Increasing microbiology literacy about the public health threat of antimicrobial resistance through Art-Science interactions

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Abstract

In response to the recognized urgent global public health threat of antimicrobial resistance (AMR), the cause of drug-resistant infections, art-science activities are increasingly utilised as public engagement (PE) and public outreach (PO) tools to increase microbiology literacy. Though AMR art-science activities aim to increase public awareness, research evaluating the platform as one conducive to the aims of AMR engagement, including long-term behavioural change, is lacking. The aim of this research study is to explore interactive art-science activities aiming to promote microbiology literacy in AMR. Existing activities lack critical evaluation, and development details are not shared with wider audiences. The SARS-CoV-2 pandemic introduced a global shift to online platforms, driving the necessity to reevaluate current PE/PO methods and integrate interactive tools. Two AMR SciArt activities exploring gamification and interactive fiction are described and analysed as case studies. Both were informed by the existing research and evidence-based theories in this chapter, and operated in pre- and post- SARS-CoV-2 pandemic limitations. These activities' methods show promise, however, the most effective strategy in AMR PE is yet to be defined. By establishing a standardised framework and sharing evaluated activities based on evidence-based learning research, more work can be done to inform and strengthen future activities.

Key Words

Antimicrobial resistance, Microbiology literacy, Public engagement, Science communication, Comics, Health literacy

9.1 Introduction

In 2019, Timmis et al. emphasised the urgent need to improve microbiology literacy in society, stating that "unlike other subjects having a pervasive impact upon humankind, such as financial affairs, health, and transportation, of which there is a widespread understanding, knowledge of relevant microbial activities, how they impact our lives, and how they may be harnessed for the benefit of humankind– microbiology literacy – is lacking in the general population, and in the subsets thereof that constitute the decision makers." Antimicrobial Resistance (AMR) awareness is a critical aspect of microbiology literacy. AMR results in drug-resistant infections, and is recognized as an urgent global health threat currently causing approximately 5000 annual deaths in England and over 700,000 annual deaths globally. This number is steadily increasing (Interagency Coordination Group on Antimicrobial Resistance, 2019). The most recent systematic analysis of 2019's global burden data suggests that in 2019, there were 4.95 million deaths associated with bacterial AMR, with 1.27 million of these deaths directly caused by bacterial AMR (Murray et al., 2022). Despite the significant global burden of AMR, there remains misunderstandings in the general population of how an individual can take action to help slow and prevent AMR (World Health Organization, 2015).

Public engagement (PE) and public outreach (PO) are considered promising methods to slow AMR rates by increasing public awareness of the topic. (National Co-ordinating Centre for Public Engagement (NCCPE), n.d.a; Illingworth and Allen, 2016). PE requires two-way interaction between the public(s) and practitioner while PO involves one-way communication of research and higher education-based topics (Illingworth and Allen, 2016). ‘Art activism’ is a method involving PO and PE showing promise in communicating public health related topics with the aim of long-term behavioural changes such as AMR. The scientific consensus is that both learning and long-term memory is facilitated by emotional and therefore meaningful

connection (Davies, 2019). For these reasons, it is important to continue creating AMR engagement projects, strengthening, and pushing the boundaries of current practice.

There are many mechanisms that can influence public knowledge and attitudes, with a wealth of research in which the arts have been used (referenced in Curtis et al., 2012), however, the most effective strategy in AMR PE is yet to be defined. For this reason, there is a call for the exploration of innovative AMR PE approaches, as long as they are published and evaluated as to fast-track development of a strong framework (Redfern et al., 2020).

To evaluate the effectiveness of interactive art-science activities as a tool for promoting AMR awareness and microbiology literacy in the public realm there must exist a standard evaluation and key aim to compare, contrast, and therefore strengthen activity methods (Redfern et al., 2020). Due to the lack of standardised design framework and evaluation in this field, this chapter explores existing literature that may inform the development of an effective AMR PE and outreach activity design framework. Although research literature on AMR PE and outreach activities is relatively new and not yet well developed, research undertaken in other fields may offer considerable insight into factors contributing to effective AMR awareness activities.

It is important to consider the influence of the SARS-CoV-2 pandemic on public perception of microbiology when considering future AMR outreach approaches. This pandemic unprecedentedly forced the world into collective immersion of microbiology and health education through pandemic social messaging, resulting in drastic, widespread infection-prevention behavioural changes, such as mask wearing, hand washing, sanitising, and social distancing. Due to this immersion, the public baseline understanding of SARS-CoV-2 and microorganisms' critical role in public health have increased (Read et al., 2022). However, fear surrounding SARS-CoV-2 infection may drive misconceptions about microorganisms, specifically the belief that all microorganisms are pathogens causing disease that need to be destroyed; less than 1% of microorganisms are pathogens with the rest harmless, helpful, or critical to human and environmental health and need to be understood to inform decisions at a personal and global policy level (Carvalho and Lima, 2022)(Robinson et al., 2021)(Timmis et al., 2019).

Negative perceptions driven by misunderstandings about microorganisms coupled with an increased baseline in the publics' microbiology literacy level, specifically a greater understanding of hand washing's role in infection prevention, may require re-evaluation of key

education aims of future microbiology art-science activities. This may allow greater complexity in PE/PO art-science AMR awareness activities, but it also may require practitioners to focus on unravelling additional misunderstandings associated with microorganisms while emphasising positive roles.

Furthermore, the SARS-CoV-2 pandemic transformed communication methods utilised in public education. The lockdown restrictions forced educators to shift delivery from traditional, direct communication to one heavily utilising technology and online platforms. Educators were challenged to create engaging online content that facilitated learning despite the lack of face-to-face interaction. This has driven innovative approaches in online education. A technique utilised to promote greater student engagement and reinforce knowledge includes integrating more interaction through gamification, incorporating game motivation techniques and mechanics to non-game subjects (Joshi, 2021; Lee and Hammer, 2011). Comics were also increasingly utilised, viewed as a natural medium for public health education during the pandemic, "as a vehicle to present science in graphic narratives, harnessing the power of visuals, text, and storytelling in an engaging format" and as a medium established as having great accessibility to low literacy levels in both children and adults (Kearns, C. and Kearns, N., 2020).

Despite limitations to online learning, it is a major source of health literacy for the global public and considered a valuable tool to connect with a wider audience and disperse public health information (Jia, Pang, and Liu, 2021). With the pandemic driving innovative, interactive ways to better engage online, it is important to learn from these ideas and build upon identified strengths. With face-to-face interaction no longer restricted, continuing to utilise supplementary online platforms may provide a valuable resource to widen PE/PO activities' impact and reach from an isolated event to a globally accessible online resource. This is especially critical in regards to the public health threat of AMR, which, to prevent unneeded deaths and economic burden, urgently requires global, collective efforts and widespread policy changes (Tarin et al., 2022).

Two case studies utilising art-science practice to increase AMR awareness will be compared and contrasted to provide insight into the benefits and limitations in shifting methods utilised in art-science activities in response to the SARS-CoV-2 pandemic. One activity was developed and enacted pre-pandemic while the other activity was developed in response to pandemic restrictions.

9.2 Literature Review

This literature review aims to understand why art-science activities are considered impactful, and determine their potential as an effective PE/PO tool that should continue being utilised by antimicrobial resistance (AMR) activists. First, the demand for AMR public art-science activities will be described. Then, art-science activities will be defined to understand how and why this platform developed into an activism tool. Following this, literature relating to art-science activities promoting increased microbiology literacy in AMR will be analysed for their strengths and weaknesses. Finally, two case studies will be evaluated to compare and contrast interaction methods used pre COVID-19 pandemic versus restricted in response to the pandemic.

Due to the lack of published evaluations relating to AMR PE activity design and impact, this chapter will refer to related literature aimed to increase awareness of similar, activism-based topics requiring global policy changes and collective action. By studying activities based on similar topics, this chapter aims to provide insight into the strengths and weaknesses of the PE platform based on more established research. The literature review will describe research undertaken in other fields including social sciences and public health to gain insight into the factors contributing to effective AMR PE activities. Common themes in successful art-science activism activities will be identified and will contribute to the proposition of a framework yet to exist for those wanting to develop their own AMR PE/PO activities. Finally, the existing art-science activities that ran pre-pandemic and in response to pandemic restrictions, both promoting microbiology literacy in AMR awareness, will be detailed and analysed as case studies.

9.2.1 What is Antimicrobial Resistance (AMR)?

Antimicrobial Resistance (AMR) results in drug-resistant infections, and is recognized as an urgent global health threat, causing approximately 5000 annual deaths in England and over 700,000 annual deaths globally. This number is steadily increasing (Interagency Coordination Group on Antimicrobial Resistance, 2019). AMR occurs when microscopic organisms that can cause infections such as bacteria, viruses, parasites and fungi develop weapon-like abilities allowing them to fight and defeat antimicrobial drugs like antibiotics, normally used to fight infections. These mutated, drug-resistant microorganisms are called ‘superbugs’. When they are

not killed, they continue to grow and spread until the person they have infected is either treated by a different method, has overcome the infection, or dies (World Health Organization, 2018). AMR occurs due to misuse of antimicrobials where an antibiotic treatment is stopped early, when antimicrobials are overused in humans, animals, and plants, or due to poor hygiene (Interagency Coordination Group on Antimicrobial Resistance (IACG), 2019, p. 3).

It is predicted that without intervention, in 30 years, drug-resistant infections, no longer treatable by antibiotics, may cost 100 trillion US dollars and take the lives of up to 10 million people each year (Review on Antimicrobial Resistance, 2016, p. 15). This would overturn modern medicine making simple medical procedures like surgery, caesarean sections, organ transplants, and cancer therapy life-threatening with significant economic burden (World Health Organization, 2018). A systematic analysis of global burden data suggests that in 2019, there were 4.95 million deaths associated with bacterial AMR, with 1.27 million of these deaths directly caused by bacterial AMR (Murray et al., 2022).

9.2.1.1 Why is Antimicrobial Resistance public engagement and outreach important?

In 2016, The United Nations Global Assembly politically declared AMR as an established priority for intervention, securing it within the global political agenda (United Nations General Assembly, 2016). In this declaration, "Member States requested the Secretary-General, in consultation with the Food and Agriculture Organization of the United Nations (FAO), the World Organisation for Animal Health (OIE) and the World Health Organization (WHO) to convene an ad hoc interagency coordination group (IACG)"; the Inter-agency Coordination Group (IACG) on AMR was appointed to generate common direction among global sectors, industry, and nations (IACG, 2019). IACG released an updated global initiative in 2019 urging stronger regulations to be put in place, because AMR rates can only be reduced by collective, worldwide action.

