

Superbugs online: Co-production of an educational website to increase public understanding of the microbial world in, on and around us

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Co-production, public involvement and engagement, educational resources, science teachers, infection, antimicrobial resistance, online learning

Abbreviations

AMR: antimicrobial resistance; STEM: Science, Technology, Engineering and Mathematics

28 1. Abstract

29 Digital tools and online presence have become a cornerstone to public engagement and involvement
30 strategy and delivery. We here describe the co-production process behind launching a new multilingual
31 resource for schools in the UK and beyond, jointly between university scientists, engagement
32 professionals, primary and secondary teachers, and web designers. The 'Superbugs' website aims at
33 raising awareness and increasing public understanding of the microbial world in, on and around us,
34 and has attracted >19,000 online visitors, >33,500 page views and >775,000 Twitter impressions over
35 the past 24 months. *Superbugs.online* is available in English, Welsh, Irish and Scottish Gaelic, thus
36 making it accessible to everyone in the UK and Ireland, regardless of the language in which they receive
37 and deliver their science education. The website is easy to navigate and features background
38 information, quizzes, animations, videos, illustrated stories, interactive timelines, games and protocols
39 for home experiments. All materials are presented in a non-prescriptive way, aimed at allowing
40 flexibility for the materials to be adapted to the individual needs of teachers and pupils alike. Our work
41 has led to demonstrable impact on the co-production team and on pupils and teachers as key
42 stakeholders, based on a comprehensive evaluation of the co-production process itself, the impact of
43 the end product, and the creation of lasting relationships with stakeholders and co-producers, for the
44 mutual benefit of everyone involved.

45

46 2. Data summary

47 The authors confirm all supporting data have been provided within the article or through
48 supplementary data files.

49

50 3. Introduction

51 Digital tools and online presence have become a cornerstone to public engagement and involvement
52 strategy and delivery [1, 2]. The COVID-19 pandemic enforced an involuntary pivot to such virtual
53 approaches – extended periods of lockdowns, closure of public spaces and schools, and social
54 distancing meant that public engagement activities had to adapt, or stand still [3, 4]. 'Superbugs', a
55 research-driven initiative at the universities of Cardiff and Swansea, aimed at improving public
56 understanding of the microbial world in, on and around us [5], was no different. The original goal of
57 'Superbugs' was to investigate the mechanics of how to communicate and educate on complex topics
58 such as microbiology and antimicrobial resistance (AMR), through novel engagement strategies in
59 public spaces [5]. When it became impossible to conduct in-person outreach throughout most of 2020
60 and 2021 as a result of COVID-19 restrictions, the new aspiration was to widen the scope and
61 catchment of communicative work around research and education, condense the enthusiasm from in-
62 person events into an equally inspiring virtual format, and in partnership with teachers co-produce an
63 interactive educational online resource.

64 The principle of co-production within this context may be most succinctly defined by the National
65 Institute of Health Research (NIHR); '*an approach in which researchers, practitioners and the public
66 work together, sharing power and responsibility from the start to the end of the project*', based on the
67 assumption '*that those affected by research are best placed to design and deliver it*' [6]. Central to this
68 is the fact that the partners in the co-production process would also be the primary beneficiaries of its
69 outcomes. In the case of Superbugs, we specifically wanted to target teachers and students of Key
70 Stages 2 (KS2) and 3 (KS3) (school years 3-9 in England and Wales).

71 A co-production approach was particularly beneficial in the creation of the website as the project
72 coincided with the launch of the new Curriculum for Wales [7]. As such, a key ambition of the
73 Superbugs project was to develop educational resources that would meet the 'four purposes' that aim
74 to support children and young people to be (i) '*ambitious, capable learners, ready to learn throughout*
75 *their lives*'; (ii) '*enterprising, creative contributors, ready to play a full part in life and work*'; (iii) '*ethical,*
76 *informed citizens of Wales and the world*'; and (iv) '*healthy, confident individuals, ready to lead fulfilling*
77 *lives as valued members of society*'. Similarly, despite a primary focus on microbes, infection and
78 antibiotics we wanted to ensure that our materials spanned across all six 'areas of learning and
79 experience' defined as *Health and Well-being; Science and Technology; Mathematics and Numeracy;*
80 *Expressive Arts; Humanities; and Languages, Literacy and Communication*. The expertise and
81 experience of co-producing teachers ensured that our resources aligned with the content and the spirit
82 of this new framework [7].

83 Additionally, in line with the Welsh Government's aim to promote and facilitate the use of the Welsh
84 language and to ensure that Welsh is treated no less favourably than English [8], we were keen to
85 provide all Superbugs resources bilingually from the start. This was to take into account the fact that
86 there is a free choice of Welsh and English-medium schools in Wales, and to make 'Superbugs' equally
87 available to all children in Wales independent of the language in which they receive their education.

88 The Co-production Network of Wales outlines five key values that underpin successful co-production:
89 (i) '*value people and build on their strengths*'; (ii) '*develop networks that operate as silos*'; (iii) '*focus*
90 *on what matters for the people involved*'; (iv) '*build relationships of trust and shared power*'; and (v)
91 '*enable people to be change makers*' [9]. These values were kept central to our project at all times.
92 Herein we provide an account of our co-production process, its implementation in launching a new
93 microbiology resource for primary and secondary schools in Wales and beyond, the evaluation of both
94 the co-production process itself for developing educational materials and the initial impact of the end
95 product, and the creation of lasting relationships with stakeholders and co-producers, for the mutual
96 benefit of everyone involved.

