Antimicrobial resistance: a ‘wicked problem’ affecting today’s society

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At the beginning of semester, Chris Browne challenged us to delve further into complex problems, and to pick away at their inherent wicked nature using different disciplines to understand how they behave, rather than superficially accepting their outcome. This challenge was made after discussing the purpose of University and its place in society, with many, including Boulton and Lucas believing that Universities have shifted from a place where interdisciplinary discourse challenges our beliefs, to being a marketable production line pumping out ‘skilled’ graduates and innovation(1). This myopic pedagogical shift has led us to miss the fundamental purpose of University- one that fosters enquiry, one that allows the intergenerational sharing and debate of ideas and thoughts, and one that enables the next generation to tackle ‘wicked problems.’ This leads me to question what I have really gained from University. Despite my learnt knowledge, am I really any better equipped to help tackle the interconnected complex problems facing Australia and the world including climate change, indigenous disadvantage and weight-gain?(2) Consequently, Chris’ challenge to pick away at wicked problems became my personal challenge to try and understand the complex nature of an issue imbedded in my field of research- antimicrobial resistance (AMR).

My aims for this piece were to:
1. Provide a background into Antibiotics and demonstrate evidence of AMR.
2. Explain how AMR has occurred from a biological perspective.
3. Explain how AMR has spread worldwide and is compounded by stakeholders.
4. Draw upon methodologies in the course to suggest future directions to limit AMR.
5. Explain all of these things in laymans terms. I have included diagrams throughout to help communicate complex problems.
A. Background.

Antimicrobial resistance is a ‘wicked problem’

‘Wicked’ problems are highly impervious to resolution, often because they are difficult to define, arise from inter-dependent and multi-causal factors and are socially complex. As a result of their flexibility and instability, ‘wicked’ problems often have unforeseen consequences, making clear solutions difficult to identify. When solutions are evident, they do not sit in one jurisdiction, and often involve changing societal or individual behaviour (2). This report focusses on AMR, a multi-faceted issue having the potential to cause considerable burden of disease worldwide. AMR is a ‘wicked’ problem, due to both its causes and solutions being founded upon the behaviour of multiple jurisdictions at numerous levels of society— from bacteria, to individuals, government and multinational corporations (3). Due to common behaviours associated with these stakeholders driven by lack of education and economic incentives, AMR is currently occurring in society at an exponential rate to the point where we are now at the dawn of a post-antibiotic era (4, 5). For the future, this would mean that the majority of disease causing bacteria are resistant to common antibiotics (4, 5).

Antibiotics: the past and present situation

When one of the first antibiotics, penicillin, was initially widely mass produced in 1945, it’s inventor Alexander Fleming warned society of the danger of over-relying upon antibiotics, as bacteria will naturally seek to develop resistance (6). This draws upon Professor Lindell Bromham’s fundamental principle that natural systems are not inherently driven towards complexity, but instead become more complex in order to diversify and continue surviving in a given environment. Despite this warning and an understanding of the inherent principles in nature, society viewed antibiotics as ‘wonder drugs,’ jumping upon their ability to cure bacterial infections between the 1940s-1960s (Fig.1). The ability of antibiotics to cure infections revolutionised medicine. Unfortunately, their success also caused individuals, society and governments to abandon common sense hygiene and quarantine practices (7). Due to this behavioural shift and the inherent nature of bacteria, we are now again in an era where we are unable to treat some bacterial infections (5, 8). This issue is compounded by a lack of commercial antibiotic development, with no new antibiotic classes being discovered since 1987 (Fig.2)(9).
Although generally estimated and extrapolated from data, the objective evidence for AMR is abundant (4). AMR has been reported in high, middle and low income countries and in both common and reserved antibiotics. In Pakistan, 50-60% of gram-negative pathogens\(^1\) that cause urinary tract infections, such as *E.coli*, have become resistant to commonly used oral antibiotics (10-12). In the USA, 4-6% of hospitals have reported cases of infection caused by gut bacteria resistant to the last resort drug Carbapenem (8). This evidence supports there is increased global bacterial resistance to commonly used and also, alarmingly, last resort drugs. As a result, we have created a post-antibiotic era, where some bacterial infections are now untreatable (4).

