Antimicrobial Resistance: Raising Awareness and Inspiring the Next Generation of Scientists

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Abstract Antimicrobial resistance (AMR) poses a major threat to modern medicine and has a wider socio-economic impact worldwide. Public awareness is a key priority in decreasing the burden of AMR, and so we describe the development and execution of 'Antibiotic Awareness', a workshop for key stage 3 (KS3) pupils delivered by researchers from the University of Warwick. The workshop aimed to highlight the importance of antibiotic resistance, in addition to providing a novel opportunity for students to engage with scientists in this widening participation project. The session was one hour, comprising an introductory talk, three activities and a plenary question and answer session. The workshop was delivered to 233 students, in two schools, and complemented the KS3 curriculum. The workshop was assessed on three criteria; student responses to questions (at the end of the session and in a two month follow-up), student feedback, and teacher feedback. Overall, 88% of students felt that we 'had done a good job'. Immediately after the workshop, the majority were able to define antibiotic resistance and answer plenary questions. However, at follow-up, retention was low. The initial delivery of the workshop indicated that it was informative and engaging, but also identified opportunities for improvement.

Peer review: This article has been subject to a double blind peer review process

Keywords: Antibiotic Resistance; Key Stage 3; Outreach; Science; STEM; Workshop

GLOSSARY OF TERMS

Antibiotic: Drugs used to treat bacterial infections

Antibiotic resistance: When bacteria develop or acquire mechanisms that prevent them from being eliminated by antibiotics

Antimicrobial resistance: The resistance of microorganisms (bacteria, viruses and fungi) to the drugs used to eliminate them

Bloom's taxonomy: A hierarchy of learning objectives by complexity

Elaborative interrogation: A technique in teaching whereby students give explanations in support of a stated fact or concept

Human capital: (As used in the Review on Antimicrobial Resistance) A strategic priority describing the need to increase the number of people researching antibiotics and resistance mechanisms

Office for Fair Access (OFFA) Agreement: A strategic document for universities which states fee limits and mandates the outreach and financial support that are required as access measures

Process question: A question where students answer with an explanation

Product question: A question to which students give a single answer

Single colony streaking: A technique in microbiology whereby the way in which a culture of bacteria is spread on an agar plate causes dilution of the cells, such that 'single colonies' (groups of cells that have grown from one single cell) can be observed

Rosenshine's principles of instruction: A set of principles for teachers to maximise the impact of instruction

Widening participation: A policy in UK Higher Education that aims at increasing the proportion of under-represented groups that enter higher education

INTRODUCTION

It is estimated that by 2050, deaths linked to antimicrobial resistant infections could reach 10 million globally per year, surpassing deaths linked to cancer (O 'Neill, 2016). Antibiotic resistance occurs when bacteria develop or acquire mechanisms that prevent them from being eliminated by antibiotics (drugs used to treat bacterial infections). Antibiotic resistance is a growing threat to modern medicine; in addition to treatment of infections, antibiotics are important for medical procedures involving surgery, and are key in the management of conditions such as cancer and diabetes.

The Review on Antimicrobial Resistance (AMR) (O 'Neill, 2016) generated a set of 10 key recommendations and interventions that could best address the problem. Among these were public awareness; sanitation and hygiene; and human capital (i.e. increasing the number of research scientists), which served as the catalyst for this widening participation project. The importance of public awareness and education in AMR is increasingly being recognised with yearly campaigns such as 'Handle Antibiotics with Care' from the World Health Organisation, which serves to communicate key messages in tackling antibiotic resistance. In addition, in 2006, Public Health England (PHE) led the e-Bug project, an online educational resource that was aimed at educating children about microbiology, prevention, control and treatment of infectious diseases, as well as AMR (Kostkova *et al*., 2010).

In this article we describe the design, execution and reflection of 'Antibiotic Awareness' a workshop for key stage 3 (KS3) students, which addresses the three aforementioned recommendations from the Review on AMR (O 'Neill, 2016). The workshop builds upon key concepts that have been addressed previously in other resources, but tailors them towards use in the classroom, specifically for KS3 students. In contrast to the e-Bug project, 'Antibiotic Awareness' offers hands-on activities facilitated by research scientists. The workshop aimed to pique the students' interest in science, technology, engineering and mathematics (STEM) and widen their choice of career options.