97

98 **4. Methods**

99 **Pre-production preparation.** Three interactive sessions by the Co-production Network for Wales
100 (<https://www.copronet.wales>) for the Superbugs core members (Tyrrell, Hatch, Eberl) and two
101 professional web designers (Fricker, Hullis) emphasised the underlying concepts and philosophies of
102 co-production, and how to design, implement and evaluate the process. Recruitment of co-production
103 partners was primarily by utilising the existing communication network of all schools from across
104 Wales, compiled by the Cardiff University School of Medicine Engagement Team. While being limited
105 to virtual meetings due to COVID-19 restrictions in place at the time [10], and not being able to take
106 advantage from in-person teambuilding as foundation for constructive co-production, we were able to
107 involve teachers from the whole of Wales, thus covering a geographical area of 20,000 km². These
108 virtual meetings benefited from our extensive experience with the all-Wales 'Life Science Challenge'
109 inter-school competition, which features online quiz rounds [4], and the development and delivery of
110 online and hybrid teaching material both for school children and university students. We recruited 25
111 teachers to attend an initial introductory session, delivered over Zoom, where they were introduced
112 to the background and philosophies behind the 'Superbugs' initiative, the idea of developing an
113 educational tool for remote learning, and their potential role in this project. Teachers represented
114 primary and secondary schools across Wales and covered both English and Welsh-medium education.

115 15 teachers expressed an interest to continue to be involved in the project and became our official co-
116 production partners.

117

118 **Co-production process.** Once partners had been recruited, co-production unfolded through three
119 online workshops, delivered over Microsoft Teams and facilitated using interactive tools such as
120 Mentimeter (www.mentimeter.com), Slido (www.slido.com) and Padlet (padlet.com). All co-
121 production workshops were attended by university scientists and engagement professionals, primary
122 and secondary school teachers, and web designers, to ensure that all scientific, educational and
123 technical aspects of the project were represented. With the official launch of the Superbugs website
124 (www.superbugs.online) in October 2021, the project entered the post-co-production phase.

125

126 **Evaluation of processes and outputs.** As with our Superbugs pop-up shop project [5], a multifaceted
127 evaluator approach was taken. This was in part directed by the use of the 'Measuring What Matters'
128 tool, provided by Co-production Network for Wales (info.copronet.wales/audit-online), a practical task
129 which allowed us to identify the important questions to ask in order to rigorously achieve our
130 evaluation aims. As a result, it was agreed that our evaluation would consist of four distinct elements.

131 The horizontal evaluation comprised of a self-assessment by project participants combined with peer
132 review, primarily via a self-audit at the beginning, during, and at the end of the project.

133 For the participatory approach evaluation, we collected direct feedback from primary stakeholder
134 participants, through bespoke questionnaires for teachers and school children during the 'Piloting
135 Draft' element of the project.

136 The impact evaluation consisted of two parts – an evaluation of the impact upon our co-production
137 partners with regard to their own personal knowledge of microbiology and AMR, and their self-
138 reported confidence and competence in teaching on these topics.

139 Finally, for the product evaluation we assessed the success of the Superbugs website itself, gauged
140 through monitoring website traffic, feedback collected through questionnaires and interactive
141 elements within the website, and anecdotal feedback.

142

143 5. Results and Evaluation

144 **Outcomes of co-production workshops.** The overall study design, including a series of co-production
145 workshops, is visualised in [Figure 1](#). When conceiving the project, an initial logic model was developed
146 during the pre-production phase to define our aspirations and the processes by which we would
147 achieve our aims and objectives. Upon recruitment of our co-production partners, the logic model
148 evolved further to more accurately reflect the changing focus and priorities of the wider team. This
149 revision formed a repeated exercise through the course of three co-production workshops, the final
150 output of which can be seen in [Figure 2](#).

151 Workshop 1 was an in-depth introduction to the project and what we were hoping to achieve. It
152 provided a useful understanding of teachers' individual experience in designing, using and evaluating
153 digital teaching during the COVID-19 pandemic when schools were forced to resort to remote and
154 hybrid learning over extended periods – a setting which was entirely novel for both teachers and pupils
155 at the time ([Table 1](#)). In particular, insight was gained into a range of educational online platforms
156 already employed, and how best to communicate for the remainder of the project ([Figure 3A](#)). These

157 formed the basis of our delivery strategy for the pilot development of *Superbugs.online*. Teachers also
158 undertook a benchmarking exercise in form of a simple quiz, delivered via Slido, to gauge their level of
159 knowledge of basic microbiology.

160 Workshop 2 was centred around developing *Superbugs.online* in close alignment with the needs of our
161 educational partners, and was split into two parts. Firstly, we delivered an interactive lecture,
162 introducing teachers to key concepts of microbiology, infection and AMR. This ensured all participants
163 were on a consistent level of knowledge for the remainder of the project and able to engage
164 constructively with the scientific aspects of the discussions. The second half of the workshop included
165 discussions around the new Curriculum for Wales [7], to determine how our ambitions might fit into
166 this new scheme, and whether and how its confinements might affect the design and content of
167 *Superbugs.online*. A key point raised unanimously by all teachers was the preference for a non-
168 prescript, flexible resource which would allow educators to apply and adapt *Superbugs.online* for their
169 own purposes. To quote our partners directly; “*Prescription takes away from being able to adapt*
170 *material to variety of ELOs [expected learning outcomes] across the curriculum*”, and “*having golden*
171 *nuggets [of microbiology] that people can incorporate into their own teaching... would be more useful*”.

172 In Workshop 3 we began to develop the initial pages of the website to be reviewed and discussed, and
173 co-produced feedback questionnaires that would sit across the Superbugs platform, to allow for
174 continuous monitoring of usage and feedback. Pupil feedback questions were co-produced with the
175 help of a year 5 class at Llanedeyrn Primary School, Cardiff, and year 11 pupils at Ysgol Clywedog,
176 Wrexham, with support by their teachers. Additionally, we collected valuable feedback from teachers
177 on the pilot version of *Superbugs.online* and on how best to promote this website (**Table 2**).