One key strategic objective out of the five proposed by the WHO's global action plan is to reduce AMR rates by raising the general public's awareness and understanding of this issue (WHO, 2015 p.8). This awareness is regarded as critical in driving long-term behavioural changes regarding misuse and overuse of antimicrobials (IACG, 2019; WHO, 2015 p.8). Since

this plan was proposed, many institutions and organisations have designed and delivered AMR-based activities termed ‘public engagement’ or 'public outreach' activities (Redfern et al., 2020). Additionally, The Society for Applied Microbiology (SfaM), the oldest microbiology society in the UK whose goal is to use microbiology to address challenges significant to humankind, calls for the “urgent need for microbiology literacy in society” as it is currently lacking. They argue that “microbiology literacy in society is indispensable for informed personal decisions, as well as for policy development in government and business, and for knowledgeable input of societal stakeholders in such policymaking”, specifically emphasising the importance of microbiology literacy regarding AMR (SfaM, 2019; Timmis et al., 2019). This lack of microbiology literacy in society further drives the necessity to analyse and develop strong AMR public engagement activities.

Public engagement (PE) and public outreach (PO) are considered promising methods to slow AMR rates by increasing public awareness of the topic. PE is defined as the “myriad of ways in which the activity and benefits of higher education and research can be shared with the public” in a way that allows two-way interaction, conversation, and mutual benefit (National Co-ordinating Centre for Public Engagement (NCCPE), n.d.a). PO is defined as, "a one-way discourse, in which scientists communicate their research to the general public, with particular focus on schoolchildren and young people" (Illingworth and Allen, 2016). Though we refer to the general public as a singular term, it should be noted that the public is commonly referred to as ‘publics’ due to there existing many different target groups within the ‘general public’ that may require different considerations when choosing a PE method.

Showing widespread public interest in an issue may adjust long-term behaviour to one of appropriate antimicrobial use, generate more time/funding to support further research in alternative treatments to drug-resistant infections and antibiotic discovery, target important stakeholders such as those in the health profession to adjust prescription behaviour, and push political leaders to set in motion public policies needed to make a significant, lasting change (Anderson et al., 2020 p.47; Hoffman and Outterson, 2015 p.364; SfaM, 2019; Timmis et al., 2019). For these reasons, it is important to continue creating AMR engagement projects, strengthening, and pushing the boundaries of current practice.

9.2.1.2 Art-Science public engagement activities and art activism

'Art activism' is a PE/PO method showing promise in communicating public health related topics with the aim of long-term behavioural changes such as AMR. The scientific consensus is that both learning and long-term memory is facilitated by emotional and therefore meaningful connection (Davies, 2019). With this basis in mind, 'artistic activism' developed as a promising PE method in which the aim "is not to force compliance, which art can never do, but to persuade by creating moving experiences that prompt people to question the world as it is, imagine a world as it could be, and join together to make that new world real" (Guerilla Science, 2018). With the mounting evidence supporting science communication as 'emotion work' in which wonder and curiosity is harnessed to facilitate effective science communication, 'art activism' is a term that informs this movement (Davies, 2019). Thus, science and art practitioners have collaborated in creating art-science public engagement activities in hopes to adjust targeted publics' understanding of behaviour in some way.

Art in combination with the sciences has been shown to be effective in communicating complex concepts of science to a broader audience by promoting curiosity in a subject and resulting in viewing a concept in a different way (Grimberg et al., 2018; Jensen and Buckley, 2014). Art-science or 'SciArt' activities have also been found a potential catalyst for scientific advocacy and community action as supported in research by Curtis et al. (2012) who described the role of art in engaging the public in communicating "unpalatable" urgent messages about climate change with the aim of inspiring collective public understanding, behaviour change and action. Curtis et al. (2012) represented climate change issues through visual/performing arts (theatre, music, and dance) and it was concluded based on surveys that the arts should be harnessed to "convey complex scientific information, promote new ways of looking at issues, touch people's emotions, and create a celebratory atmosphere".

There are many mechanisms in which to influence public knowledge and attitudes with a wealth of research in which the arts have been used (referenced by Curtis et al., 2012), however, the most effective strategy in AMR PE is yet to be defined. For this reason, there is a call for the exploration of innovative AMR PE approaches, as long as they are published and evaluated as to fast-track the development of a strong framework (Redfern et al., 2020).

9.2.1.3 Gaps in current Antimicrobial Resistance public engagement and outreach activities

"*Few of these events for a general public audience are documented or able to be sourced by those who might wish to repeat, adapt, or modify, particularly those events that are successful. 'Insider knowledge' appears to be the best search tool.*" (Redfern et al., 2020)

The first systematic review summarising and analysing AMR-specific PE and PO activities was published in March 2020 by a Manchester Metropolitan University based research group (Redfern et al., 2020), and it outlined the range of AMR PE activities delivered in the UK (2020). The study recognized that a wide range of creative AMR public engagement and outreach activities exist worldwide, however, there remains a lack of published papers on these activities, and those that are published rarely include success and impact evaluations. Their review concludes that, "implicit in all of these activities should be the identification of the key hypothesis/message and the particular audience, the design and delivery of the activity, and an evaluation of its success." Only with critical, standardised, and published evaluation can activities be meaningfully compared and an evidence-based framework to adjust and strengthen future activity impact be built (Redfern et al., 2020).

Redfern et al. (2020) further notes the broad range of AMR art-science interactive public activities that exist on a variety of platforms, including film, journalism, online games, festivals, and museum exhibitions. Although the goals of these AMR art-science activities are similar, their impacts are affected by different factors, including the audience type and key aim of the activity. The NCCPE suggests that tailoring an activity based on these factors is critical to effective PE and PO (NCCPE, n.d.b). Effective communication changes based on your target audience's preliminary understanding of the topic and established belief system (NCCPE, n.d.c).

9.3 Defining the Key Aim of AMR Art-science Public Engagement and Outreach Activities

Redfern et al.'s conclusion, as mentioned above, identified that "implicit in all of these (AMR public engagement and outreach) activities should be the identification of the key

hypothesis/message and the particular audience, the design and delivery of the activity, and an evaluation of its success" (2020). Supported by the findings of Redfern et al. (2020), the WHO's global action plan on AMR (2015), and IACG (2019), we propose two key aims of AMR PE and outreach activities which will contribute to slowing down AMR rates, a key component of tackling the urgent global public health concern of AMR:

1. Awareness of AMR, specifically regarding common misconceptions in the public;
2. Long-term behavioural adjustment regarding misuse and overuse of antimicrobials.

The following section evaluates the effectiveness of existing AMR public engagement and outreach activities based on these key aims by interrogating existing 'behavioural interventions' attempted through AMR activities to result in effective AMR awareness. If a strong theme in method/methodology is identified, this could be used to formulate an AMR art-science activity framework.

9.3.1 How effective are current AMR activities to long-term AMR awareness and AMR stewardship?

Since the WHO global action plan was established, many AMR-related activities have been funded and developed with the overarching goal of effective 'behavioural intervention' of the public in two main ways: increasing the public's awareness of AMR and determining long-lasting AMR stewardship behaviour (Redfern et al., 2020; Price et al., 2018). AMR stewardship (AMS) behaviour in the context of PE activities refers to responsible, AMR-informed actions that limit antibiotic overuse and misuse. Increasing the public's awareness of AMR can be tested through pre-activity and post-activity knowledge gain. The latter is more difficult to test, because it involves a follow-up survey assessing long-term behavioural changes as a result of an intervention (Price et al., 2018). When discussing 'effectiveness of behavioural interventions' or mentioning 'effectiveness' in regards to AMR PE in the subsequent sections, the two criteria above established by Price et al. (2018) in their landmark analysis of evaluating effectiveness of AMR interventions will be referred to.

In 2015, researchers from the Department of Health in Turin, Italy published findings suggesting that the general global population's knowledge and usage surrounding antibiotics is lacking by performing the first systematic review and meta-analysis of analysed surveys from January 2000 to November 2013 (Gualano et al., 2015). They found 33.7% of the sample subjects were unaware that antibiotics can treat bacterial infections, 53.9% of the sample did not know antibiotics are not useful against viruses, 47.1% of the sample subjects declaring that they stop taking antibiotics when they start to feel better, and though 59.4% of the sample "was aware of antibiotics resistance, 26.9%" did not realise antibiotic misuse causes this resistance. The researchers recognize their limitations include the lack of standardised questionnaire administration and controlled sampling selection that may lead to biases.

McCullough et al., (2015) from the Centre for Research in Evidence-Based Practice in Australia, performed a similar systematic review of literature as Gualano et al. (2015) regarding the global public's knowledge about antibiotic resistance using a different methodology, and came to the same conclusion. They also address the limitations of their study being the lack of standardised evaluation methods. Nevertheless, these studies have since been referenced as evidence of the need for increased AMR public engagement as they suggest that there may be a lack of antibiotic resistance awareness in society, supporting the need for effective public engagement interventions to be explored and developed (Redfern et al., 2020).

A suggested lack of AMR awareness in the general public led to the landmark analysis by Price, et al. in 2018, assessing if AMR behavioural interventions to date have resulted in significant improvements regarding the public's AMR knowledge and AMR stewardship behaviour (Price et al., 2018). This research project from the Institute for Applied Health Research at Glasgow Caledonian University, compiled all existing 'interventions' and found that a majority targeting the general public were effective in improving AMR knowledge and antimicrobial stewardship behaviour. Some, however, did not show behaviour/knowledge improvement with two studies showing a decrease in AMR knowledge/antimicrobial stewardship behaviour. Price et al. (2018) recognized that these results suggest certain PE/PO methods may facilitate effective activities, and this is an area which should be further explored. Additionally, they recognized limitations of their analysed data including the findings being heterogeneous and complex with no distinction regarding PE and PO platform/method. They "highlight the need to

examine differences in content between these interventions targeting the general public" (Price et al., 2018).

Price et al. (2018) established that the results of behavioural interventions regarding AMR are mixed with the public continuing to show misconceptions and lack of knowledge, and a few months later, McParland et al. (2018), a research group containing several of the same researchers as in Price et al., responded by publishing the first formal analysis of AMR PE activities to determine "the 'active ingredients' of interventions targeting the public's engagement with antimicrobial resistance" and how they might work. They found that national, European, and global AMR awareness campaigns used a wide range of methods including factsheets, posters, videos, social media, and interactive games, however, no studies "identify exactly what works, why it works, for whom, when, and in which circumstances" making it "impossible to determine which intervention components are typically used or indeed which are associated with effectiveness" which in turn makes it "impossible for others to understand, evaluate, and replicate the active content of behaviour change interventions" (McParland et al., 2018).