DESIGNING THE WORKSHOP

In line with the strategic priorities from the University of Warwick's Office for Fair Access (OFFA) Agreement, and in recognition of the importance of public awareness and outreach in tackling AMR, a KS3 workshop entitled 'Antibiotic Awareness' was designed. With the widening participation policy in mind, the workshop was trialled at two schools with differing OFSTED results and levels of pupil premium. Furthermore, the two schools varied in classroom environment, teaching style and student behaviour, which provided a suitable sample population for a small-scale trial. The use of small-scale trials/pilot studies permit the identification of logistical problems and assess the likely success (van Teijlingen & Hundley, 2002) of the workshop, within a limited budget.

The authors and workshop designers are PhD students working in the field of AMR mechanisms at the University of Warwick. Inspiration, advice and guidance was initially garnered from key public health campaigns and professional educators in order to best achieve the twin goals of effective communication about antibiotic resistance, and widening participation in science. The School of Life Sciences (SLS) outreach team and the Centre for Professional Education (CPE) assisted with the workshop design, preparation of activities and demonstrator training.

Devising the Content

The content of the workshop was founded on a combination of key messages from public health campaigns, the priorities of the Review on AMR, and in supporting areas of the KS3 national curriculum (Department for Education, 2014) - see Figure 1. The underpinning concepts of the workshop, such as the differences between bacteria and viruses, are discussed within the UK national curriculum (Department for Education, 2014). AMR may be covered with teaching of concepts such as evolution at KS3, and ‘health, disease and the development of medicines’ at key stage 4 (KS4) (Department for Education, 2014). Since prior learning is important in permitting progression of learning (Parkinson, 2002, 153 - 67) consideration was given to delivering the workshop to KS4 students. However when discussing outreach initiatives for engineering, Wilson & Chizeck (2000) suggest that recruitment of students into science by outreach is more effective prior to high school, as fewer students will have lost interest in science at this stage. KS3 was therefore chosen as the target audience for the workshop, and the introductory talk was structured such that the students’ current understanding could be assessed, and the content adjusted to the appropriate level. Hattie (2003) identified feedback, instructional quality, classroom environment and questioning among a set of influences that have a large effect on student learning. The incorporation of these influences into the workshop was sought through the training of demonstrators, and the structure and pedagogy of the workshop itself.

Training of Demonstrators

All demonstrators were provided with comprehensive training to ensure the highest teaching standards (incorporating Hattie’s (2003) influences) and the best learning experience was provided. The demonstrators participated in two training sessions, the first from the CPE, which encompassed the Teachers’ Standards, best teaching practices, and classroom management techniques. Demonstrators were then equipped with strategies to support students in completing the activities and maintaining focus. This was beneficial for the instructional quality and classroom environment of the workshop.