178

179 **Design of the Superbugs website.** As a direct result of the co-production workshops we created a
180 website aiming to be informative, self-explanatory and non-prescriptive, and at the same time easy to
181 navigate, interactive and fun to visit (see Supplementary Information). Careful consideration of
182 software solutions and design options ensured that the final product was straight-forward to maintain
183 and develop further by the Superbugs team, without need for extended support by professional web
184 designers and programmers after the initial set-up and training. *Superbugs.online* was launched
185 bilingually in English and Welsh in October 2021 ([Supplemental Figure S1](#), [Supplemental Table S1](#)).
186 The ease with which content could be hosted in different languages quickly made us realise the full
187 potential of the project, and with the help of Stòrlann Nàiseanta na Gàidhlig we were able to launch a
188 Scottish Gaelic version in 2022. Grant funding from An Chomhairle um Oideachas Gaeltachta agus
189 Gaelscolaíochta (COGG) enabled us to have an Irish version in place ready for the new school year
190 2023/2024. Thus, *Superbugs.online* now covers all four languages officially used for education at public
191 and private schools across the British and Irish Isles. With a paucity of high-quality modern teaching
192 resources in Welsh, Gaelic and Irish (compared to English), especially in STEM subjects, this puts the
193 Superbugs project in a unique position to fill an urgent educational need and meet the demands and
194 ambitions from teachers and pupils [11, 12].

195

196 **Impact on co-production partners.** At the end of the co-production process, the partners were asked
197 to undergo a self-evaluation and provide feedback on individual aspects of the project. All teachers
198 (100%) among the co-production team agreed or strongly agreed with the notion that the project
199 structure had provided enough opportunities for them to contribute, that they had been made feel
200 comfortable and confident to engage, that they had felt their views and inputs were respected and
201 valued, and that co-production was a positive approach for developing innovative and impactful

202 educational tools (**Figure 3B**). Importantly, all teachers (100%) also considered that the level of their
203 involvement had been just right for them, with nobody feeling that the level had been too little or too
204 much (data not shown). This positive evaluation was complemented by constructive and supportive
205 verbal feedback (**Table 3**), demonstrating that the co-production element had been designed optimally
206 to benefit from involving key stakeholders in the conception, design and implementation of the
207 project.

208 The Superbugs core team together with the web designers completed the Co-production Network for
209 Wales's self-audit tool before, during and at the end of the project. At the beginning of the projects,
210 all five categories (Assets, Networks, Outcomes, Relationships, Catalysts) only ranked either as "Made
211 a start" or "Making progress" (**Figure 4**). This initial assessment had improved considerably by the end
212 of the project, with all five categories either ranking as "Doing well" or "Doing as well as you can", as
213 testimony of the achievements and learnings during the co-production phase.

214

215 **Impact on participating teachers.** It was important to the outcomes of the project that we imparted
216 a positive impact on all co-production partners. As such, during Workshop 1, a simple benchmarking
217 exercise was carried out to ascertain the baseline knowledge of our partners on topics around
218 microbiology, AMR and antibiotic stewardship. All teachers (100%) showed a basic working
219 understanding of antibiotics, their selective toxicity against micro-organisms, and some basic good
220 stewardship practice. This was encouraging as being informed to this level would enhance the
221 intellectual level of input that could be gained throughout the co-production phase. However, many
222 teachers suggested to have reservations in their ability to communicate/educate these topics further,
223 with only 46% feeling confident enough to deliver teaching on AMR and microbiology. Additionally,
224 31% of teachers indicated at the beginning of the project that they did not feel informed enough to
225 teach on these topics, compared to 69% who answered "a little bit" or "very much". Importantly, this
226 original hesitation quickly disappeared so that by the end of the project all teachers (100%) felt
227 informed and confident in their abilities to design and deliver classes framed around the content of
228 *Superbugs.online*.

229

230 **Impact on pupils.** During the development of *Superbugs.online*, early versions of the website were
231 shared with pupils, and feedback from a total of 247 pupils was received. Despite only accessing a
232 prototype of our resources, it was reassuring that 78.1% of pupils rated the preliminary website
233 'excellent' or 'good', and that 38.0% would have been happy to share it with friends (compared to
234 11.4% who would not be happy to do so) (**Supplemental Figure S2**). Verbal feedback emphasised the
235 breadth of content that the students found interesting (**Supplemental Table S3**).

236 From the time of the official launch, student feedback was collected via feedback forms embedded in
237 the Superbugs website. To avoid biases due to responses from individual visitors with a markedly
238 positive or negative view of our resources, we here focused on feedback given by whole groups of
239 students accessing the website jointly. In one particularly informative exercise at the time of the
240 launch, all students of the same year 6 class attending an English-medium primary school in Cardiff
241 were encouraged by their teacher to complete the online feedback form. Out of 22 submitted
242 questionnaires, 59.1% of pupils rated *Superbugs.online* 'excellent' or 'good', 72.7% found it excellent
243 or good navigate, and 68.2% found the graphics and visuals excellent or good (**Figure 5A**).

244 Of the pupils who visited the corresponding sections, 66.7% rated the 'Adventure Trail' excellent or
245 good, 88.9% the 'Story Time' section, and 62.5% the 'Being a Scientist' section. Encouragingly, only
246 very few pupils considered *Superbugs.online* overall or aspects of it 'poor' or 'bad' (**Figure 5B**), and at

247 least one of these negative responses may have been due to a mistake as it was accompanied by
248 positive comments in the free text parts of the questionnaire (not shown). After visiting
249 *Superbugs.online*, 38.1% of pupils felt more confident about speaking about science with friends and
250 family, 68.2% were more interested in science in general, and 27.3% stated they were more likely to
251 choose one or more science subjects at A levels (the school leaving certificate in England and Wales);
252 again, only very few pupils gave negative responses (Figure 5C). These overall positive impressions
253 from the questionnaires were reinforced by anecdotal comments provided by pupils about the most
254 interesting thing they had learned and their favourite part of *Superbugs.online* (Supplemental Table
255 **S3, Supplemental Table S4**).