Both research groups stated that a major limiting factor in their analyses was that most studies did not base their intervention designs on established behavioural change theories (BCT) in the field of Psychology and the studies that have were found only to have employed 15% of possible BCT's (McParland et al., 2018). BCT's are evidence-based interventions that are considered by the Medical Research Council as the key intervention components and the 'mechanisms of change' when understanding, developing, and evaluating complex interventions such as AMR (Craig et al., 2008). McParland et al.'s work concluded that BCT's should be referenced and employed when designing AMR PE activities with the goal of long-term behavioural change in participants as evidence-based methodology versus "designed with implicit theoretical assumptions in mind". McParland et al. (2018) suggests that BCT's in the most successful interventions include "promoting beliefs about capability and reinforcing behaviour, as well as encouraging a commitment to change behaviour and imagining future outcomes if behaviour is not changed, monitoring behaviour (with and without feedback) and providing information on the antecedents of behaviour", but argue that due to the heterogeneity of the interventions found and a majority of BCT's yet to be harnessed, these factors are not

definitive, and a “new generation of different interventions” using different combinations of BCT’s are needed.

9.3.2 Learning from ineffective AMR national engagement campaigns

“*The study highlights that there has been* ***no change in the status quo with respect to awareness of antibiotic usage and AR even after the implementation of several awareness campaigns*** *in England. Overall, public respondents residing in* ***affluent areas possessed much better knowledge and understanding on AR problems and antibiotic usage*** *and this was statistically significant…. In addition, public respondents* ***in deprived areas possessed much poorer knowledge on prudent antibiotic usage*** *compared to those in affluent areas*” (Mason et al., 2018)

In attempts to raise AMR awareness and reduce inappropriate antibiotic use in the general public, Public Health England launched several nationwide campaigns including one in 2008 and one in 2014 called 'Antibiotic Guardians', part of European Antibiotic Awareness Day (EAAD). However, there was no significant evidence of long-term behaviour change or increased AMR knowledge in the general publics between these time frames (McNulty et al., 2010; Bhattacharya et al., 2017). In 2018, Mason et al. surveyed 768 residents of London and suggested that there was no significant change in the publics' AMR awareness since a study completed by McNulty et al. (2010) that was undertaken 10 years prior, despite implementation of Public Health England's campaigns. Analysis of the survey results suggested that, "any efforts to date to educate the general public have not made a remarkable impact" and "exposure to the antibiotic awareness campaigns did not enrich knowledge of those respondents on how to take an antibiotic correctly, as the responses did not differ statistically to those who had not been exposed to campaigns" (Mason et al. 2018). This study also found a significant difference in AMR understanding between those from affluent areas versus deprived areas. Residents of affluent areas possessed greater knowledge of AMR compared to those of deprived areas. Despite these findings, both residents of affluent and deprived areas had misunderstandings of AMR (Mason et al., 2018). These findings highlight the need for additional toolkits concentrated on engaging the public,

particularly in disadvantaged communities with lower socio-economic status and education, with the topic of AMR.

Utilising established engagement methods, how can AMR awareness campaigns be improved? The Public Health England campaign, 'Antibiotic Guardians' (AG), utilised informational pamphlets, posters, a website, and social media content in which people are prompted to sign up as an 'AG', to pledge their support to AMR and to promote discussion with their network (see https://antibioticguardian.com/). Despite pledges totalling "185325" in 2023, qualitative evaluation of this campaign by Kesten et al. found that a majority of AG's were healthcare professionals and those with pre-existing AMR knowledge with established supportive behaviours (2018). The study suggests that pledging as an AG succeeded in reinforcement of pre-existing behaviours and AMR understanding, however, it did not reach its intended 'general public' audience, those with limited AMR knowledge, and it did not significantly change behaviours. Furthermore, the perceived visibility of the AG campaign was referred to as 'lacking' among the public and among interviewed healthcare workers, with some failing to remember the 'one simple pledge' AG's signed up with. Several AG's interviewed commented that "they were not the most appropriate target for the campaign and that the campaign is “preaching to the converted” with some GP's giving negative feedback, viewing the campaign as "patronising" (Kesten et al., 2018). These findings suggest that engagement of non-scientist publics is lacking and finding ways to widen reach using evidence-based methods must be addressed going forward.

Analysing the 'Antibiotic Guardian' website and resources available, the colourway is restricted to mainly black, red and white, and the educational materials are primarily blocks of text, defining terms and statistics with little to no visualisations or intuitive interactivity (Antibiotic Guardian, 2023). The UK's National Health Service (NHS) states that "6 out of 10 adults struggle with health content that includes numbers and statistics" with there being a "close link between socio-economic deprivation and low health literacy" (NHS, 2021). To engage a wider audience, platforms that are inclusive and accessible are important to explore, especially those mediums that are research-backed as effective learning and integrate behaviour change techniques (BCT) in the non-science literate. The Office of Disease Prevention and Health Promotion (OASH) suggests in their research-based health literacy guide that to increase health literacy, interactivity, graphics, recall questions, and multimedia that meaningfully appeals to the

targeted are essential when communicating public health issues and motivating those to take action (OASH, 2016). The UK's National Institute for Health and Care Research (NIHR) emphasises OASH guidelines, for health information to be as widely accessible as possible, "a crucial element of tackling health inequality and misinformation. This was demonstrated by the COVID-19 pandemic." (NIHR, 2022)

There are many mechanisms in which to influence public knowledge and attitudes, however, the most effective strategy in AMR PE is yet to be defined. For this reason, there is a call for the exploration of innovative AMR PE approaches (Redfern et al., 2020).

In response to McParland et al.'s (2018) call for innovative combinations of BCT's, the need for AMR PE practitioners to cite evidence-based methodologies, and shifting methods utilised in art-science PE/PO activities in response to the SARS-CoV-2 pandemic, two case studies utilising art-science practice to increase AMR awareness are compared and contrasted below to provide insight into the benefits and limitations of such projects. One was developed and enacted pre-pandemic while the other was developed in response to pandemic restrictions, using a previously unexplored online platform in microbiology communication, to support microbiology PO. They both aim to challenge differing levels of understanding about AMR by developing narratives that delve into understanding of norms, beliefs and practices about bacterial infections, antibiotic use and hygiene, through interactive art platforms.

9.4 Case Studies

The following case studies: *Antimicrobial Avengers!* and *Bacteria, the Future: A time travelling Twine game to save Hugh-manity!* are the results of artist-scientist collaborations. They are PE/PO activities developed to increase AMR awareness and promote microbiology literacy through evidence-based learning research, utilising playfulness, storytelling, and interaction to promote wonder and natural curiosity, aspects that facilitate learning (Davies, 2019; Timmis et al., 2019). Each case study includes detail about the production of the activities; identifying successes, limitations, evaluation methods, and recorded impacts. Both cases are part of a wider intention to develop public engagement/outreach toolkits that may be utilised as a framework for effective future PE and PO art-science projects. The first case study took place pre-SARS-COV-

2 pandemic restrictions, and the second case study was created with pandemic lockdown limitations.

9.4.1 Case Study 1: *Antimicrobial Avengers!* - Antimicrobial resistance public engagement with comics and co-creative activities

> *Did you know that shark skin can prevent bacteria from sticking to it or that Komodo dragon blood is naturally antimicrobial? Liverpool University's D'Sa Lab and Liverpool School of Art and Design's MA Art in Science programme present the superheroes 'Shark Girl' and 'Komodo Dragon' versus the evil 'Superbugs' in the "Antimicrobial Avengers!"*

The aim of the *Antimicrobial Avengers!* project was to facilitate learning about microbes and antimicrobial resistance through co-creative participatory activities, which would encourage public dissemination of health information and research to friends and family members, and more widely within local communities.

9.4.1.1: A co-creative approach

Antonini (2021) defines co-creation as a cooperative process that brings people and professionals together to find innovative solutions for everyday problems. It is a common method used in arts-in-health practice, whereby arts-based activities can activate dialogue between stakeholders that is not based on assumptions (Padfield, 2011). Unlike therapeutic arts-in-health practices where the art-making is primarily for 'healing' (Koon Boon Tan, 2018) and accessed when the individual is unwell (Gordon-Nesbitt, 2017), *Antimicrobial Avengers!* instead adopted a participatory arts-based approach where activities, such as dance, sculpture, drawing or photography are used in the conceptualisation, data collection and dissemination of scientific research (Lapum, et al. 2014) and the artist/researcher is the facilitator of the process (Archibald and Blines, 2021).

Arts-based participatory approaches have been used to inquire about current understanding of health, to intervene in drivers of health problems, and to stimulate empathy by allowing people to situate themselves in specific scenarios (Bunn, et al. 2020). Archibald and Blines (2021) state that “arts-based health research offers unique opportunities to integrate evidence of patients’ lived experience with other forms of research evidence to improve understanding and knowledge translation” and participatory arts-based health approaches have been noted to influence behaviour, and cognitive and linguistic competencies, especially with children (Gordon-Nesbitt, 2017). Such approaches have been proven to successfully facilitate improved health literacy in communities that have varying concerns and understanding about health. An example includes using the arts to increase public health knowledge about the danger posed by the Ebola epidemic in sub-Saharan Africa and how to respond to symptoms (Bunn, et al. 2020).

In addition, Melonio and Gennari, (2012) advocate for the involvement of children in co-creative approaches, noting that “adults do not experience the world as children do and do not have the same insights into the world as a child”. They also state that children are natural partners because they have “unconventional viewpoints and are always ready to share ideas” (Melonio and Gennari, 2012). The affordances of a participatory, arts-based, co-creative method led to this approach being implemented in the *Antimicrobial Avengers!* project.

9.4.1.2: A Graphic Medicine approach

'Graphic Medicine' is a method of visual storytelling utilising comics. It shows promise as a valuable tool for presenting information on difficult or often misunderstood topics, particularly valued by adults with low literacy levels (Green and Myers, 2010; Waite, 2019). According to the National Literacy Trust, "16.4% of adults in England, or 7.1 million people can be described as having very poor literacy skills" meaning that reading from "unfamiliar sources, or on unfamiliar topics" is difficult (National Literacy Trust, 2019). To support a collective, global understanding of AMR, PE and PO must target all levels of literacy, therefore practitioners must consider mediums accessible to lower literacy levels.

Comics are also increasingly utilised, viewed as a natural medium for public health education "as a vehicle to present science in graphic narratives, harnessing the power of visuals,

text, and storytelling in an engaging format" and as a medium established as having great accessibility for both children and adults (Kearns and Kearns, 2020). In 2019, a group of microbiologists published an article citing research demonstrating the potential of comics in microbiology communication. They called for the development of comics communicating microbiology public health threats such as AMR with the caveat that, "we have to make them publicly available and, most importantly, we have to evaluate their effectiveness in microbiology communication" (Scavone et al., 2019). Based on this information, *Antimicrobial Avengers!* sought to promote AMR public engagement through comics and co-creative activities.