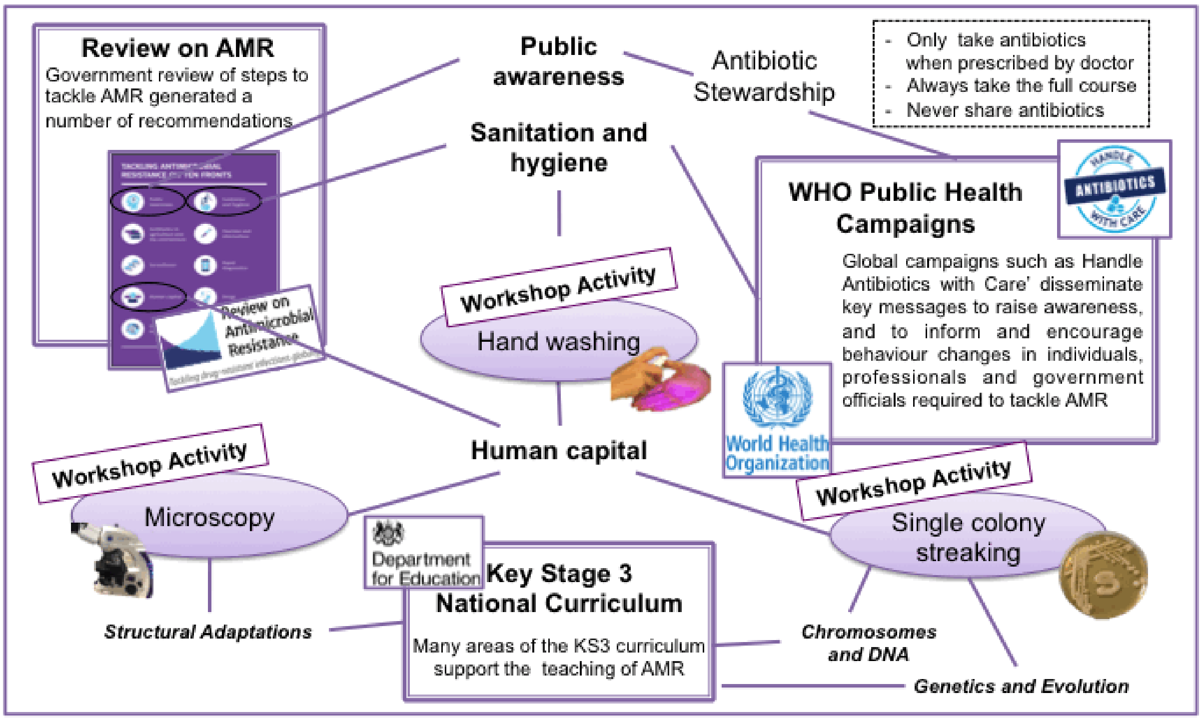

Figure 1: *Key components of the workshop. Key messages from the Review on AMR, public health campaigns and certain areas of the key stage 3 national curriculum contributed to the content of the 'Antibiotic Awareness' workshop. The workshop aimed to tackle 3 of the 10 recommendations of the Review on AMR, namely human capital; public awareness; and sanitation and hygiene. The latter two are also primary goals of global public health campaigns such as 'Handle Antibiotics with Care', which prompted the inclusion of the hand washing technique activity. The microscopy and single colony streaking activities were designed to promote science and assist human capital whilst directly supporting three subject areas within the KS3 national curriculum.*

The characteristics of good science teachers are defined by Parkinson (2002, 2) as enthusiasm; identification and communication of clear learning objectives; and knowledge about the science being taught. In addition, teachers' level of content knowledge has been linked to gains for students (Coe *et al*., 2014). In order to nurture these attributes in the demonstrators, the second training session, delivered by the organisers, focused on providing demonstrators with the level of content knowledge required for supporting student learning throughout the workshop; and defining clear desired learning outcomes (Box 1). Demonstrators were instructed to communicate these to students during the initial introductory talk, and then subsequently at each activity station. Emphasis was placed on clear communication of desired learning outcomes, as this is likely to increase chances of students' achieving them (Hattie, 2012, 47). Along with their natural enthusiasm for science, these training sessions ensured that the demonstrators were equipped with the characteristics of good science teachers.

BOX 1 – DESIRED LEARNING OUTCOMES

- Discuss (as a class) what antibiotic resistance is
- Describe how antibiotic resistance develops, and how different factors may contribute (e.g. prescribing, hygiene, patient compliance, farmers' use of antibiotics)
- Explain why antibiotic resistance is an important issue, and who will be affected by it
- Develop skills in single colony streaking, and discuss how this technique is used by microbiologists
- Conceptualise bacterial growth on agar plates and relate this to mutations in DNA that give rise to antibiotic resistance
- Demonstrate how effective hand washing technique can be used to reduce the spread and development of antibiotic resistance
- Compare the structures of the cell wall in Gram-positive and Gram-negative bacteria, and apply information in the workbook to identify Gram-stained bacteria using light microscopes

Structure of the Workshop

The workshop was designed for delivery to classes of approximately 30 pupils during timetabled science lessons (one-hour duration). It comprised an introductory talk followed by rotation around three activities; hand washing technique, microscopy, and single colony streaking of Baker's yeast (to mimic bacterial growth). Students also received a workbook and were encouraged to complete it during the session. Figure 2 gives an overview of the structure of the workshop.

The introductory talk began with a word game, where students were asked to raise their hands to assess familiarity with words and phrases such as 'germs', 'DNA' and 'antibiotic resistance'. To gauge students' understanding of these words, they were subsequently asked to provide definitions; this created an optimal classroom climate for learning by encouraging participation and establishing an atmosphere where student engagement and feedback is the norm (Hattie, 2003).

The hands-on activities were expected to improve student engagement and the overall impact of the workshop, since studies show that they improve students' perception of involvement and autonomy, resulting in more positive results (Vennix *et al.*, 2017). Throughout the workshop, an open dialogue between instructors and students was actively encouraged. Particular emphasis was placed on responding to, and encouraging questions, as well as checking students' understanding, in line with Rosenshine's principles of instruction (Rosenshine, 2012).

Sanitation and hygiene was a key recommendation of the Review on AMR (O 'Neill, 2016) and in addition, The National Institute for Health and Care Excellence (NICE) recently publicised advice that children should be taught how to wash their hands effectively, to reduce spread of infection and thereby decrease use of antibiotics (Regis & Stone, 2017). This prompted the inclusion of the hand washing technique activity which used GloGerm™ Spray Oil, a hand gel which simulates the spread of bacteria and illustrates sites on the hands that have been missed during washing.