256

257 **6. Lessons Learned**

258 **Co-production.** The co-production process led to the development of lasting relationships. Several
259 partners remained with the project in a productive and cross-disciplinary team, even after the end of
260 the official project, and are still being consulted on many aspects of *Superbugs.online*, and the wider
261 Superbugs initiative. We very much see these partners now as a part of the core Superbugs team, and
262 as such no longer officially evaluate their input. Whilst perhaps idealistic, this has certainly been an
263 organic route of travel, and testifies to the long-term success of our co-production.

264 **Multilingual challenges.** With its provision of multilingual materials, *Superbugs.online* meets a key
265 educational need in the UK's devolved nations (Wales, Scotland and Northern Ireland) and in the
266 Republic of Ireland. However, accurate provision of educational content in four different languages has
267 turned out to be more demanding than anticipated as it needs to be cross-checked by translators and
268 education experts to make sure the texts are both scientifically accurate and at an appropriate
269 language level for pupils [11-14]. It is important to note that some Superbugs content is at present
270 provided in English only – e.g. certain videos, animations and online games where simultaneous
271 translation is technically not possible. Ongoing work aims at replacing those English materials with
272 multilingual alternatives and/or appropriate subtitles wherever possible. The inclusion of a glossary
273 that lists scientific terms and explains them in simpler words for each language is planned but has not
274 been started.

275 **Promotion.** Creating an educational resource is only the beginning of raising awareness and increasing
276 understanding as it needs to be promoted heavily to make it visible and stand out against potential
277 competitors [15]. As such, social media campaigns, direct contact with teachers, a printed brochure
278 and word of mouth recommendations were all important in promoting *Superbugs.online* and in
279 ensuring its relevance for science education (Supplemental Figures S3 and S4). The co-production
280 process helped considerably in this regard, allowing us to gauge the wishes and interests of teachers
281 and pupils alike, whilst simultaneously developing materials that directly catered for our stakeholders'
282 needs. As of October 2023, *Superbugs.online* was already listed as a recommended educational
283 website by Hwb (Digital Learning for Wales, the Welsh Government's provision of educational tools),
284 Gaelic Education (maintained by Stòrlann Nàiseanta na Gàidhlig), and the Federation of European
285 Microbiological Societies (FEMS), with evidence of direct traffic referrals from each site.

286 **Feedback.** Collecting meaningful feedback from anonymous visitors remains a challenge. Although
287 *Superbugs.online* features three bespoke (and co-produced) questionnaires for pupils, teachers and
288 other members of the public alike, uptake of this option has been very poor so far outside a supervised
289 setting in the classroom. This is likely to be due to general survey fatigue [16, 17] and needs to be
290 addressed going forward. The long-term aim is to embed more seamless evaluation strategies as part
291 of the engaging activities. In the meantime, we will continue and intensify our collaborations with

292 teachers and schools to learn how to improve our resources further, and keep monitoring web traffic
293 to understand which parts of *Superbugs.online* are particularly successful. The web and Twitter
294 statistics so far, together with direct feedback from teachers and pupils, demonstrate the effectiveness
295 of our engagement with key stakeholders and the interest in our resources, thus directly addressing
296 the original objectives set out in the co-production workshops.

297 **Long-term investment.** Developing and debugging an educational resource such as *Superbugs.online*
298 and keeping it up to date comes with considerable expenses, even if the content itself is largely
299 contributed free of charge. Costs for long-term website maintenance currently amount to approx. £750
300 per year for domain registration and Squarespace and Weglot subscriptions, in addition to translation
301 and proof-reading services. So far, our team has been able to cover those expenses from grants related
302 to the development and translation of *Superbugs.online* but going forward this will require ongoing
303 support to ensure a stable provision of our educational website in the long run.

304 **Added value for in person activities.** The possibility to provide online materials to complement our in-
305 person events is an attractive option for extended engagement with the public and was successfully
306 explored at small Superbugs workshops held during the 2023 summer holidays at Swansea Central
307 Library (Swansea, UK) and the Broadlands Fun Day (Bridgend, UK). In addition to our ever popular
308 activities such as a microscope station and a 'Grow your own Microbe' body swab station, these events
309 also featured guided tours through *Superbugs.online* and the possibility for visitors to explore the
310 online content at their own pace. The 'Behind the Scenes' blog section now regularly contains
311 summaries and photos from live events, thereby increasing the audience reach and promoting in-
312 person activities and website alike.

313

314 **7. The Future of Superbugs**

315 Our approach of combining public engagement and co-production with analyses into the effectiveness
316 of the delivery and the impact lends itself to further academic training and investigation. In this regard,
317 we have started to offer public engagement-based projects for students of the MSc Biomedical Science
318 (Clinical Microbiology) module at Swansea University (UK). The first four projects successfully
319 completed addressed the development and assessment of novel in person activities or online content,
320 in co-production with teachers and pupils, and comprised a pre-production phase, a pilot phase in a
321 public setting, and the final delivery at a local school (Cefn Glas Infant School, Bridgend, UK). We
322 believe that this is a powerful way to train the next generation of scientists and equip them with a rich
323 set of transferrable skills in science communication, education, teamwork, creativity and evaluation.

