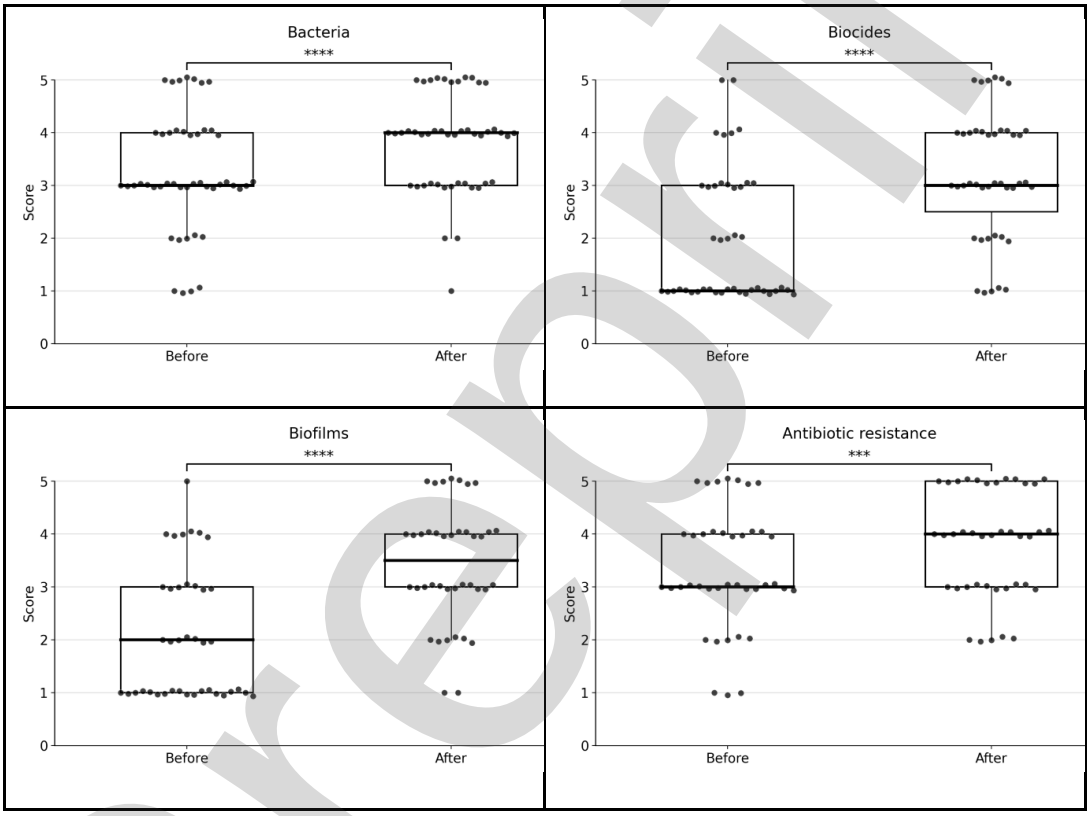

Figure 3. Significant increases in knowledge were seen across all topics discussed. Participants were asked to score "how much do you know about…?" "Bacteria" (n = 47), "Biocides" (n = 43), "Biofilms" (n = 40) and "Antibiotic restisance" (n = 40) on a 5-point Likert scale before and after the session. Interquartile range shown. Comparison of before and after scores by two-sided Wilcoxon signed-rank test (Pratt's method for tied pairs); * indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$ and **** indicates $p < 0.0001$.

Perception of science and intended actions

To explore if participants' perception of science had altered, participants were asked to rank their views before and after the event in the question “What was the impact of today on…” (Figure 4).