The microscopy activity addressed a number of points within the KS3 curriculum including 'how to observe, interpret and record cell structure using a light microscope' (Department for Education, 2014).

The single colony streaking activity used baker's yeast as a safe alternative to bacteria. This activity provided an opportunity for students to develop a technique commonly used in microbiology laboratories. In addition, this activity allowed on-going interaction with the classes, as their plates were incubated at the SLS, and images were uploaded to the Integrate AMR website (http://www2.warwick.ac.uk/fac/cross_fac/wamic/integrate/outreach/). These were then shown to the students as a class during a short follow-up session, delivered by the teachers.

The classes were divided into three groups of ~10, by randomly allocating students to a colour (red, orange, green) which corresponded to the starting activity. Microscopy and hand washing activities were explained by the demonstrator to the entire group of 10, which were then split into smaller groups of two or three for practical purposes (microscopy and hand washing activities). Students completed the single colony streaking activity individually after a single demonstrator explained to the entire group, with additional demonstrators providing one-to-one support where necessary thereafter.

During the sessions, student feedback was collected using a voting system, with coloured tokens and jars. Students were asked 'Which activity did you like best?' with a jar for each activity for students to cast their vote; and 'Did we do a good job explaining what Antibiotic Resistance is?', with green for 'yes', yellow for 'sort of', and red for 'no'. Teachers were asked to provide any qualitative feedback via email following the conclusion of the workshop.

RESULTS

Feedback at the time of the workshops was overwhelmingly positive in each case, with 88% of students voting that we had done 'a good job explaining what Antibiotic Resistance is'. There was a high level of engagement from the majority of pupils, and the preference for the different activities (both on the day and on follow-up two months later) is presented in Figure 3a. The desired outcomes, as assessed by the plenary questions, were well achieved, as all classes were able to answer the questions and discuss their thoughts. Follow-up data on students' answers to the same set of questions are presented in Figure 3b. Feedback from teachers at each school was both positive and complimentary; examples of feedback received are presented in Box 2.

BOX 2 – QUALITATIVE FEEDBACK

'The level of support provided by your staff was extremely good and allowed all the students to fully access the content. The booklet was interesting and informative with appropriate activities. All staff involved thought it was an extremely worthwhile activity for the students, not only for the content but also to give them a chance to interact with people from University, which has helped to raise their aspirations. This is particularly important for boys' - Teacher

'The sessions were very well planned, explained and delivered. Most of all everyone learned new aspects of microbiology' - Teacher

'I enjoyed learning about how many germs get around so quickly' - Student

'I know that hand washing is really important because of a amazing workshop. Big thanks to the Warwick University' - Student