9.4.1.3: Developing the *Antimicrobial Avengers!* comics

Three comics were created as part of a wider AMR public engagement toolkit, and printed and digital online versions were produced. An artist in residence was hired to work alongside antimicrobial researchers in the D'Sa Laboratory at the University of Liverpool's School of Engineering to create a number of narratives that would explore antimicrobial biomaterials and resistance. Three research strands were chosen to be explored in the comics:

1. Researchers have developed coatings for high-touch surfaces to fight the spread and growth of microbes. For example, the skin of sharks is made up of a highly-ordered series of bars arranged in a diamond pattern that can fight off bacteria without antibiotics (Dundar Arisoy, et al. 2018), and 'Sharklet', a product produced by Sharklet Technologies Inc. (https://www.sharklet.com/), is a coating that mimics shark's skin, reducing the ability of bacteria to stick to these surfaces.
2. Antimicrobial peptides (AMPs) are small molecules that are part of the immune system of various organisms, including humans, animals and plants. They are one of the first lines of defence to invading pathogens. If you look at the saliva of Komodo dragons, they have a lot of pathogenic bacteria, but the dragons are unaffected, and this is because their blood contains AMPs that effectively fight off even the deadliest of bacteria (Bishop, et al. 2017). These AMPs can be developed into drugs that can be added to our arsenal in the war against deadly infections.
3. Antibiotics were discovered approximately 100 years ago and are used to and treat bacterial infections, however, the overuse and misuse of antibiotics has meant that

> bacteria have evolved in ways to become resistant to these drugs. The more antibiotic resistance that develops, the harder it becomes to defeat these stronger bacteria.

Following a literature review and detailed briefings between the artist in residence and the D'Sa Lab researchers, three partial storyboards comprising four 'frames' of a comic were produced for each research strand. These introduced each strand succinctly but left the endings unfinished. The intention was for a 'layered elaboration' approach for storyboarding and prototyping (Walsh, et al. 2010) to be used in the next stage of the co-creation process. Working with local primary school pupils and the general public, the narratives would be developed in conjunction with the researchers and artist in residence. Here, a spectrum of possibilities for the stories and their endings could be developed quickly, and without one being favoured over another (Walsh, et al. 2010).

To co-create the comics, a number of events were scheduled to include diverse age and socio-economic groups in the co-creation and production of the stories. Two outreach events took place first in a local South Liverpool primary school during March 2019, where pupils could meet the researchers and artist in residence. The pupils watched presentations about the three research strands from D'Sa Lab researchers and were then provided the partially complete storyboards. They were asked to draw and/or write the endings to the three stories (Fig 1 and Fig 2) with opportunities to speak and learn from the researchers throughout. Comments from the school pupils and researchers likened the titular characters of each story as superheroes, a common comic book trope, and the *Antimicrobial Avengers!* name was chosen to group the three stories under one umbrella. The artist in residence then used the narratives provided by the school children to produce three mock 'completed' comic stories featuring each superhero that were to be used in the next public-facing event.

Fig 1: Drawing the endings to the three stories using partial storyboards during an outreach event in a South Liverpool primary school. Photograph by Prof Raechelle D'Sa.

Fig 2: Drawing the endings to the three stories using partial storyboards during an outreach event in a South Liverpool primary school. Photograph by Prof Raechelle D'Sa.

In May 2019, the research team and artist in residence took part in the public engagement event 'LightNight Liverpool' organised by Open Culture. Light Night is Liverpool's free one-night arts festival, where over 100 organisations collaborate annually to create an inspiring trail of events with talks, workshops, performance, live music and more (https://lightnightliverpool.co.uk/). The *Antimicrobial Avengers!* Stand was installed in the

Atrium Gallery at Liverpool John Moore's University's John Lennon Art and Design building. This building sits at the heart of Liverpool's Knowledge Quarter and was a central event hub during the evening, with over 500 visitors passing through the building. Here the public were encouraged to speak to the researchers, read the three comics. and draw and write alternative endings to the stories produced by the school children (Fig 3 and Fig 4). It was hoped that this process would encourage and enhance learning beyond simply reading an already completed comic. Participants were also able to create their own microbes using craft materials (Fig 5), touch sculptures of animals that have naturally antibacterial resistant skin surfaces (Fig 6), and take photographs with life-sized cut-outs of the *Antimicrobial Avengers!* characters (Fig 7).

Fig 3: Drawing the endings to the three stories using partial storyboards at LightNight, Liverpool. Photograph by Mark Roughley.

Fig.4: Drawing the endings to the three stories using partial storyboards at LightNight, Liverpool. Photograph by Mark Roughley.

Fig 5: Creation of microbes using craft materials while learning about 'Bad' versus 'Good' bacteria. Photograph by Mark Roughley.

Fig 6: Touchable sculptures of animals that have naturally antibacterial resistant skin surfaces by sculptor Helen Birnbaum. Photograph by Mark Roughley.

Fig 7: Members of the project team posing for photographs with the *Antimicrobial Avengers!* cut-outs at the John Lennon Art and Design Building on LightNight (Left: Artist in Residence, Jessica Irwin; Middle: Professor

Raechelle D'Sa, Director of the D'Sa Lab; Right: Programme Leader for the MA Art in Science programme, Mark Roughley). Photograph by Mark Roughley.

After the LightNight event the three comic stories were refined and finalised, and made available in printed format and online. The final comics can be viewed in their entirety here: https://germwars.co.uk/, and figures 8 - 11 show the front pages of each comic and subsequently three pages from inside each comic. The comics have since been used as part of an AMR public engagement toolkit by the D'Sa Laboratory at a number of public engagement events including one at Alder Hey children's hospital, Liverpool in May 2019.

Fig

Fig 8: The front pages of each of the comics in the *Antimicrobial Avengers!* series. Illustrations by Jessica Irwin. Reproduced with permission.

Fig 9: Three pages from 'The Adventures of Sharkgirl'. Illustrations by Jessica Irwin. Reproduced with permission.

Fig 10: Three pages from 'Komodo Dragons Save the World Illustrations by Jessica Irwin. Reproduced with permission.

Fig 11: Three pages from 'The Drugs Don't Work' (fourth row). Illustrations by Jessica Irwin. Reproduced with permission.

9.4.1.4: Reflecting on the *Antimicrobial Avengers!* project:

Over 500 people visited the John Lennon Art and Design building during the LightNight event on Friday 17th May, and of these visitors, over 250 hundred people directly engaged with the hands-on activities associated with *Antimicrobial Avengers!*. Attendees were asked to complete a six-question anonymous paper-based feedback questionnaire after partaking in one or more of the activities. Twenty four people responded and submitted the completed questionnaires in a post-box in the Atrium Gallery, however, not every question was answered on each returned questionnaire.

Using a 1-5 Likert scale with 1 being 'Not at all' and 5 being 'Loved it', 16 people answered with a 4 or 5 for the question *Did you like the Antimicrobial Avengers! characters?* For the question *Did you learn anything new about microbes and antimicrobial resistance?* sixteen respondents chose 'Have learned a lot', six respondents chose 'Have learned a little" and zero respondents chose 'Haven't learned anything new'. When asked *What activity was your favourite?* six respondents wrote comments about the touchable sculptures, two wrote about taking selfies with the *Antimicrobial Avengers!* cut-outs, four wrote about drawing the endings to the comics, two stated it was reading the comics, and twelve noted it was creating microbes using craft materials.

For the questions *Do you think that events like this are a good way to learn about antimicrobial resistance?* and *Would you attend a similar event in the future?*, two respondents chose 'Maybe' and twenty-one chose 'Yes' from the 'No, Maybe, Yes' options available. The final question asked the respondents to '*Tell us three words that you associate with this event*'. The words written include "educational; informative; interactive; entertaining; important; unexpected; imaginative; scary; creative".

No feedback was gathered from the school children during the co-creation process, and while the questionnaire responses about the LightNight event were mostly positive about the activities and knowledge acquisition, the response rate is too low to make definitive conclusions about the success of the co-creation methods used in the hands-on activities and the AMR transfer of knowledge. It is hoped that by using partially complete storyboards for the comics at each event, the participants were not intimidated by an empty canvas and that learning about AMR would take place through 'playful exploration' of the AMR topics (Archibald and Blines, 2021), and that word-of-mouth communication (WoMC) and dissemination of the science would occur naturally via social diffusion; reaching beyond those who directly took part in the activities (Compton and Pfau, 2009). It is recognised that there is potential for misrepresentation of the science during WoMC to social networks including family members and peers, especially via children to adults, although simply stimulating conversation about health issues has been shown to be beneficial on the whole rather than detrimental, with a stronger number of messages that promote the accurate spread of intended information (Compton and Pfau, 2009).

9.4.2 Case Study 2: *Bacteria, the Future: A time travelling Twine game to save Hugh-manity!*

Bacteria, the Future: A time travelling Twine game to save Hugh-manity! is an interactive online story-telling adventure game devised by Natasha Niethamer in 2020 as her master's project for the MA Art in Science Programme at Liverpool School of Art in Design (Roughley et al., 2022). The project was developed over 3 months in collaboration with artists, scientists, and educators associated with this programme. It explores interactive fiction-based public outreach in which the participants embody a bacterium, imagine what it is like to be a bacterium within a colon,

and explore a potential future in which AMR is not sufficiently addressed. The outcome can be viewed here: https://nniethamer.itch.io/bacteria-the-future.

Published research literature exploring AMR PE / PO suggests that there is a general lack of understanding how and why certain public engagement methods work in certain contexts in this field. This project is built on several findings established in the literature review for this chapter:

1. It is important to critically evaluate an activity in both its successes and failures because this is lacking in the field of AMR public engagement and is restricting identification of factors that will ensure AMR PE is fulfilling its aims (Redfern et al., 2020).
2. It is important to make design, evidence-based methods, and reasonings accessible to support those who have an idea for this field yet are unsure how to proceed.
3. The aim of AMR public engagement is long-term behavioural change, however, this is hard to evaluate. Many call for the creation of a standardised framework in which AMR PE practitioners should follow to develop stronger techniques. 'Behavioural Change Theory' (BCT) studies in the field of social science may provide critical insight when developing evidence-based, methodological frameworks in PE. This should be referenced and further explored.

9.4.2.1: Anthropomorphising microbes facilitates learning

According to Timmis et al. (2019) it is essential for microbes to "transit from abstraction to pictorial perception and substance and take up their rightful position in the human psyche" and they suggest that 'anthropomorphisation' is effective as a microbiology teaching approach. Kirk Dorion (2011), a researcher of science communication at the University of Cambridge, found that although most animals do not have human intentions and emotions, anthropomorphisation may facilitate learning of abstract concepts due to generating an emotional connection and therefore interest/moral concern. This suggests that generating a human, emotional connection to microbes through anthropomorphising them may better facilitate learning and long-term memory of what Timmis et al. (2019) describes as a largely invisible, abstract world.