\[\text{Figure 1: The impact of antibiotics on bacterial infections. This graph depicts the percentage survival following a bloodstream infection (sepsis) of pneumococcal pneumonia, before and after penicillin treatment was available. As can be clearly seen, penicillin has had dramatic impacts on survival rates in the past, explaining why antibiotics were called ‘wonder drugs’ (5). (Obtained from WHO, 2014).}\]

\[\text{Figure 2: Timeline illustrating the lack of antibiotic discovery since 1987. Following the commercial development of the first antibiotics, there was a splurge of drug discovery in the 1950s-1980s to screen for new antibiotic targets, however, since 1987 there has been a discovery void (9, 13). Given this void, the emergence of antibiotic resistance against reserved antibiotics such as Carbapenems is alarming (10). This discovery void is largely blamed upon the withdrawal of big pharmaceutical companies from antibiotic research (13). However, this void is likely caused by the disengagement and lack of communication between a variety of stakeholders, which need to work in collaboration to stimulate research and development (3). (Obtained from Prasad and Smith, 2013).}\]

\(^1\) A pathogen is any organism that causes disease. Gram-negative and gram-positive is a means to distinguish bacteria based upon their composition, which influences their ability to respond to particular antibiotics (20).
The burden of AMR

Ultimately, antibiotic misuse at every level of society has led to a situation where there are currently no known antibiotics available to treat some strains of multi-drug resistance bacteria (5)(Fig.3). Although poorly quantified, the burden of AMR is thought to be concentrated into three major areas;

i) longer illness duration and increased chance of mortality in patients with resistant infections,
ii) higher costs for treating resistant infections.
iii) inability to perform procedures that rely upon effective antibiotics to prevent infection (4).

This burden is even more extreme in low and middle income countries (LIMC), where poverty limits the ability to fight infections through reduced health and access to expensive ‘reserve’ antibiotics (14). This has led to far worse health outcomes, particularly in neonates (4). As AMR has a considerable impact on society, after examining its complex biological and social causes, this paper will discuss the possibilities for striking a balance between antibiotic usage and access. In doing so, a way forward for this ‘wicked’ problem will be suggested.

Figure 3: The global spread of AMR in 2013 using available data. As can be seen, in numerous countries including Australia (n=89), bacteria have been found to be resistant to more than 5 different combinations of antibacterial drugs. This suggests that AMR is wide-spread. The information here is based upon the World Health Organisation requesting figures from official national sources, and is therefore relatively reliable. Data for the United Arab Emirates is only from Abu Dhabi (5). (Obtained from WHO, 2014).
B. The development of AMR from the biological perspective

**Fundamental causes of AMR**

The underlying causes of the dramatic escalation of AMR in the population are largely due to inherent human nature and learnt behaviours. As Dr. Steven Cork noted in his panel, humans crave simplicity, shunning ‘wicked’ complex systems that are nested, have memory and have complex feedback loops. Likewise, society views antibiotics as an ‘easy fix’ simple solution. As we will discuss however, individual misuse of antibiotics has the potential to affect numerous systems on multiple levels (4). Here, we examine the fundamental mechanism by which antibiotic resistance develops and spreads in bacteria in order to gain insights into its complex causes.

**Interactions between microbes and human hosts**

From birth, the human immune system is exposed to a variety of microbes through the air and food, abrasions and cuts, as well as contact with the surrounding environment (15). Although the majority of these microbes are beneficial, known as commensals, others are pathogens, capable of stimulating disease (16). Throughout our lives there is a complex battle occurring between invading pathogens and a host’s immune system. This ‘tug-of-war’ is dependent upon many factors, including host susceptibility and pathogen activity (15). In addition to competing against our immune system, pathogens have to compete against other microorganisms for limited space and resources on the human body (17). This can be thought of as different stakeholders competing against each other for limited funds. Therefore, like in any business deal, any element that a given bacterial microorganism has which benefits its ability to thrive over any other microorganism is favoured and termed a ‘selective advantage’ (18).