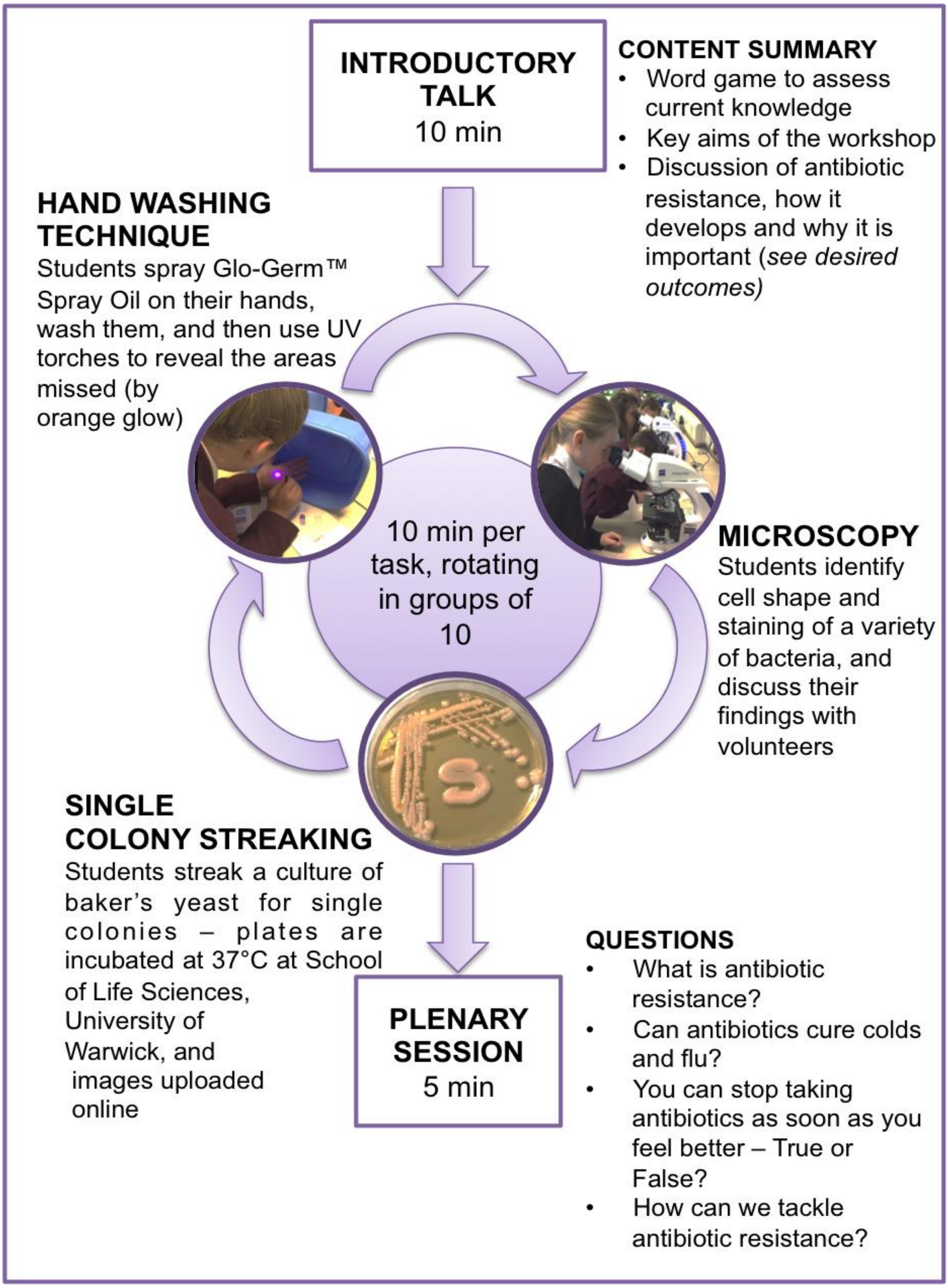

Figure 2: *The structure of the 'Antibiotic Awareness' workshop. The introductory talk was presented using a PowerPoint presentation, with class engagement through questions and discussion. The class was split into three groups at random, with each group rotating between the three activities. The workshop was concluded with a plenary session in which progress was measured using the questions shown.*