324 AMR is of global concern, and improving modern science education and keeping it current and relevant
325 is an ambition everywhere. The English content of *Superbugs.online* is naturally accessible to a
326 worldwide audience, as reflected in the web traffic to our website from Europe, the Americas, Africa,
327 Asia and Australia ([Supplemental Figure S5](#)). Building on this positive momentum, we are increasingly
328 working with international partners raising awareness in their communities to explain the underlying
329 scientific and health principles of hygiene, infections, vaccines and AMR, for instance with volunteers
330 in Tanzania and Liberia. We also participated in the virtual 'Night of Science' 2022 (bilingually in English
331 and Ukrainian), organised by colleagues at Zaporizhzhia Polytechnic National University, Cardiff's
332 official partner university in Ukraine. These collaborations involve promoting and supporting local
333 activities, participating in events and activities, and developing joint outreach programmes. Our
334 Superbugs initiative will continue to drive improved microbial literacy worldwide through a growing
335 portfolio of research-driven, innovative public engagement projects.

337 **8. Tables**

338

339 **Table 1: Significant outputs and discussion points from the co-production workshops.**

Workshop 1: Learning from teachers' experience in online and hybrid education

- Keep in mind how *Superbugs.online* may appear on tablets/smart phones, which is the primary method of consumption by pupils
- Link quizzes to online tools for immediate application of learning
- Provide instant feedback (pop-ups, sounds, scores etc.) on activities – pupils value being able to gauge their own progression
- Students engage well with, and learn through, competition/challenge – gamification
- Embed videos and visual representation of information – avoid too much text. Ensure sections are not too long: short and sharp (approximately 10 minutes)
- Try to make instructions for activities visual or oral, as opposed to text-based
- Include live broadcasts of scientists, experiments etc.
- Notable educational resources/tools mentioned: Google resources (Classrooms, Suite, Jamboard), Oak Academy, Kay Science, E-Bugs, Minecraft, BBC Bitesize

340

Workshop 2: A focus on the Welsh Curriculum

- Consider the value of having a 'teachers corner' for material to be used by educators to design their own lessons and classes
- Unanimous desire to avoid prescript 'lesson' plan approach and focus on 'simple-to-complex' information delivery; this will allow educators to employ the material in a manner that fits their specific use
- Create interdisciplinary material spanning the six areas of learning
- Provide elements to focus on career advice, including real life stories from actual scientists

341

Workshop 3: Feedback on website elements

Questionnaires

- Students want to be able to explain WHY they have given the opinions they give in feedback
- Focus on gauging 'learning', not just on 'fun'
- Simplify to maximise engagement, e.g. 1-5 star rating on activities

Content

- Include short quizzes at the end of each section
- Re-iteration to use videos to deliver information rather than through text.
- Take the level of information back to the very basics, e.g. define what cells are, for the benefit of both pupils and teachers
- More of an interdisciplinary approach – teach microbiology through the context of other topics (maths, physics, history etc.)
- Further confirmation of a preference for topic-focused material that is adaptable to a variety of teaching frameworks/scenarios. No desire for prescript lesson plans.
- Highlighted the spectrum of material allowing a seamless transition from KS2 to KS3
- Website visuals described as 'attractive, friendly, and engaging'

342

343 **Table 2. Suggestions by teachers on how best to promote our educational resources throughout**
344 **schools in Wales.** Feedback from 14 primary and secondary school teachers during the co-
345 production phase of the Superbugs website.

Suggestion	Action taken
<i>"Pencils and mugs with web address into staff rooms. Teachers love pencils and mugs."</i>	
<i>"Merchandise"</i>	Purchase of Superbugs-branded merchandise such as water bottles, bookmarks, pencils, torches and rulers that are given out at events
<i>"Superbugs-branded chocolate biscuits"</i>	
<i>"Are there events you can attend where all schools meet?"</i>	
<i>"At events where all schools meet."</i>	Distribution of brochures at Cardiff University's 'Science in Health Live!' event 2023 and at the Teacher and Career Adviser's Conference 2023
<i>"Are there teaching meetings/conferences that we can showcase at?"</i>	
<i>"Social media – Twitter."</i>	
<i>"Twitter, Facebook groups"</i>	Establishment of a very active Twitter profile; also creation of accounts on YouTube and TikTok
<i>"Facebook. Email. Hwb."</i>	
<i>"Get in touch with Hwb.gov.wales and ask them to include it."</i>	<i>Superbugs.online</i> now hosted on the Hwb resources page of the Welsh Government and on the 'Gaelic Education in Scotland' page hosted by Stòrlann
<i>"Facebook. Email. Hwb."</i>	
<i>"Email out to science co-ordinators"</i>	Targeted campaign to reach science teachers and/or science departments via direct messaging on Twitter
<i>"Use teachers communications network?"</i>	Successful contacts with science teachers across Wales and beyond via Email and Twitter; establishment of long-term relationships with some of the co-production partners
<i>"Through the network we have developed."</i>	

347 **Table 3. Self-reflection of teachers on the co-production process.** Feedback from 14 primary and
348 secondary school teachers involved in co-producing the Superbugs website.

349

Do you think the Superbugs project team created a positive co-production environment?

“Yes a fantastic and open forum to share ideas and knowledge.”

“Yes – I think there were constraints due to only meeting online (due to Covid) but certainly a positive environment.”

“Yes, time was given to discuss and share our thoughts on an equal footing with all stakeholders”

“Yes. Opportunities for inclusion of all. Everyone had an opportunity to share their ideas and thoughts. Everyone was listened to.”

“Yes, time was given to discuss and share our thoughts on an equal footing with all stakeholders”

“Yes i think it has been very positive. My opinions have been valued and used. All info and ways forward have been shared. It was a friendly group”

“Good interactive discussions in the workshops and via Teams”

“Fantastic opportunities offered through zoom meetings for all parties to contribute.”

“Yes, definitely – it felt like everyone was able to share their thoughts and contribute fully.”

“Yes, very inclusive and all ideas and opinions were valued.”

“Yes, excellently organised”

“Definitely. Everyone was able to have the opportunity to share their own ideas, thoughts, opinions to the discussions. You felt that each contribution no matter how small was always valued in the group. Expertise/knowledge/skills were valued.”