**How antibiotic resistance occurs**

Antibiotics are generally taken because they have the ability to interfere with bacteria’s mechanistic or structural properties to induce bacterial death (19). Antibiotics however impose a selection pressure on bacterial systems (Fig.4). Unfortunately, due to antibiotics being derived from certain types of bacteria, there is inherent resistance against these antibiotics in nature. Resistance may also arise spontaneously (20). Therefore, bacteria that have resistance to this antibiotic are able to thrive and reproduce, creating a ‘success-to-successful’ systems archetype selecting for AMR (4, 21) (Fig.5). Importantly, the propensity for bacteria to transfer resistance genes to other bacterial strains and species means that one event of antibiotic resistance has the potential to quickly spread (Fig. 4) (22).
Figure 4: Simplified mechanism of how Antibiotic Resistance develops in an individual bacterial community. (4.1) There are many bacteria, some of these bacteria are naturally resistant to a drug. (4.2) When you apply this same drug, the antibiotics will kill any susceptible bacteria. Some bacteria do not die though, because they have resistance. (4.3) The resistant bacteria now thrive and reproduce, as they are not competing against any other microorganisms for limited resources (eg. nutrients). (4.4) Bacteria are able to give genes that code for drug resistance to other bacteria, and therefore AMR can rapidly spread (23). (From CDC, 2013).

Figure 5: The success-to-successful systems archetype illustrates how antibiotics place a selection pressure on bacteria, allowing resistant forms of bacteria to thrive. When an individual begins a course of antibiotics, the bacterial community is exposed to an antibiotic selection pressure. Here, bacteria that have resistance to this level of antibiotic have a selective advantage, improving their chance of reproducing, whilst those that are non-resistant are disadvantaged, being less likely to reproduce (4). Thus, simply using antibiotics creates resistance (23). (Figure produced by Rebecca Wardell).
**World-wide spread of resistance**

Individual antibiotic use has the propensity to select for resistant strains, which can then be rapidly disseminated globally. Humans unknowingly propagate this resistance by continuing to use large quantities of antibiotics due to social norms and lack of education (Fig.6) (4). ‘Goldilocks’ conditions therefore occur in which a combination of bacterial strains, individual habits and external factors allow the rapid diaspora of AMR resistant bacterial strains (Fig.6). Metaphorically, resistance can be thought of as a ‘butterfly effect,’ with one resistant bacteria being able to multiply and transmit resistance worldwide, as illustrated in Figure 7. This spread is fuelled by a variety of stakeholders including consumers, prescribers, food-production, hospitals and governments; and is driven by factors including social norms, education and the economy (24).

![Figure 6: The Goldilocks conditions that allow AMR to spread world-wide.](image)

- **Coursework links:**
  - Space and time when discussing the Goldilocks effect.
  - Behaviour of complexity in relation to the butterfly effect.
  - Stakeholder engagement and framing complex problems.
  - Communicating complexity and conditions through figures.

![Figure 7: An example of how antibiotic resistance spreads in the community.](image)

- **Coursework links:**
  - Space and time when discussing the Goldilocks effect.
  - Behaviour of complexity in relation to the butterfly effect.
  - Stakeholder engagement and framing complex problems.
  - Communicating complexity and conditions through figures.
C. The role of key stakeholders in spreading AMR

Antibiotics are unique from all other drug groups, as the effects of their usage have the capacity to extend far beyond an individual. Antibiotic usage and stewardship is a major multifactorial cause contributing to the development and spread of AMR (Fig.8)(4, 26). Given the complexity and delay that exists within this system, the contribution of each stakeholder has been examined in Table 1 to understand how resistance has spread and emerged against so many types of antibiotics. As can be seen in Figure 8 and Table 1, the main stakeholders include; patients/ general community, prescribers, hospitals, agriculture, national governments and the pharmaceutical and technology industries.