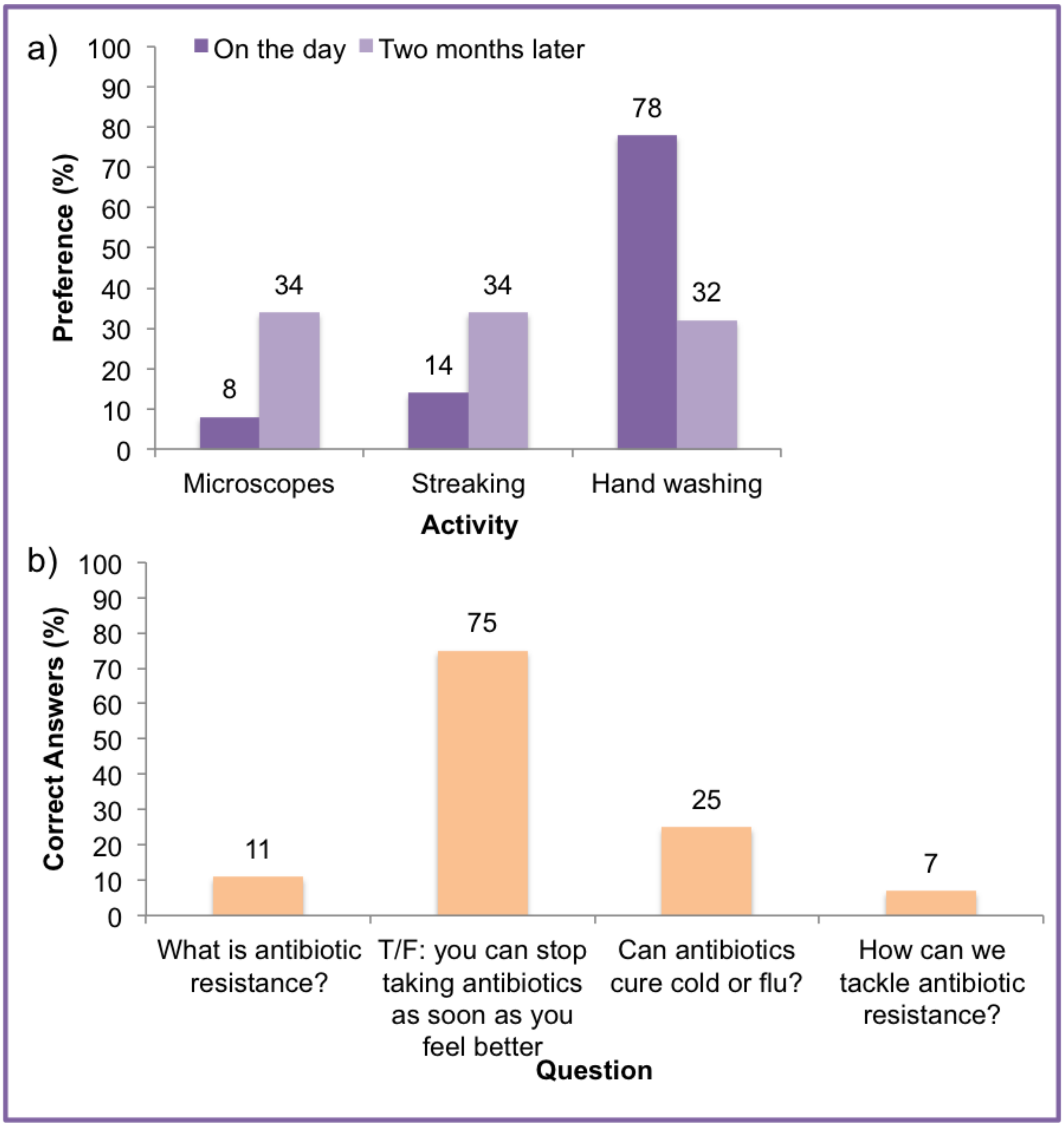

Figure 3: *Measures of the popularity of the various activities, and learning outcomes for the pupils. For both data sets, the total number of respondents was 44. a) Comparison between the day of the workshop (dark purple) to two months later (light purple) for student activity preference (by overall percentage). Whilst preference on the day was for the hand washing activity, there was a more even distribution of preference when checked two months later. b) The proportion of correct answers (by overall percentage) to the plenary session questions at follow-up two months after the workshop. The majority of students correctly answered 'false' to 'you can stop taking antibiotics as soon as you feel better', but retention was low for the other questions. T/F: True or false.*

DISCUSSION

Workshops such as 'Antibiotic Awareness' are a powerful tool to engage school-age children with the issue of antibiotic resistance and to empower the next generation to tackle this problem. Within a one-hour session with each class, pupils were able to progress from having not heard of antibiotic resistance, to discussing how it arises and what preventative measures can be taken, whilst also learning new scientific skills.

Assessing the Workshop Outcomes

During the plenary session the key learning points were discussed as a class. At this time, the majority of students could correctly answer the questions. This was not the case at follow-up two months later when students were asked to individually answer the same set of questions. Figure 3 shows that, at follow-up, 25% of students understood that antibiotics do not cure cold or flu, and 75% correctly identified 'you can stop taking antibiotics as soon as you feel better' as false. However, a consideration for the future would be the phrasing of questions; when asked 'can antibiotics cure cold or flu?', a yes/no answer was expected, however 11% of students misinterpreted this question and selected either 'cold' or 'flu' as their answer – this therefore produced a bias in the results to this question making it difficult to include in the analysis. For more complex questions, such as 'what is antibiotic resistance' and 'how can we tackle antibiotic resistance', only 11% and 7% of students were able to provide correct answers such as 'always using the full course of antibiotics' and 'washing hands better'. Multiple choice answers may be a useful tool in the future.

Interestingly, the timing of obtaining feedback appeared to influence the results; two months after the workshop, activity preference was more evenly distributed, with 32%, 34% and 34% preferring hand washing, microscopy and single colony streaking respectively (Figure 3). This disparity may be explained by the difference in the nature of the feedback (i.e. voting versus a questionnaire), as well as a reduction in participation in feedback at two months. In the future, use of a questionnaire would standardise the feedback and allow direct comparison of retention of information by students after two months. Similarly, due to time pressures on teachers the feedback obtained was minimal and non-constructive, therefore standard questions for feedback from teachers may provide a more informative assessment of the workshop.

Benefits of University-Led Outreach Programs

Whilst tools such as e-Bug are an excellent resource for assisting teachers' lesson plans, the 'Antibiotic Awareness' workshop aims to engage with students using hands-on activities and inspire them into STEM subjects by providing a unique opportunity to interact directly with research scientists. This is supported by feedback from a teacher involved, who said the workshop gave students *'a chance to interact with people from University which has helped to raise their aspirations'*. A study of a similar 'scientist in the classroom' program, The Science Squad, reported (from interviews with school teachers and facilitators of the program) up to 92% enhanced interest and engagement in the program (Laursen *et al*., 2007). The '*novelty of a presenter different from the regular teacher*', was also found to impact upon students, with interviewees from both groups reporting increased attention in comparison to the usual teacher. These results corroborate observations from the workshop – the majority of students engaged with the presentation and activities, and asked questions to the demonstrators, indicating their interest in the content.