“It has been a very refreshing project. I have loved working with different scientists.”

“Yes” (3x)

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Do you think the adopted co-production approach has been successful in achieving the intended outputs?

“Yes, all stakeholders were able to contribute to the final product including views from pupils within schools and clear changes have been evident throughout the coproduction.”

“Yes- can't add to those other comments!”

“Yes, the website has plenty of content that came from the initial workshops.”

“The end website is very different from the original idea, which has been driven by working as a co-productive team”

“Yes. The links with science and other curriculum areas such as Humanities has been well integrated.”

“I think it has been better than I expected! I think the website is just great. It is user friendly, packed with content and will be well used. All of our ideas have been incorporated in some way or another.”

“Yes, I think it has achieved this with regard to outputs. It's just a pity that we have had such a high dropout rate of people throughout the workshops so we are not getting as much feedback as we would have liked.”

“Yes. The website is more accessible to children due to input from teachers being noted. The careful step by step approach to the development of the site gave all contributors time to consider, experiment and respond. Timeframe suitable for teachers.”

“Yes, the website is fabulous and is of great value to us as teachers and to the children that we teach.”

“Yes, good mix of teachers and academia”

“very”

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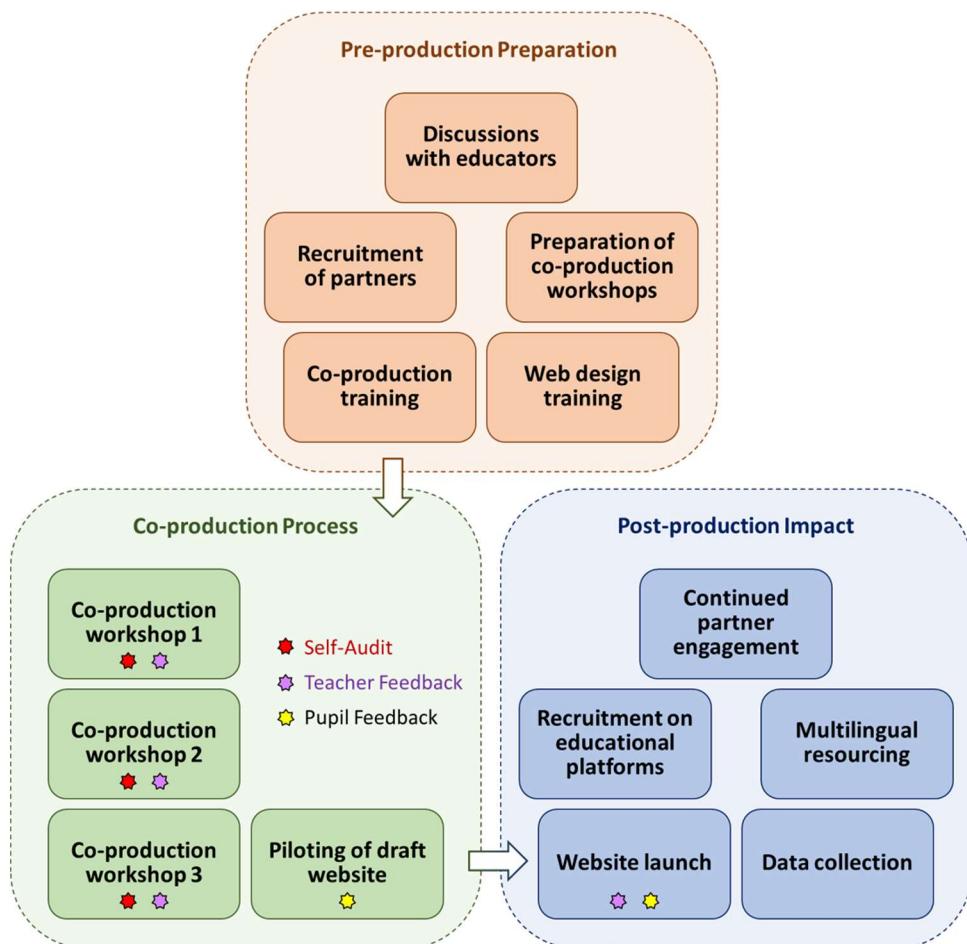
352 **9. Figures**

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360 **Figure 1. Schematic overview of the co-production project structure.** Time line: Pre-production
361 preparation, November 2020 – February 2021; Co-production process, March 2021 – September 2021;
362 Post-production impact, October 2021 – September 2023.