9.4.2.2: Gamification as a Learning Tool

Gamified learning results in improved student-engagement, motivation, confidence, attitude, perceived learning, and performance and due to these significant findings, gamification has been integrated for higher-learning and health related purposes allowing material to be accessible to broader audiences (Subhash and Cudney, 2018). Additionally, gamifying complex material may appeal to broader audiences including those of all ages and lower-literacy levels to facilitate deeper understanding (De Freitas, 2018). Using gamification in AMR PE and PO may encourage participants to consider and discuss AMR in the relaxed, light-hearted environment of their own home, with the aim of contributing to the generation of widespread support and intentional global policy changes needed to delay and prevent AMR from resulting in significant global death and economic burden.

9.4.2.3: Utilising pandemic driven online technology for AMR education

The SARS-CoV-2 pandemic transformed communication approaches for widespread public education. The lockdown restrictions forced educators to shift delivery from traditional, direct communication to one heavily utilising technology and online platforms. Educators were challenged to create engaging online content that facilitated learning despite the lack of face-to-face interaction. This has driven innovative approaches in online education. A technique utilised to promote greater student engagement and reinforce knowledge includes integrating more interaction through gamification, incorporating game motivation techniques and mechanics to non-game subjects (Joshi, 2021; Lee and Hammer, 2011).

Despite limitations to online learning, it is a major source of health literacy for the global public and considered a valuable tool to connect with a wider audience and disperse public health information (Jia, Pang, and Liu, 2021). With the pandemic driving innovative, interactive ways to better engage online, it is important to learn from these ideas and build upon identified strengths. With face-to-face interaction no longer restricted, continuing to utilise supplementary online platforms may provide a valuable resource to widen PE/PO activities' impact and reach from an isolated event to a globally accessible online resource. This is especially critical in regards to the public health threat of AMR, which, to prevent unneeded deaths and economic

burden, urgently requires global, collective efforts and widespread policy changes (Tarín-Pelló et al., 2022).

9.4.2.4: Developing *Bacteria, the Future: A time travelling Twine game to save Hugh-manity!*

With these ideas in mind, this project was created with the aim of this work to explore alternative ways to communicate the public health threat of AMR and increase microbiology literacy. This activity was originally created as a public engagement project involving interactive theatrical performance (https://collaborativeumf.wordpress.com/), accepted as a physical PE activity to engage the publics in Liverpool during LightNight 2020 (https://lightnightliverpool.co.uk/). Due to the SARS-CoV-2 pandemic, the festival was cancelled as well as any physical PE activities. This required the original performance script to be adapted into an online version. Research into novel interactive online platforms that are low-cost, accessible to non-coders, and achievable within the time constraint of 3 months, led to discovery and utilisation of 'Twine', an online interactive text platform allowing one to create a 'choose-your-own-adventure' game.

For this activity, participants were invited to take part in a text-based, choose-your-own-adventure, ‘interactive fiction’ game using the online platform ‘Twine’ (https://twinery.org/). The game involves the player entering a time machine in the year 2050. In 2050, AMR has wiped out much of the human population, and the player’s consciousness has been chosen to inhabit the body of an Escherichia coli (E. coli) bacterium. In this bacterial body, the player travels back in time to 2020, and embarks on a mission to ‘neutralise’ AMR bacteria in the gut of human, Hugh Mungus (Fig 12). The player’s aim is to ‘save the millions of future humans that will die from an evolved, stronger strain of the neutralised AMR bacteria’. However, there is a plot twist: the millions of humans that die include you. By succeeding with this mission, you are saving yourself from premature, AMR-caused death. However, does this come with consequences?

Fig 12: *Bacteria, the Future* scene, showing the player (bacterial form) with their ship looking into the abyss of a human intestine, about to embark on a dangerous mission to save humanity. Illustration by Natasha Niethamer.

During this mission, the player explores the digestive system, questions the threat of AMR, and explores concepts surrounding AMR. A moral dilemma is raised when the player realises that the bacterial body they inhabit can trigger emotional reactions to the events occurring. The player comes face to face with current, top AMR bacterial health threats established by the Center for Disease Control and Prevention (CDC), antibiotic resistant strains of Clostridium difficile, Escherichia coli, and Salmonella (CDC, 2020). In 'neutralising' these AMR bacteria, the game raises questions about the misuse of antibiotics and imagines a world in the near future predicted to occur if antibiotic misuse is not addressed. It challenges the validity

of demonising bacteria when in truth, bacteria are neither ‘good’ nor ‘evil’ (Fig 17). Most gut bacteria are harmless or even helpful for your health. It leaves us humans in 2020 with the questions: Are we capable of preventing this apocalyptic future through adjusting our current behaviours? Can we fight AMR by working with bacteria versus wiping them out?

This project explored the effectiveness of non-linear interactive fiction using the ‘Twine’ platform on AMR public awareness. The ‘Twine’ platform (https://twinery.org/) is a free, open source online game platform that allows those with limited coding knowledge to create non-linear (multiple endings are possible), interactive stories (hyperlinks, audios, pictures, and animations can be placed) in which the player can ‘choose-their-own-adventure’ while also playing in second-person (Fig 13). ‘Twine’ has been used as an educational tool in certain classrooms, and it is seen as a way to develop empathy in the player as the platform allows the player to take part in the story in second-person (Salter, 2016). This platform, however, has not been used to communicate AMR. For this reason, this project was created to explore if this platform was an effective way to increase microbial literacy and AMR awareness.

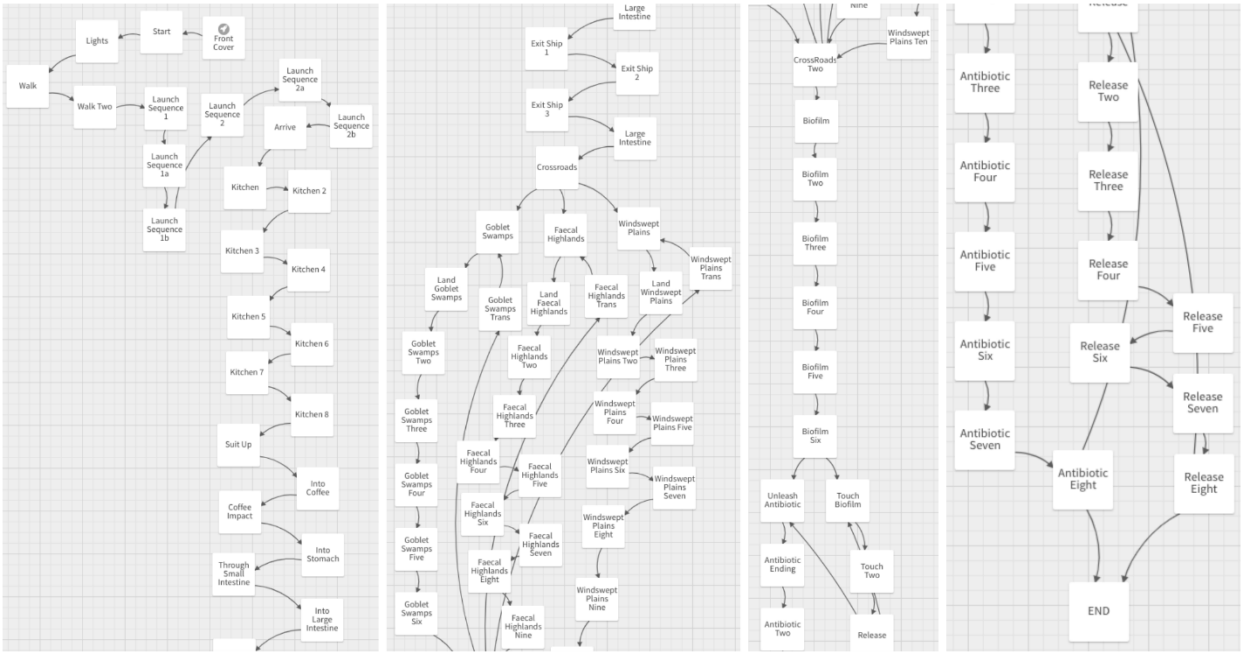

Fig 13: *Twine* program storyline flowchart displaying the choices the player is given in *Bacteria, the Future* in the form of branching plot points with resulting storyline consequences in sequential order from left to right. Created by Natasha Niethamer.

Bacteria, the Future is a reference to *Back to the Future*, a science fiction film in which the protagonist is sent 30 years back in time. This interactive fiction game was inspired by a few different works including *Red Dwarf, Star Trek DS9/Next Generation*, the H.P. Lovecraft short story, *The Colour Out of Space*, and a Lovecraft-inspired video game, *Bloodborne*. *Red Dwarf* and *Star Trek* integrated time travel to change events of the future, also integrating humour/technology-based main characters. Lovecraftian descriptive words and literary style were integrated. *Bloodborne* inspired the bacterial tentacle monsters and the idea of the "monsters" having previously been innocent if it was not for harmful community decisions (similar to the AMR bacteria being mutated, previously helpful bacteria). The structure of this game was inspired by researching choose-your-own adventure games, traditional Twine game examples that were found on itch.io (http://itch.io) like *You Are Jeff Bezos* and *The Temple of No*, and puzzle games such as *Myst* and *Sam and Max*.

Digestive system locations were researched to make the setting realistic, using research referencing bacterial morphology descriptions, cells, such as the goblet cells in the large intestine which excrete mucus found at the 'Goblet Swamps' in figure 15, and details regarding the colonic landscape. Defecation was researched to ensure leaving the rectum in the game was realistic with its activation by stretch receptors. A BBC Earth Lab video of a pill camera moving through the digestive system was watched to describe the story's environments (BBC Earth Lab, 2016). Mechanisms of antibiotics on bacteria were researched as well as information on how bacteria communicate/work together. This involved investigating academic papers, because microbiology-based mechanisms as well as simplified inner organ descriptions were unable to be found by Google search.

Visual storyboards were then created as well as illustrations of bacteria (Fig 14). Narratives were brainstormed, involving peer feedback and writing of non-linear thoughts. A backstory was created for the main character. Eventually, ideas were brought together in a linear, understandable way. The game was designed by creating flowcharts of plot point ideas on paper. A few story lines were explored as prototypes before deciding on the final form.

The script was then entered onto the Twine platform application, adjusting the ideas frequently to better fit game play. Coding elements were adjusted to ensure the game player would not revisit a page. When choosing fonts and styling the game, it was desired to make it

more accessible to those who are dyslexic, suggested by a dyslexic collaborator and beta tester, so the font, “open dyslexic” was used (https://opendyslexic.org/).

Niethamer, who had no coding experience at the beginning of this project, learned Twine-specific coding syntax by referencing the book, ‘Writing Interactive Fiction with Twine’ by Melissa Ford. This book takes one with no coding experience through traditional Twine game techniques and recommends persuasion/engagement elements to ensure an effective, engaging narrative design tailored to interactive fiction with a flowchart of checkpoints to structure a traditional Twine game (2016).