The workshop was delivered by a diverse group of researchers with equal female to male representation: since frequent, quality contact with successful in-group members (such as female scientists) contributes to improving implicit self-beliefs and raising career aspirations, which is particularly important for inspiring girls into STEM related careers (Asgari *et al.*, 2010). The involvement of research active staff in delivery of the workshop may also benefit the teachers in a professional capacity; respondents, both Science Squad members and teachers, in the study of The Science Squad program, reported gains for teachers including new teaching approaches, and advice on improvements for experiments and activities (Laursen *et al*., 2007).

Another advantage of 'Antibiotic Awareness' (over school-delivered resources) is that the teaching style is different compared to standard classroom teaching, with a higher demonstrator to student ratio. Similarly to a reduction in class size, this may result in higher levels of student engagement (Schanzenbach, 2014). However, a disadvantage of the 'Antibiotic Awareness' workshop is the cost of materials and access to equipment. However, when delivered by a university, funding and equipment can be made available; and the workshop offered free of charge to schools.

Consequently, this workshop format is particularly well suited to collaboration between Universities and local schools. In contrast, if adaptation for delivery by teachers was desired, a number of alterations would be required, and so initial involvement with research-active staff may be mutually beneficial. Different tasks would need to be chosen to suit the cost and availability of equipment, and the timing of activities may need to be altered to account for the lower demonstrator to student ratio.

Pedagogical Techniques

The workshop was designed to encourage imaginative and original thinking, as well as achieving simple recall of key facts from the students. Furthermore, a number of different teaching strategies were implemented throughout the workshop from whole class discussions to small group work, to ensure accessibility of material to different students.

Imaginative and original thinking was encouraged through the use of questioning. In developing their dynamic model of educational effectiveness, Creemers & Kyriakides (2006) described questioning and class discussion as effective teaching, although importance was placed on the technique. The authors particularly valued process questions, where students provide explanations, in contrast to product questions, where students give a single response. Whilst the talk did contain a high ratio of product to process questions, this was balanced by the use of the plenary session questions, which required explanations of some of the key concepts introduced in the workshop. For example, one question asked 'can antibiotics be used to treat colds and flu, and why?' requiring understanding of the messages that colds and flu are viral; and that antibiotics cannot treat viral infections. The responses to the plenary questions also allowed us to reinforce key messages and correct any misunderstandings.

The combination of cross-contextual questions with the puzzles and 'lab book' spaces of the workbook was intended to encourage students to achieve a higher level of thinking, (understanding) as described by Bloom's Taxonomy (Krathwohl, 2002). In addition, the lab book allowed students to learn to record and evaluate the tasks, which are key aspects of practising science and a requirement of the KS3 curriculum (Department for Education, 2014).

Throughout the introductory talk, a number of additional discussion points were raised, such as the impact of inability to treat infections. This technique, designated as 'elaborative interrogation' (whereby students give explanations in support of a stated fact or concept) is ranked by Dunlosky *et al*., (2013) as having 'moderate utility' in a ranking of 10 learning techniques, indicating the possibility for better retention of the knowledge conveyed than by simple rereading of the materials provided.

Praise was used throughout the introductory talk to encourage students to engage with the discussion questions, whereas the activities offered opportunities for demonstrators to give feedback to students. Feedback has been found to have a lesser effect on achievement when combined with praise (Hattie 2012); these two aspects of classroom interaction should therefore continue to be kept separate.

In summary, the pedagogy used in 'Antibiotic Awareness' would be expected to improve learning outcomes and complement material delivered in the curriculum.

Implementing the Activities

Activities were explained to students in groups of 10. However, within-class grouping (groups of four or five) has been shown to be beneficial, especially in science subjects, and therefore division into two or three smaller sub-groups may be a useful method for improving the activities (Lou *et al*., 1996). Recent studies indicate that the highest performing student pairs are girls' friendship pairing whilst boys' friendship pairs perform at the lowest levels, interestingly both female and male acquaintance pairs were found to perform at a mid-level (Kutnick & Kington, 2005). Therefore in order to facilitate learning for both girls and boys, to minimise off-task behaviour and to streamline the process, students were randomly allocated to groups prior to the workshop (Kutnick & Kington, 2005). This also alleviated the pitfalls of ability-based grouping in terms of false ideas of uniformity (Coe *et al*., 2014). Groups were assigned in advance, and assistance from teachers ensured appropriate groupings (e.g. to avoid behavioural issues between particular individuals). This was highly beneficial and maximised time spent on the activities.