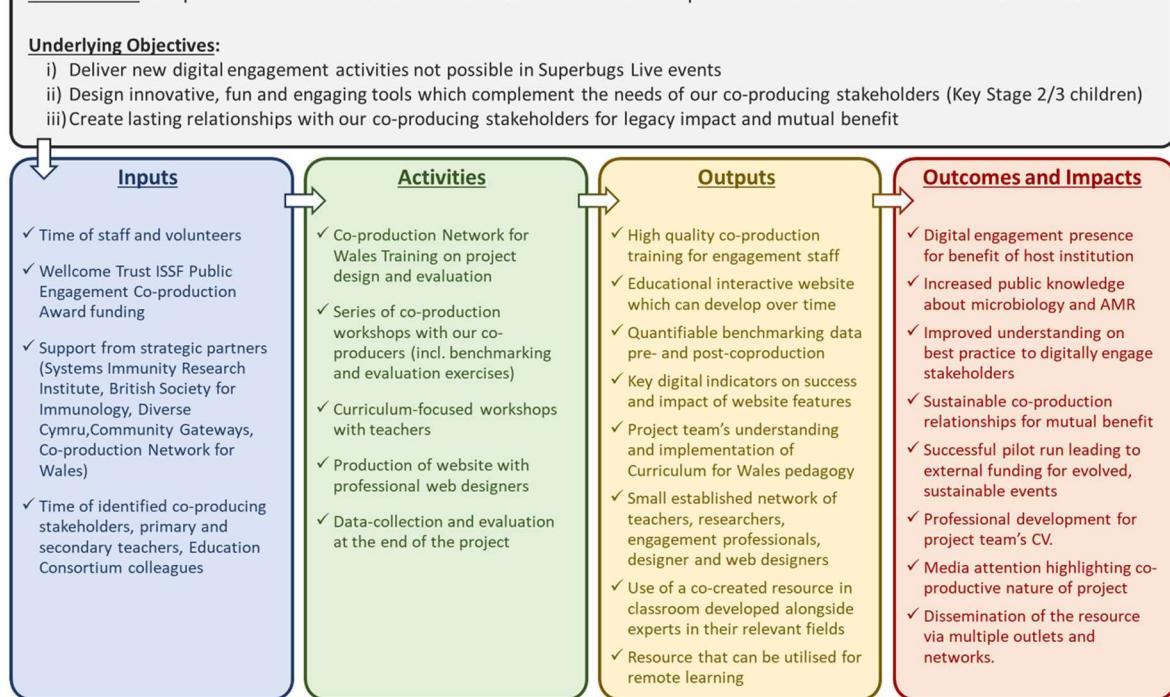
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Overall Aim: Co-production of an interactive website to continue to improve awareness around the societal issue of AMR

Underlying Objectives:

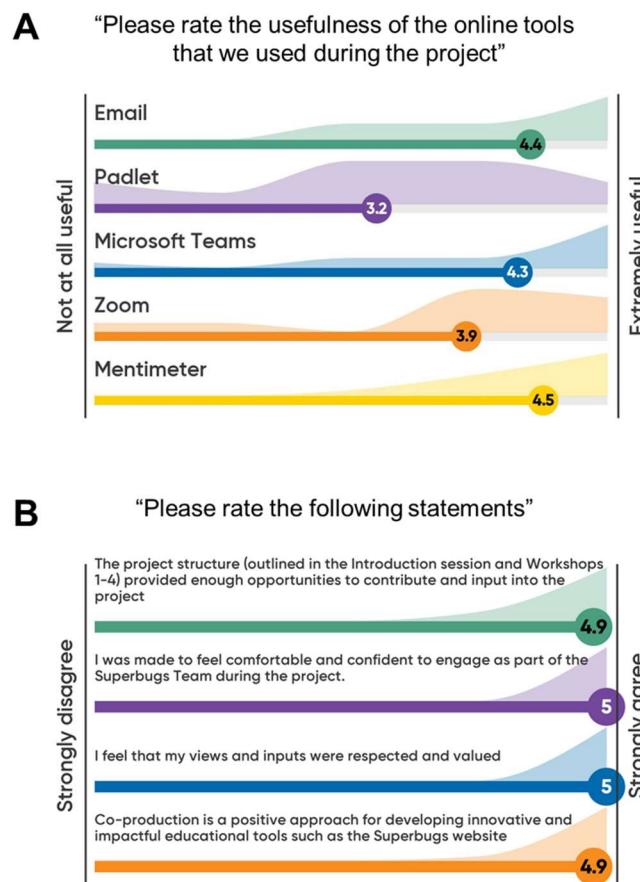
- i) Deliver new digital engagement activities not possible in Superbugs Live events
- ii) Design innovative, fun and engaging tools which complement the needs of our co-producing stakeholders (Key Stage 2/3 children)
- iii) Create lasting relationships with our co-producing stakeholders for legacy impact and mutual benefit



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373 **Figure 2. Co-produced logic model illustrating the relationship between project resources, activities**
374 **and intended impact.** This is based on an initial draft that was amended and expanded during the co-
375 production workshops.