The website, ‘itch.io’ (https://itch.io), was used to upload the html code associated with the game. ‘Itch.io’ used the html to host the game on its website, where it hosts other online indie games. In 2020, this was the only free platform available to host Twine games.

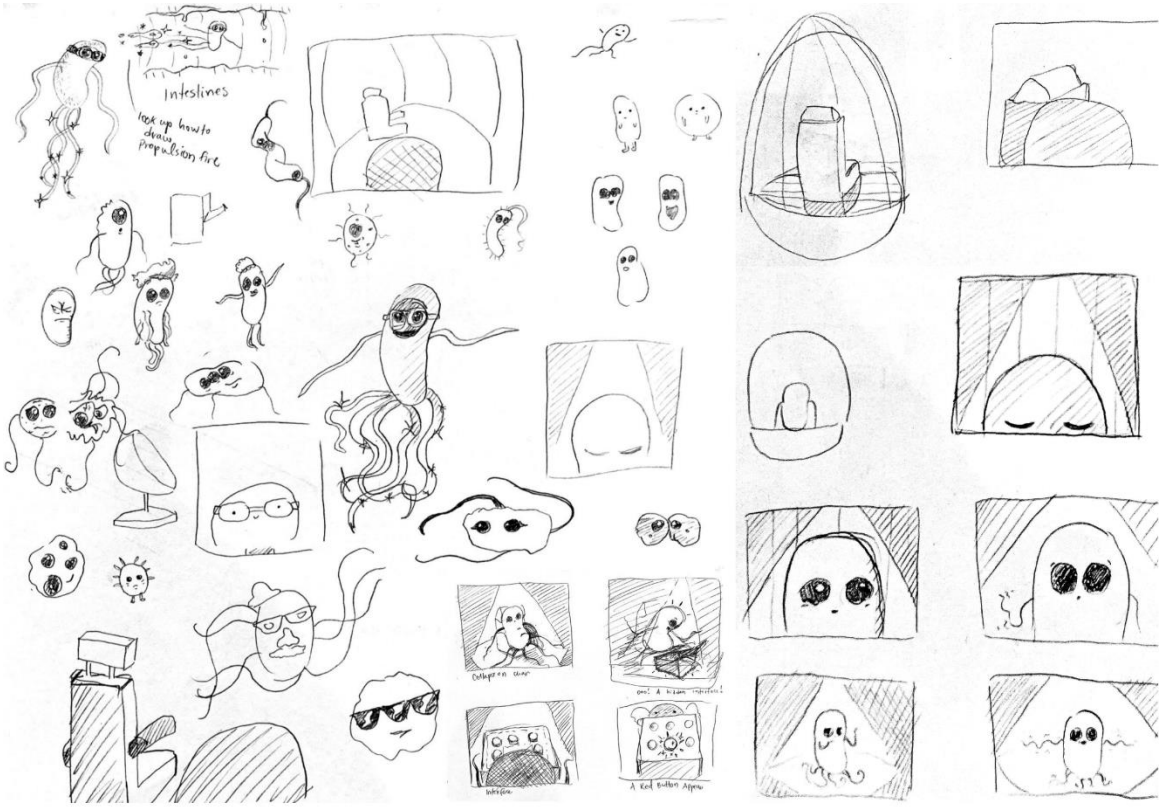

Fig 14: *Bacteria the Future* character development. Illustrations by Natasha Niethamer.

Artists and scientists associated with the LJMU MA Art in Science programme played the prototype game, with gameplay excerpts shown in figures 15, 16, and 17. The game was

adjusted in response to their feedback. Beta testers suggested the first script seemed too violent with antibiotics described as 'killing' bacteria, especially when role playing as the bacterium. On further discussion with beta testers, wording was changed from “kill”, “destroy”, and “shoot” to “medicate” and “treat”, words more suggestive (Fig 16). Collaborating with a game enthusiast, physics educator, and SciArtist, Tom Hyatt, at LJMU, the physics of time travel was discussed as well as what makes a game effective. This resulted in adding realistic elements suggested by the collaborator such as “Tachyon” drive, an element in physics believed to allow time travel. During this conversation, the game storyline was finalised. The final prototype game was then sent out to artists and scientists in LJMU with pre- and post-game surveys. The feedback allowed adjustment of coding errors, spelling/grammar errors, and timing errors. The game continues being improved based on feedback and updated scientific information.

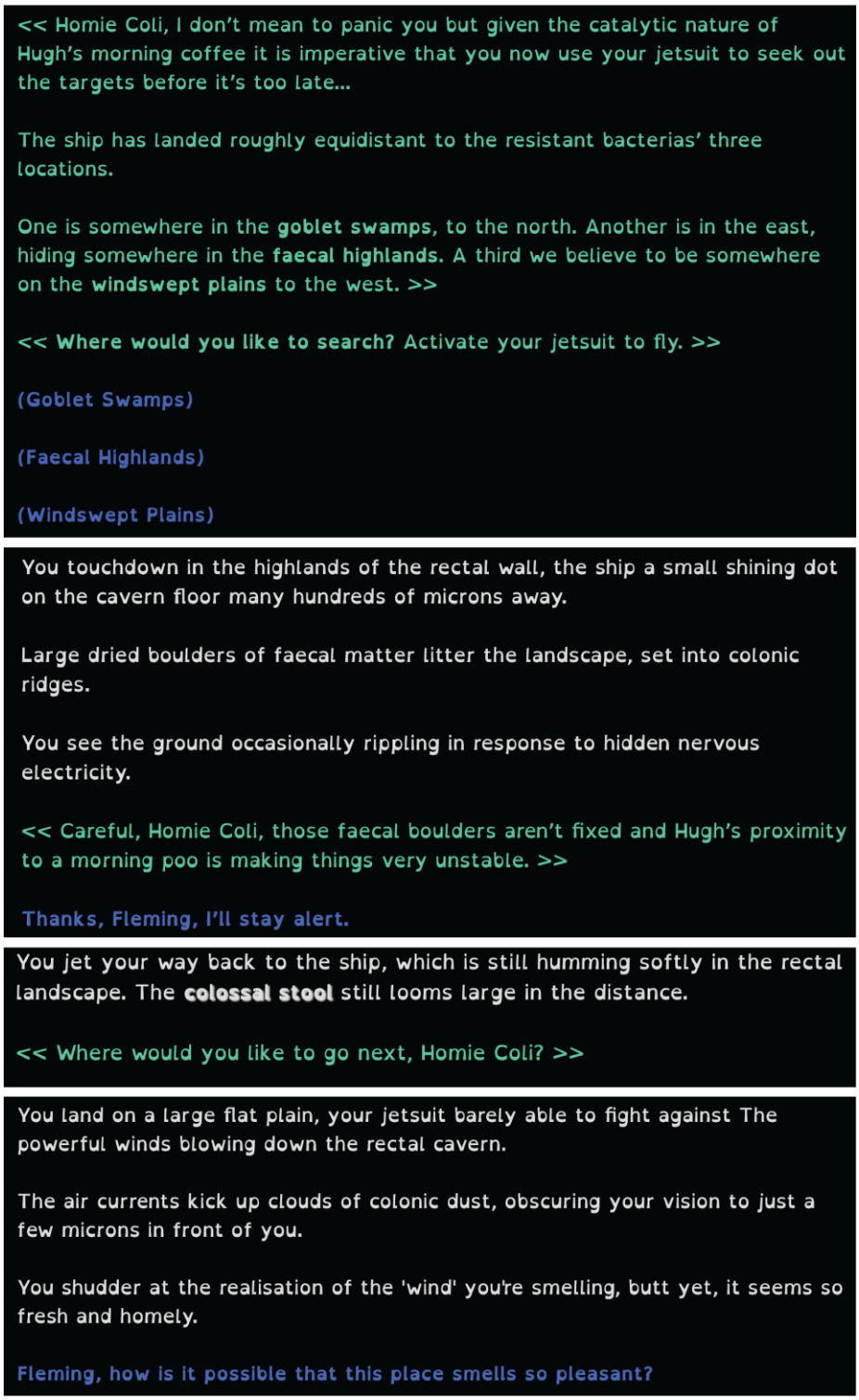

Fig 15: Four gameplay screenshots from *Bacteria the Future*. Green text represents the ship's AI computer, Fleming, who assists during gameplay. Blue text is clickable to advance the game. Created on *Twine* by Natasha Niethamer.