The activities were delivered in 10-minute time slots with a two-minute warning, prior to rotation to the next activity. This provided structure to the workshop, ensuring that it ran smoothly. For both microscopy and hand washing technique activities, 10 minutes was adequate; however, for single colony streaking, where more context was required in order for students to understand the premise of the activity, the time was not sufficient. Whilst it was possible to streak plates in the allocated time, demonstrators and teachers felt that the students did not learn as much as in the other activities. This may explain the students' feedback, where single colony streaking was preferred by only 14% of students.

The hand washing technique activity was enjoyable and informative, with 78% of students voting it as their favourite activity. Students appeared to enjoy and benefit from microscopy during the workshop, but this was the favourite activity of only 8%. This may be because microscopy is more familiar to students, and was less interactive, as the students were only required to look down the microscope.

Evaluation of the Workbook

The workbook was fun and educational, and helped bridge the gap between pupils of different abilities by providing additional work to the higher attaining students. It also helped maintain focus for students who were waiting their turn during an activity.

The order of pages within the workbook could be re-considered, since the current layout with the 'Lab book' at the back and relevant information distributed throughout the workbook proved to be engaging for many students, but more challenging for less able members of the class. It may be more useful for the workbook to be assembled into activity-based sections.

Completion of the puzzles in the workbook was incentivised by a prize draw of two 'Giant Microbes' per school. This greatly aided in the engagement of students with the content of the workshop, as understanding of the content presented was required to complete the puzzles. The workbooks were collected by teachers following the workshop, and on reflection this would have been better supported with provision of a crib sheet for 'marking' the workbook. This would also have encouraged continued dialogue about AMR between students and teachers beyond the workshop itself.

Key Considerations for Future Workshops

The workshops herein discussed were highly enjoyable both for the majority of students, and for the demonstrators who delivered the sessions. In order to build on this success and ensure the smooth running of future workshops, the following constitute the areas the authors feel are key to address.

During the planning stage, communication with the school via the head of department was most often by email or telephone. Difficulty was experienced in finding a suitable time to talk directly, introducing delays due to existing restraints on teachers' time. For future workshops, it may be more effective to build a stronger relationship with the school by having a trainee teacher leading the project, with whom the school can liaise directly and provide a more suitable channel of communication.

A number of small improvements to the workshop would include development of additional activities to form a repertoire, from which schools can select specific activities best suited to their needs; improvement to the order of the workbook; potential inclusion of additional, more challenging work for high achieving students; and providing a crib sheet for teachers to continue dialogue about AMR following the conclusion of the workshop. If these changes were implemented a second small-scale trial would be beneficial to assess the effectiveness of refinements, and would increase chances of obtaining funding on a larger scale.

CONCLUSIONS

Overall, this workshop was very well received; feedback indicated that 88% of participants felt that *'[you] did a good job at explaining antibiotic resistance'*. The format therefore appears to be successful in communicating key messages relating to AMR to KS3 students, whilst also engaging students and furthering their interest in science. A number of points within the national curriculum were addressed, and widening participation will permit students from a wide range of backgrounds to be inspired by researchers to attend university and pursue interests in STEM related subjects.

The format of this workshop appeared to result in a well-received, enjoyable session for the majority of students, with demonstrable learning on key messages related to antibiotic resistance. Between the two schools there was variation in the teaching style, student behaviour and rapport between teachers and students. Despite these differences, the workshop was well received and the outcomes similar for both schools, suggesting that it could be implemented in a range of schools. The authors intend that this workshop will be distributed to more schools within the local community in the near future and will inspire other researchers to conduct similar workshops. This format has the potential to be applied to convey other key topics in science, whilst sparking interest in STEM subjects for a wide range of students.

ACKNOWLEDGEMENTS

We would like to thank Kate Mawson (CPE), Dr Leanne Williams and Professor Kevin Moffat (SLS Outreach Team) for their expert support and guidance throughout this project as well as Dr Chandrika Nair (Warwick Antimicrobial Interdisciplinary Centre) for continued support and assistance with AMR related outreach events and activities. We would like to express our sincere gratitude to the Teaching Staff at The School of Life Sciences who kindly prepared microscope slides, plates and cultures for the activities and we are grateful to our supervisors for providing comments on the manuscript. Finally, this work has been very kindly supported by EPSRC 'Bridging the Gaps – EPS and AMR' (grants code EP/M027503/1).

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