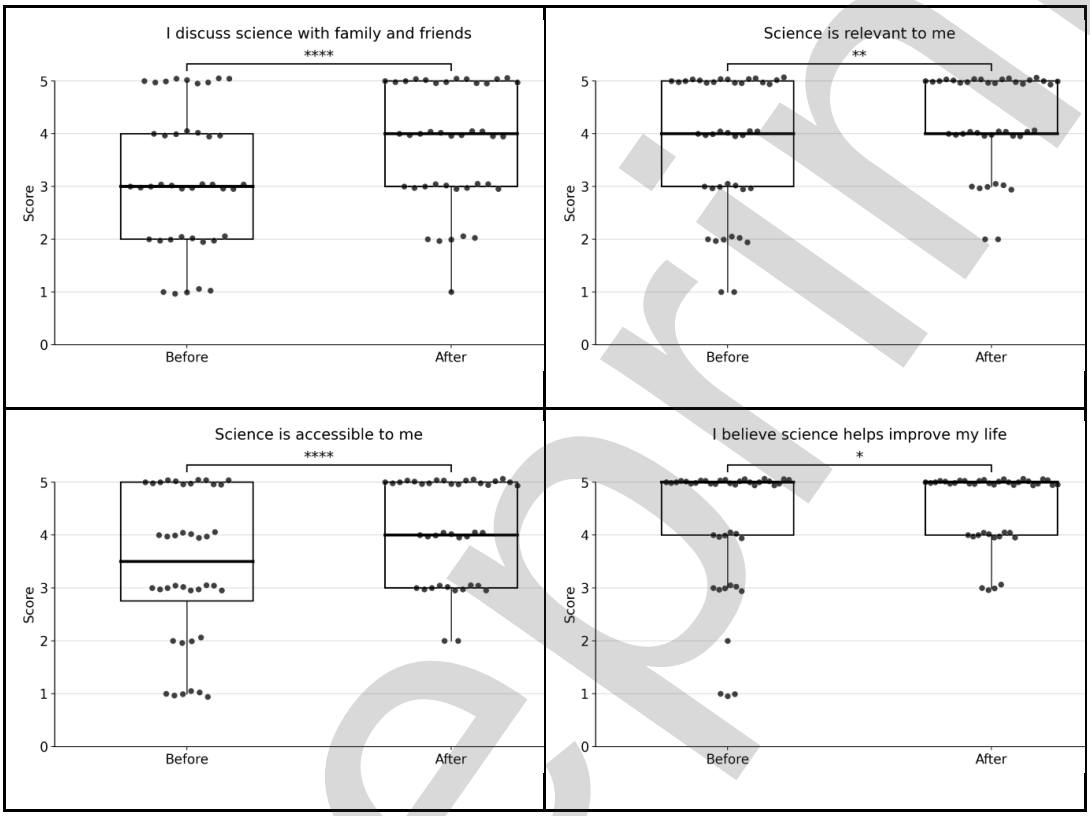

Figure 4. There were significant increases in the perceived impact of the sessions. Participants were asked to score “What was the impact of today on…” “Discuss science with family and friends” (n = 41), “Science is relevant to me” (n = 41), “Science is accessible to me” (n = 40) and “I believe science helps improve my life” (n = 42) on a Likert scale before and after the session. Interquartile range shown. Comparison of before and after scores by two-sided Wilcoxon signed-rank test; * indicates $p < 0.05$, ** indicates $p < 0.01$, *** indicates $p < 0.001$ and **** indicates $p < 0.0001$.

Participants reported that science was more relevant and more accessible to them after the session. They also had an increased view that science helps to improve their life.

To determine if these changes in perception of science translated into changes in intended actions, participants were asked: “Has this event impacted what you might do in the next… over the next week” 69% responded “yes” (n = 26). When asked “Has this

event impacted what you might do in the next… over the next month" and "the next year", 65% (n = 20) and 67% (n = 21) responded "yes" respectively. Participants were given an open text box to provide a comment for their answer (Table 2).

Table 2: "Has this impacted what you might do in the next…" Open text "comment". Responses were open-coded and themes identified (n = 22).

Themes	Week	Month	Year	Example
Increase understanding of Microbiology	7	2	3	*"Read about bacteria, biocides and biofilms"* *"Check on this project's progression"*
Try new activities and attend more events	2	5	5	*"Doing practical activities to help with learning"* *"look up more events similar like this"*
Increase understanding of Science	3	2	4	*"to go deep in finding more information"*
Improve knitting and/or crocheting	4	2	0	*"try and learn to knit"* *"to crochet better"*

The themes of "Increase understanding of Microbiology" and "Improve knitting and/or crocheting" were most frequent in action this "Week", whereas "Try new activities and attend more events" and "Increase understanding of Science" were more frequent in action this "Year".

Discussion

The study aimed to investigate the effectiveness of a STEAM-based, collective craft-based project to increase understanding and positive perceptions of Microbiology. This was achieved through a series of workshops in which participants and facilitators

knitted, crocheted and stitched bacteria into a biofilm (Figure 1). During each workshop, a semi-structured group conversation occurred, discussing lived experiences of healthcare and shared knowledge of bacteria, biofilms, biocides and antibiotic resistance. As a scientific engagement activity, the efficacy of the project was evaluated through an exit questionnaire evaluation, including before and after Likert scale questions and open-ended answers.