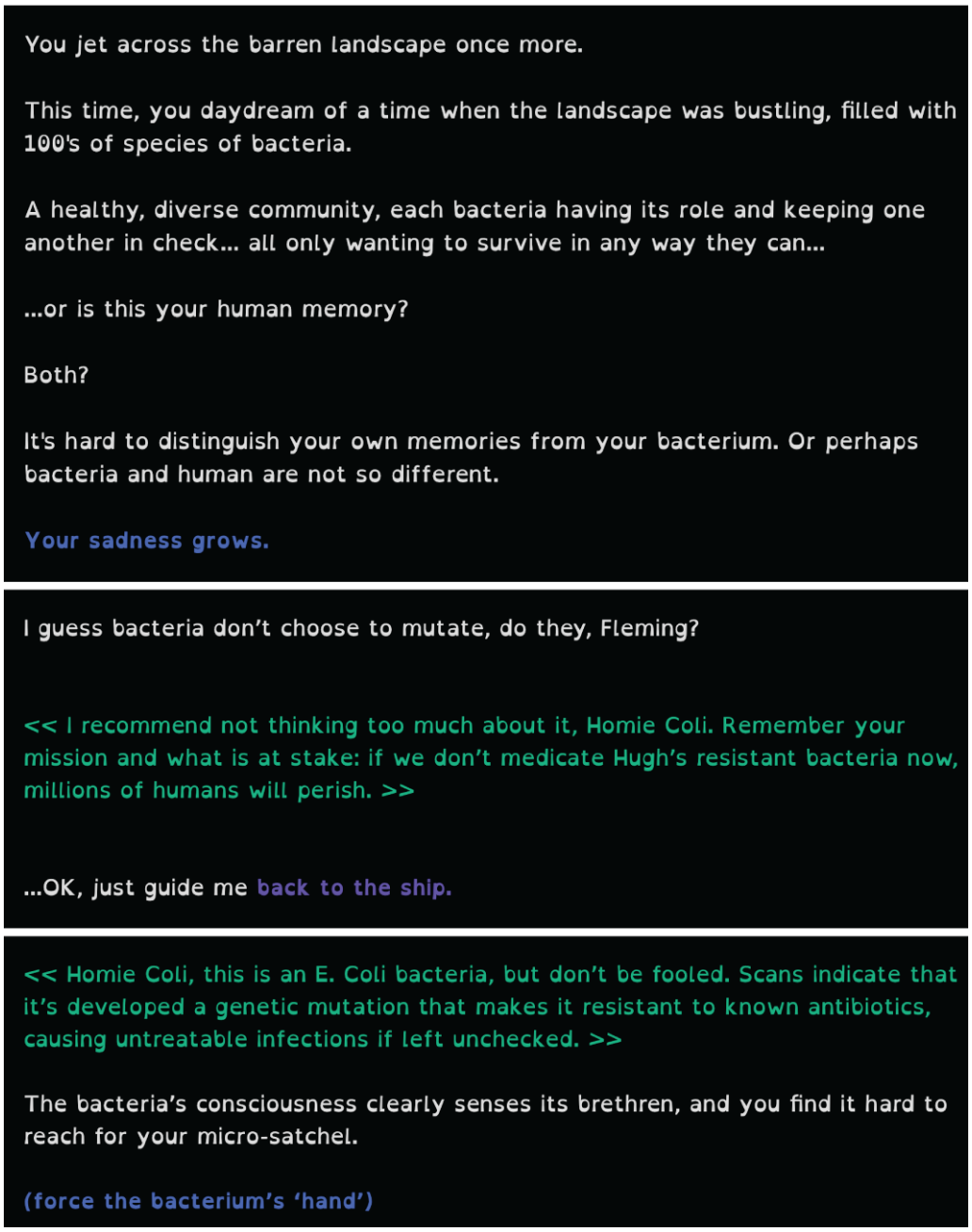

Fig 16: Three gameplay screenshots from *Bacteria the Future*, in which the overuse and misuse of antibiotics is questioned. Sentences are revealed gradually. Green text represents the ship's AI computer, Fleming, who assists during gameplay. Blue text is clickable to advance the game. Created on *Twine* by Natasha Niethamer.

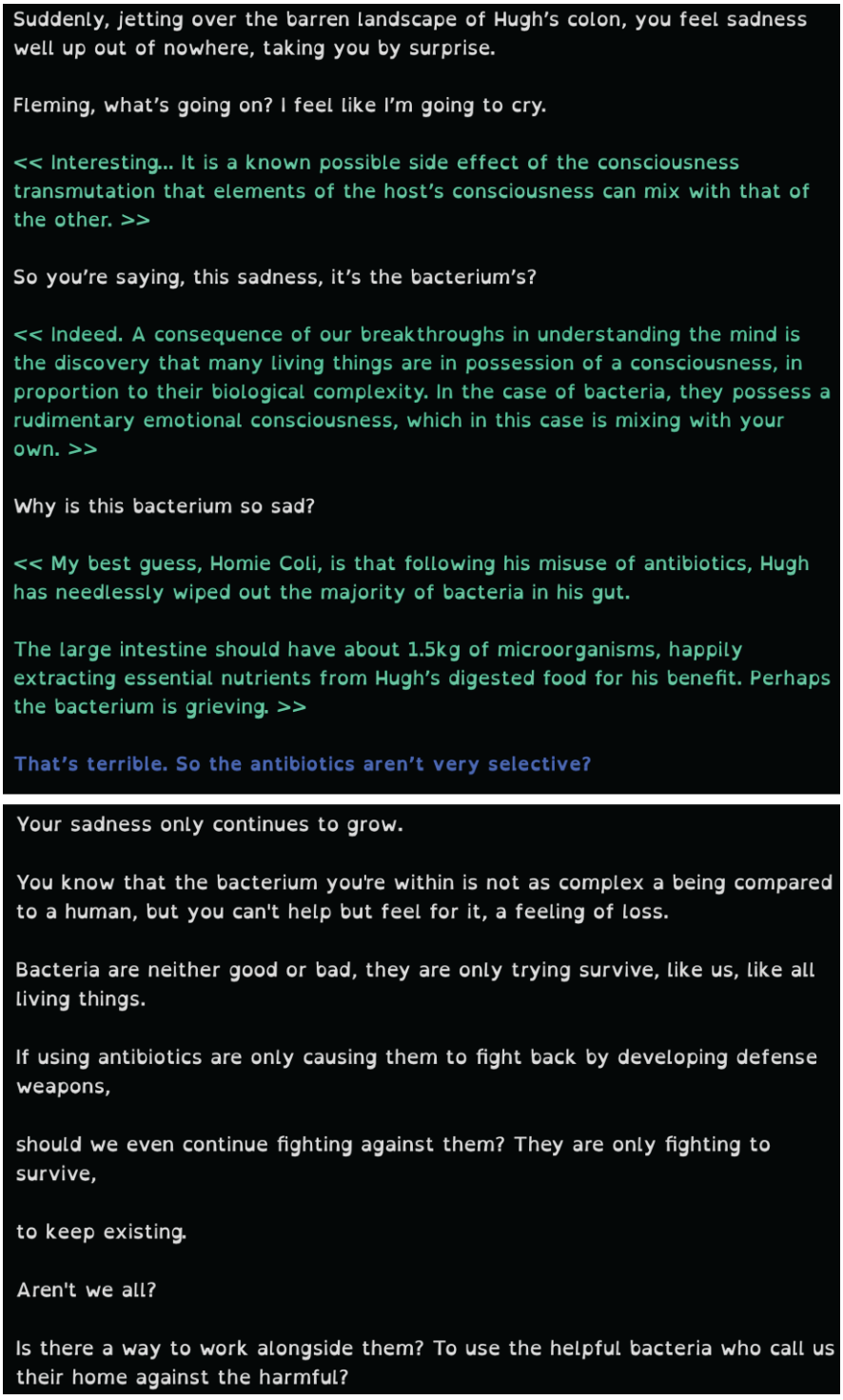

Fig 17: Two gameplay screenshots from *Bacteria the Future*, in which the overuse and misuse of antibiotics is questioned. Sentences are revealed gradually. Green text represents the ship's AI computer, Fleming, who assists during gameplay. Blue text is clickable to advance the game. Created on *Twine* by Natasha Niethamer.

9.4.2.5: Evaluating *Bacteria, the Future: A time travelling Twine game to save Hugh-manity!*

During final game prototype testing, participants were asked to complete online, pre- and post-activity feedback questionnaires. Pre- and post-game questionnaires were modelled after Ahmed et al. and their pre- and post-activity surveys to determine if there was an increase in AMR awareness (2020). A 1-5 Likert scale was used with 1 being 'Strongly disagree' and 5 being 'Strongly agree'. Google Forms were used to create the pre-game and post-game questionnaires. Questionnaires are available to view on the main gameplay page along with a participant information sheet for student research study permission.

Fifteen linked pre- and post-game survey responses were received. 11/15 participants claimed their knowledge about microbiology and antibiotics increased, with 4/15 participants reporting their knowledge about microbiology and antibiotics staying the same. 14/15 participants filling out the post-game form strongly agreed that AMR is a very serious problem with 1/15 agreeing AMR is a serious problem. In contrast, in the pre-game form, 7/15 respondents strongly agreed AMR is a very serious problem, 7/15 agreed AMR is a problem, and 1/15 answered neutrally on AMR being a serious problem. All respondents reported post-game that they disagree antibiotics will help improve their cold, cough, or sore throat more quickly, though 3/15 respondents were neutral about the issue beforehand with 1 respondent agreeing that antibiotics would help improve their cold, cough or sore throat more quickly. Most of the respondents post-game (13/15) strongly disagreed that you don't need to finish a prescribed course of antibiotics if you were feeling better. However, the remaining 2 respondents agreed with this statement. 14/15 respondents post-game strongly disagreed that you should use antibiotics left over from a prescription with one respondent responding neutrally.

In comparison, pre-game, one of the participants had strongly agreed with this statement, and 4/15 respondents changed their response from disagree pre-game to strongly disagree post-game. 13/15 respondents disagreed to the statement, '*If you have never taken antibiotics, you cannot get a drug-resistant infection*' both pre- and post- game. 1 respondent replied neutrally and 1 agreed to the statement both pre- and post- game. Most participants were neutral or agreed with the assertion that '*Your body becomes resistant to antibiotics*'. 14/15 respondents strongly agreed post-game that they could help slow down antimicrobial resistance by certain behaviours

like handwashing with 1/15 responding neutrally. This is a shift from pre-game, where 8/15 agreed (4 of these strongly) with 5/15 giving a neutral response and 2/15 disagreeing.

9.4.2.5: Evaluating *Bacteria, the Future: A time travelling Twine game to save Hugh-manity!*

Feedback suggests that interactive fiction using Twine may be an effective platform to explore further in facilitating awareness of antimicrobial resistance (AMR). In particular, comparing individual pre- and post-game survey results showed that a majority of game participants strengthened their agreement to the assertion of AMR being a serious problem, disagreed that antibiotics can improve a cold, cough, or sore throat, strongly disagreed that you don't need to finish a prescribed course of antibiotics if feeling better, and strongly agreed post-game that handwashing can slow down AMR.

However, other results were mixed with multiple reinforced misunderstandings. These topics should be addressed more clearly in the game for future adjustments. For example, all participants post-game thought that the body became resistant to antibiotics, the opposite of the desired response post-game. Participants were unsure if a human can get a drug resistant infection if never taken antibiotics. Some participants expressed confusion with wording of the survey questions. These specifications are something to explore further with a larger sample size of participants as well as with a collection of demographic information to ensure conclusions are significantly meaningful.

Some responses were critical, which brings up ways to adjust the game in future versions. These criticisms included mention of better pacing with "slow patches and fast to match the action". The feedback also includes multiple suggestions of adding more audio: "Sound / sound effects would have been good", "Maybe some more animation/transitions in text would of been fun". Two different participants mentioned creating a soundtrack with one saying, "Would have loved a soundtrack. I want to hear what it's like to be Hugh's Anal Canal. The sounds of the bacteria and the soundscapes of Fecal Highlands and Windswept Plains."

One limitation of this text-heavy based project is that it is not accessible to those of lower literacy levels. 73.3% of surveyed participants specified illustrations would improve the game with one respondent suggesting, "Illustrations would really help to not get lost through the story"

and "some visuals of the bacteria would be cool so you could see what they look like". This project may be made more appealing, understandable, and potentially reach a wider audience through heavier use of visuals, perhaps in the form of a graphic novel or adjusted, child friendly comic book.

However, there were a few that expressed a positive preference for a text-based game, with comments including, "I think not using any form of illustration or visualisation helps the viewer to create their own visual depiction of the game, which is really fun!" and one person commented that adding illustration may take away from the story – though stick figures may allow more interest: "I thought it might be interesting to add pictures and graphics, but it might take away from our own imagination...although simple and fun stick figures might add to the humor". The respondents of this study were not asked to specify their literacy level or preferred mode of learning, so a range of responses are expected. Due to the range of responses, specifying a target group and adjusting to their preferences would allow better future impact.