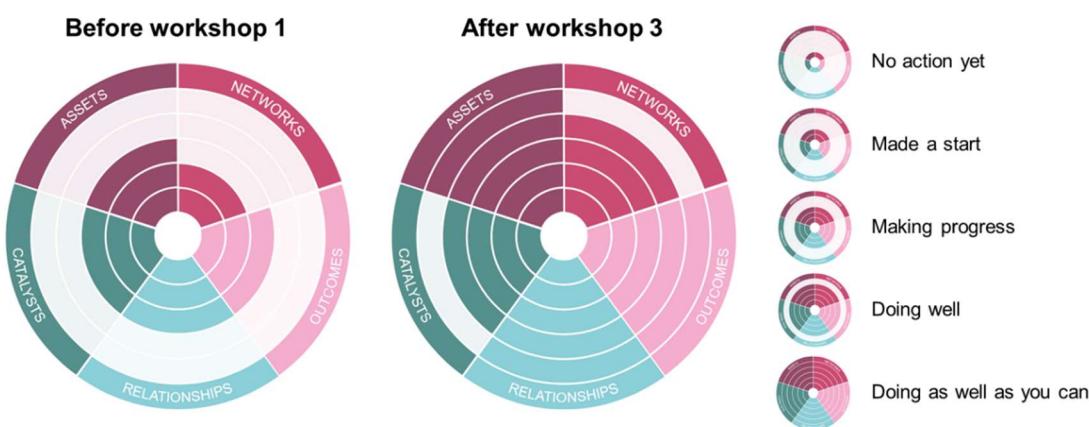
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384 **Figure 3. Evaluation of communication methods via electronic means and self-reflection of teachers**
385 **on the co-production process.** Feedback from 14 primary and secondary school teachers involved in
386 co-producing the Superbugs website was collected during the co-production workshops using
387 Mentimeter. Possible answers and scored ranged from 1: “Not at all useful” to 5: “Extremely useful”
388 (**A**), and from 1: “Strongly disagree” to 5: “Strongly agree” (**B**).
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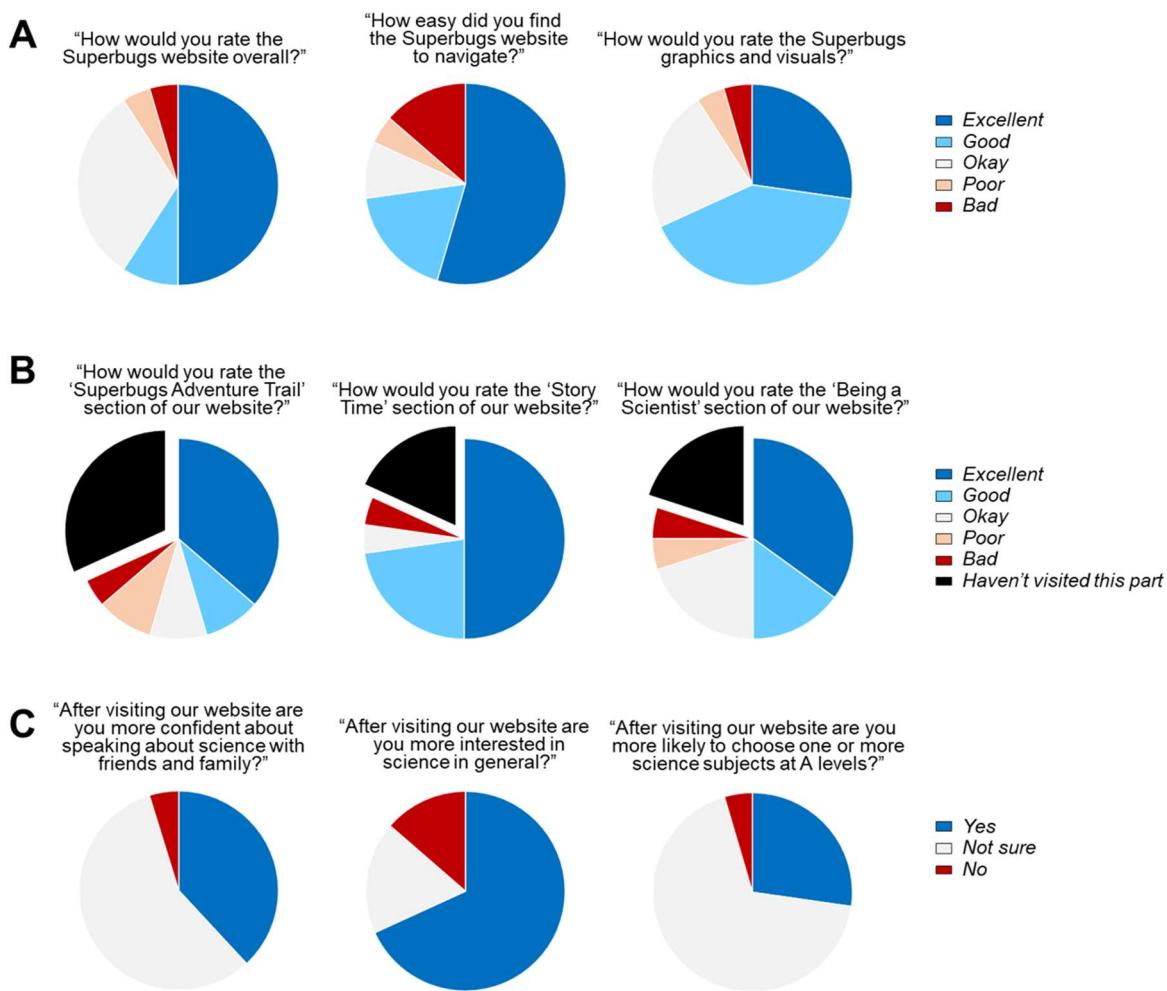


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401 **Figure 4. Outcomes of the self-audit at the beginning and at the end of the co-production process.**
402 Definitions: ASSETS, “*You value all participants and you build on their strengths and resources.*”
403 NETWORKS, “*You develop networks of mutual support.*” OUTCOMES, “*You do what matters for all*
404 *people involved with a focus on outcomes.*” RELATIONSHIPS, “*You build relationships of trust,*
405 *reciprocity and equality by sharing power and responsibility.*” CATALYSTS, “*People are change makers,*
406 *as an organisation your role is to enable this.*” Steps from the centre of the diagram to the periphery:
407 No action yet; Made a start; Making progress; Doing well; Doing as well as you can. This tool was
408 developed by the Co-production Network for Wales (<https://info.copronet.wales/the-self-evaluation-audit-tool>).

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Figure 5. Feedback from pupils attending an English-medium primary school in Cardiff. (A) Overall website rating. **(B)** Ratings of major website sections. **(C)** Personal experience. Data were compiled from the answers given by 22 pupils of the same year 6 class completing the online feedback form in October 2021, shortly after the launch of *Superbugs.online*.

422

423 **10. Author statements**

424 **10.1 Author contributions**

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436

437 **10.2 Conflicts of interest**

438 Geoff Fricker and Kirk Hullis are digital consultants and web designers, and received payments for
439 their work on this project. All other authors declare that there are no conflicts of interest.

440

441 **10.3 Funding information**

442 The development and dissemination of *Superbugs.online* received financial support from the
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448 the Annual Congress of the British Society for Immunology in Liverpool 2021 (M.E.), and the
449 Microbiology Society's Microbiology Outreach Prize 2022 (J.M.T.).

450

451 **10.4 Ethical approval**

452 This study did not classify as research involving human subjects, human material or human data, and
453 as such did not require approval by an appropriate ethics committee. The individuals involved in this
454 project were public involvement representatives and not participants in a research study. All
455 individuals provided verbal consent to take part in the discussion groups.

456

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478

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534 **12. Supplementary information**

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536 See online supplement.