Two styles of workshops were undertaken within the study: community group workshops and a workshop at a city-centre-based public engagement event. The typical age of participants differed between workshop types, with 48% being over 65 years old at the community workshops, compared to 17% at the public engagement event workshop, and 4% being 16-25 year olds at the community group workshops, compared to 39% at the public engagement event workshop. Most science public engagement focuses on younger audiences, and there is a need for outreach that engages varying demographics, including over 65-year-olds [51]. It is tempting to speculate that this distinction between the two events arose from their locations. The community group workshops were run with existing crafting groups at established locations, typically close to the community members who participated in them, while the public engagement event workshop was held in the centre of Sheffield (Figure 2). Previous successful science public engagement activities with seniors have gone into senior centres [52], [51], [53] and a food pantry [54]. Taking science public engagement activities into communities may reduce the barriers to participation for older participants.

It can be challenging to develop public engagement strategies to communicate the complexity of the scientific phenomena and technological concepts to non-scientists [55], [56]. Our findings suggest that craft-based science engagement within a STEAM framework can increase accessibility for participants, as evidenced by statistically significant increases in knowledge, by an expressed interest in further learning, and through meaningful engagement with key concepts on biofilms, which highlights both enhanced understanding and the perceived relevance of the topic. From a STEAM multimodal learning perspective, participants engage with a scientific topic in a way that mobilises different modes of thinking through making and valuing their own skills and experience [39], [40]. It is important to ensure that within STEAM, the arts are not seen as a mechanism to disseminate STEM [32]. Here, the arts in STEAM is valued equally to science, in line with transdisciplinary project design [33].

Craft activities such as the *Unravelling Biofilms: Biocultural Surfaces* workshops can make scientific concepts and phenomena more explicit and tangible to the participants through the process of creating physical objects. Crafting is particularly suited for translating ‘seemingly intangible phenomena’ into ‘sensory experiences’ [57]. Crafting can be viewed as a form of active learning, a pedagogical method that supports both

increases in confidence around learning in general and in the subject area of the activity [32], [57]. In the context of biofilms and antimicrobial use, craft can support understanding of biological processes occurring at scales invisible to the naked eye and tie them to phenomena people actively participate in. Participants within our study reported an increase in the feeling that science is accessible, which is consistent with other case studies employing textile-based crafts as a medium for teaching scientific topics such as chemistry [58].

Conversations during the crafting activity highlighted additional benefits from crafting that may have supported knowledge acquisition. Participants highlighted that crafting is a learning process which typically involves making mistakes, practice and overall persistence to understand techniques. Such learning dynamics can be paralleled with the learning of complex scientific concepts, which may seem complex at first but can be worked out in a collective manner. Craft activities typically support the formation of social groups, where the social value of crafting can be found in how communities regularly meet to craft together and share skills and resources [59], [60]. The capacity to build the participants' confidence to learn a new topic may stem from learning through a topic or skill that they have already learnt and are confident in, such as their craft; this is complemented by a multidirectional style of learning though distinct but sometimes overlapping roles in the learning activity, where scientists and crafters alike can be educators, and where expertise in each role is held by different people [59, 60].

Crafting is generally perceived as a feminine pastime, and as such, is devalued [59]. The use of craft as a means of scientific outreach supports the re-framing of the value of craft-making. Crafting is progressively recognised as an important means of creative expression, a source of wellbeing, and a vector for social and community connection, where crafting skills weave in important social networks together and contribute to making sense of everyday issues that often go unnoticed [59], [61]. *Craftivism* is a form of activism that values crafting skills and spaces as producing means and conditions for positive social change [61]. Craftivism harnesses creativity, embodies knowledge and collective making to express personal, political and social ideas, to challenge existing norms, build community, and assert agency [62]. Parallels can be drawn between the underpinning principles of craftivism and participatory Microbiology-based public engagement.

Conclusion

Unravelling Biofilms: Biocultural Surfaces showcases craft-based STEAM approaches to increase knowledge and understanding of Microbiology. By enabling participatory, multimodal understanding of complex concepts through crafts, participants report increased accessibility to microbiology.

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Conflicts of interest

ML is the pedagogy editor for Access Microbiology.

Open data

Exit questionnaire data (less demographic information) is openly available at 10.6084/m9.figshare.32678286

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