Figure 8: The complex, interconnected causes contributing to AMR. Note that no one individual is responsible for AMR spreading world-wide, with AMR developing due to a range of consequential actions from key stakeholders. Overall however, AMR has developed due to all of these stakeholders having the shared belief that antibiotics are disposable commodities. Due to this complacency, we are now in an era where there are no antibiotics remaining that are effective against some bacteria (5). (Figure obtained from Homer et. al. 2000)

Coursework links:
- Behaviour of complexity when discussing the complex system and delay.
- Stakeholder engagement. Table emphasises need for balance and suggests some strategies.
<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Major reasons for perpetuating AMR</th>
<th>Evidence for involvement</th>
<th>Identified leverage points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients and the general community</td>
<td>Irrational antibiotic use due to: • misperceptions, • self-medication, • poor adherence.</td>
<td>Lack of education: • 85% of individuals believe respiratory infections are caused by bacteria. • 87% believed that antimicrobials would be effective and 20% specifically asked their doctor to prescribe antibiotics (28).</td>
<td>Communication: • Science has been unable to effectively communicate when antibiotics should be used (24). eg. NPS medwise campaign in Australia was not effective (29). • Alternative forms of communication eg. art, television and social media may be more effective (30).</td>
</tr>
<tr>
<td>Prescribers and dispensers</td>
<td>Reasons (notably LMIC): • Lack of training, • Lack of knowledge, • Lack of diagnostic support, • Patient demands, • Financial incentives</td>
<td></td>
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<tr>
<td></td>
<td>Reasons vary depending on geographical region, healthcare systems and circumstances (4, 24).</td>
<td>Lack of diagnosis leads to incorrect antibiotics being prescribed: • 63% of antimicrobials prescribed in Chinese study were proven to be ineffective against the disease (31). Economic incentives: In LMIC where physicians are poorly paid, drug companies provide economic incentives to prescribe their drugs (4).</td>
<td>Improved diagnostic support and training: • Improve diagnostic tests and training. This is difficult in LMIC where economic funds are less available (24). Prescription habits: • Achieving a balance between prescribing antibiotics or not is difficult. Diagnostic testing may improve this (24).</td>
</tr>
<tr>
<td>Hospitals</td>
<td>Transmission is the major issue in hospitals. Susceptible patients, prolonged antibiotic usage and contact allows cross infection, making hospitals a breeding ground for AMR. This is amplified in LMIC with poor resources (29, 32).</td>
<td>Transmission: • Studies find hospitals fail to implement proper hygiene practices eg. handwashing before and after patient contact, leading to the spread and cross contamination of resistant strains (29, 32).</td>
<td>Reduce transmission: • Improve hygiene and quarantine practices in hospitals, targeting healthcare workers and community individuals (20). • LMIC should be targeted, with resources provided to contain AMR in hospitals (4)</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Irrational antibiotic use driven by: • Perception that treating livestock with antibiotics improves growth and productivity. • Little separation between the antibiotics used in animals and humans drives community AMR (Appendix figure A) (33).</td>
<td>Irrational use: • estimated that of the 100, 000–200, 000 tonnes of antibiotics manufactured per year, majority used for agricultural, horticultural and veterinary purposes(34). • strong evidence to suggest transmission between livestock and humans may occur at any stage in food system (Appendix A) (35, 36).</td>
<td>Reduce irrational use: • Regulate use of antibiotics in livestock (this has been done in Europe). • Improve hygiene and animal husbandry practices on farms. • Time balance needed to adjust for shift in behaviour (4, 24, 37).</td>
</tr>
<tr>
<td>Governments and healthcare systems</td>
<td>• Non-requirement of antibiotics as prescription medication. • Ineffective law enforcement (38).</td>
<td>Many LMIC have no regulations on antibiotic usage. Counterfeit drugs that provide suboptimal doses are not policed (4).</td>
<td>Legislating requirements for prescription only drugs is difficult in LMIC with inadequate health systems, as prescription only regulations may hinder antibiotic access (4).</td>
</tr>
<tr>
<td>Pharmaceutical and technology industries</td>
<td>• Promotion of antibiotic use onto prescribers and community. • Lack of economic incentive for developing new antibiotics (24).</td>
<td>Drug promotion and development: • Promote drugs directly to public, which may be greater issue in non-prescription countries (24). • Only 1.6% of new drugs in development by 15 largest companies were antibiotics (39).</td>
<td>Regulations and incentives: • Regulate pharmaceutical promotion of antibiotics to prescribers and public (24). • Provide economic incentives for drug companies to develop new antibiotics or alternatives (39).</td>
</tr>
</tbody>
</table>