The post-game surveys highlighted some benefits regarding 'Twine' text-based medium. First, the second-person experience in which the reader plays as a main character of their choosing, and gender does not have to play a role. This may allow greater empathy from the player with one participant saying, "Felt very immersive, truly believed I was Eliza Coli for a time". This platform also allows a player to make choices or interact with the story by clicking through, allowing greater agency to the player. Post-game surveys mentioning, "I enjoyed it, I wouldn't [sic] mind learning about other subjects in thus [sic] format", "I enjoyed it, it was fun, better than reading another report or article", "Like it - reminds me of reading goosebumps books as a kid! But also v good for learning experiences as keeps you engaged throughout. Liked the wiggly words when they moved around. Felt very immersive, truly believed I was Eliza Coli for a time and couldn't have done anything but not go for the satchel at the end!".

Regarding the choices being made, one expressed that they liked that you could explore two different endings. Another recommended more choices saying, ""i liked the ability to choose different options, more of those choices would be nice". Many respondents were positive about the enjoyability of the game: 13/15 participants expressed they enjoyed the game and would recommend it to a friend while two participants responded neutrally.

In future versions, based on this feedback, it seems adding more animation/transitions, simplistic, stick figure illustrations as well as some audio may be beneficial to interaction. To

increase accessibility and widen reach, this story could be adapted into a visual graphic novel to appeal to low literacy adults, into a simplified, visual comic to appeal to kids, or the current 'Twine' adventure can be transformed into a mostly visual version for those who prefer this. One respondent mentioned, ""I think it's a beautiful way of learning. I can really see this as a scientific app to help people learn more about their bodies on a micro level. You could also branch out into food and diet, how eating different foods affect your body and how important diet is to not just functionality, but also in aid of mental health."

Based on observations during game creation, prototyping, and prototype feedback, there are a few things that would be included in future versions to increase interaction: more audio, illustrations, and more text-animation effects would be included. A guidebook to define important terms for the player in which the player is able to reference during gameplay would also be created. More options/agency would also be given to the player. Through this process, writing many story lines as an individual was a tough, time-intensive process, so this prevented the plan to explore as many options as originally proposed. Though low literacy levels may be a barrier to accessing this text-based platform, there is the option to adjust the level of complexity of the script in the future or to create illustration/comics based off of this story.

Unexpectedly, it was a learning process in itself to design a narrative in a scientifically realistic way. It was tough to find visual descriptions/mechanisms of certain chemicals, bacteria, and inner organ walls. The internet directs one to dense scientific papers, and as a result, definitions were frequently looked up and related scientists were consulted to simplify ideas.

Because two-way interaction is not possible with the public, this project is not considered public engagement but instead, public outreach, a one-way communication of research and higher education-based topics (Illingworth and Allen, 2016). This is not seen as effective as public engagement, but it is a novel activity to consider when communicating AMR in an enjoyable way when comparing traditional methods of science communication, especially in a time in which face-to-face communication is not possible.

This form of interactive learning may have potential beyond AMR engagement. The outcomes of this project suggest that interactive fiction using Twine may be an effective platform to explore further in facilitating awareness of antimicrobial resistance (AMR), however, there are more respondents needed to create more meaningful results. In the following section, common

themes from both case studies are compared and contrasted for use in strengthening future activities, as recommended by Redfern et al. (2020).

9.5 Discussion

The aim of this chapter was to determine whether art-science public engagement (PE) and public outreach (PO) activities are an effective method for increasing microbiology literacy in the public health threat of antimicrobial resistance (AMR) by exploring literature relating to interactive art-science activities. To inform this aim, two case studies involving AMR awareness art-science PE and PO activities created in response to the existing literature were detailed and analysed. The following questions were explored:

1. What is the key aim of an AMR-based public engagement (PE) and public outreach (PO) activities?
2. How do practitioners evaluate their activity to determine if the key aim was achieved?
3. Can a framework be developed for practitioners to utilise when developing effective art-science activities promoting microbiology literacy regarding AMR public engagement?
4. How has the COVID-19 pandemic and resulting public understanding/behavioural changes shifted art-science practice in AMR awareness?

When determining the key aim of AMR-based PE activities concluded by Redfern et al. (2020) as needing to be identified in AMR-based PE activities and supported by the findings of Redfern et al. (2020), the WHO's global action plan on AMR (2015), and IACG (2019), we proposed two key aims of AMR PE activities which will contribute to slowing down AMR rates, a key component of tackling the urgent global public health concern of AMR, which are awareness of AMR, specifically regarding common misconceptions in the public, and long-term behavioural adjustment regarding misuse and overuse of antimicrobials.

NCCPE, Illingworth, and Allen state in their determination of quality public engagement that evaluation is an essential way to critically self-reflect and contribute to strengthening future activities (n.d.c.; 2016). According to Redfern et al., evaluation is lacking in the AMR PE field (2020). For this reason, two AMR awareness art-science activities were explored. Practitioners

administered pre- and post-activity surveys to participants with questions focused upon pre-activity understanding of the field, misconceptions, and believed behaviour changes post-activity (Ahmed et al., 2020; Grimberg, Williamson, and Key, 2019; Altay and Lakhlifi, 2020). However, these activities do not assess long-term behavioural changes, and according to research by Storksdieck, Ellenbogen, and Heimlich in 2006, there must be subsequent reminders to ensure long-term behavioural change.

When assessing whether a framework may be developed for practitioners to utilise when developing effective art-science activities, specifically those regarding AMR public engagement, we identified research pulled from different disciplines such as psychology, science communication, public health and environmental sciences that may hold insight into promising, evidence-based methodology to be utilised. One example is the behavioural change theory (BCT) rooted in psychology and harnessed in public health public engagement activities as suggested by McParland et al. in 2018.

The SARS-CoV-2 pandemic transformed communication approaches for widespread public education, driving innovative approaches in online engagement. Online sources remain a major source of health information access for the global public (Jia, Pang, and Liu, 2021). With face-to-face interaction no longer restricted, continuing to utilise supplementary online platforms may provide a valuable resource to widen PE/PO activities' impact and reach from an isolated event to a globally accessible online resource. This is especially critical in regard to the public health threat of AMR, which, to prevent unneeded deaths and economic burden, urgently requires global, collective efforts and widespread policy changes (Tarín-Pelló et al., 2022).

9.5.1: Comparing and contrasting case studies

Both case studies had a small sample size of survey respondents preventing meaningful conclusions to be made, despite positive feedback. Gamification was utilised in both case studies, integrated due to its established role in facilitating learning through greater engagement and reinforced knowledge (Joshi, 2021; Lee and Hammer, 2011). One case study included pre- and post- activity surveys, as advised by AMR-based PE guidelines (Redfern et al., 2020). However, long-term learning impact and behavioural change was not tested. Player agency was integrated in both case study activities, allowing participants of '*Antimicrobial Avengers!*' to

create their own endings to comics and allowing '*Bacteria, the Future: A time travelling Twine game to save Hugh-manity!'* players to choose their character name, order of location exploration, and allowing exploration of alternative endings. Both case study activities were adapted to a digital version, allowing expanded online reach. Collaboration with non-scientists and scientists were cited in both projects to be essential to its development.

The '*Antimicrobial Avengers!*' project ran pre-SARS-COV-2 pandemic restrictions, so this allowed participatory, public facing co-creation based activities at primary schools to drive the project. '*Bacteria, the Future'*, created during pandemic restrictions, required utilising an online platform as no face-to-face contact was possible. No funding was available for the development of '*Bacteria, the Future'*, with lockdown limiting resources to those accessible at home, with a time constraint of 3 months due to being a Master's research project. In contrast, '*Antimicrobial Avengers!*' was built on funding with multiple established multidisciplinary practitioners working together. Additionally, the two projects targeted two different audiences with '*Antimicrobial Avengers!*' tailored to kids of primary school age and '*Bacteria, the Future'* targeting adults. Furthermore, '*Bacteria, the Future'* being text-based, is not accessible to those of low literacy levels. In contrast, '*Antimicrobial Avengers!*' utilised 'Graphic Medicine', an established medium of accessibility to lower literacy levels (Green and Myers, 2010; Waite, 2019).

9.5.2: Proposed AMR public engagement and outreach framework

From reflections on both case studies, there are clear strengths to help develop an AMR public engagement and outreach framework. These include:

1. Integration of artist and scientist collaboration, ensuring feedback from science experts to directly discuss misconceptions
2. Feedback from non-scientist public of diverse backgrounds at every step of development
3. Utilisation of both online and public-facing activities to maximise reach
4. Utilising evidence-based interactive learning methods like gamification and graphic medicine to increase accessibility, experimenting with different combinations of methods as well as seeking out novel platforms that show promise in other disciplines

5. Consider an activity that can later be adapted to multiple literacy levels and audience targets
6. Integrate pre- and post-activity feedback, and if possible, follow up surveys to assess long-term behavioural change
7. Share and publish details of your activity including development process, strengths, weaknesses, obstacles, successes, feedback, adjustments, and lessons learnt

9.6: Conclusion

This chapter has established public engagement and outreach as a broad and complex field involving many different factors, aims, and methods. It is considered a complex practice influenced by many environmental and social factors, many still to be identified. For this reason, in agreement with Redfern et al.'s recent findings when evaluating AMR PE and PO activities, there is not enough sufficient evidence to directly support SciArt interactions as one conducive to the long-term behavioural changes regarding AMR specifically. It is agreed, however, that it is important to continue informing the limited understanding of art-science activity effectiveness in PE and PO, improving AMR awareness and microbiology literacy in the public(s), and in doing so, contribute to slowing down AMR rates, believed to be a key component of tackling the urgent global public health concern of AMR.

Currently, few PE and PO activities are recorded let alone evaluated (Redfern et al., 2020). We hope this research begins the needed discussion in regard to creating effective AMR PE activities informed by evidence-based theories. We especially hope to inform those who would like to contribute to slowing AMR rates through art-science activities, but do not have a public engagement related background. We want to ensure that strong, evidence-informed PE and PO activities are designed, developed, and shared to inform and strengthen future activities.

Acknowledgements:

The authors would like to acknowledge the support of the D'Sa Laboratory, the STEAM Lab at the University of Liverpool and the 2019-20 students of the MA Art in Science programme at

Liverpool John Moores University in the development and delivery of the school outreach and public engagement events that made the *Antimicrobial Avengers* project possible. A special acknowledgement goes to the illustrator of the *Antimicrobial Avengers* comics, Jessica Irwin, whose interpretations of the science and public/school children's drawings made the stories come to life.

The author of *Bacteria, the Future* would like to acknowledge the support of the supervisors of the 2019-20 MA Art in Science programme at Liverpool John Moores University, Mark Roughley and Kathryn Smith, and the programme's students in game development. The thoughtful feedback and discussion that they provided at every step was essential in developing the final storyline. A special thanks to Tom Hyatt, a physics educator, SciArtist, and avid gamer, who used this expertise to help write and edit the final game script.

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