Table 1: A summary of the key stakeholders involved, their behaviours contributing to the global spread of AMR, and possible behaviours that can be targeted. Some ‘carrot, stick and sermon’ approaches have been identified to potentially target behaviours.
Overarching stakeholder behaviours leading to AMR

Although these stakeholders each contribute to the spread of AMR in different ways, the underlying behaviours fuelling these contributions are the same. Essentially, in the past these stakeholders have shared the belief that antibiotics are disposable commodities. This view has mainly been driven by a lack of education and awareness of the issue, and in the cases of prescribers, farmers and pharmaceutical companies, the search for profit (4). Due to this, each stakeholder promotes systems archetypes that lead to wide spread, multiple drug resistance in bacteria; namely the ‘fixes that fail’ and ‘shifting the burden’ archetypes (Fig.9, Fig.10) (3, 4, 21). In the ‘fixes that fail’ archetype, when an individual is afflicted with an infection, they take antibiotics. However, as discussed, this likely creates antibiotic resistant strains that can spread in the community. Due to the spread of antibiotic resistance, an individual may then take more antibiotics/alternative antibiotics to overcome the infection (Fig.9). As seen in the ‘success-to-successful’ archetype however, this merely perpetuates antibiotic resistance (Fig.5)(4). In the past, if an antibiotic ceases to be effective, the mindset of stakeholders has been to then use an alternative antibiotic, described in the ‘shifting the burden’ archetype (Fig.10)(4). An example of this behaviour is clearly highlighted by the increased usage of the last resort Carbapenem drugs (Fig.11)(40). Although expensive, this drug is widely and increasingly used in LIMC including Egypt, India and Pakistan due to being one of the only antibiotics still effective against some gut bacteria (4, 41). These worldwide behaviours occur at each level of society- from the individual, to the community, to nations, acting as repeated fractals driving AMR (26). In the past, this ‘shifting the burden’ behaviour has provided society with no incentive to look for antibiotic alternatives, or to modify behaviours driving antibiotic resistance (4). This mindset has finally caught up with us however, with some bacteria now being resistant to all available antibiotics (5). Clearly, the archetypal behaviours of all stakeholders at each level of society have enabled AMR strains to spread globally.

Coursework links:
- Behaviour of complexity and framing complex problems when discussing the underlying causes of Stakeholder behaviours.
- Evidence base when providing evidence for this wide-spread behaviour.
- Communicating complex problems by showing graphs for evidence/behaviours.
- Evidence base to provide evidence for these behaviours.
- Space and time when describing how this behaviour is at every level of society.

Figure 9: ‘Fixes that fail’ systems archetype seen in AMR, illustrating how society enables AMR to develop against an antibiotic.

When an individual has a disease, they often take antibiotics. This likely creates antibiotic resistant strains which can spread in the community. In the future, an individual may then take more antibiotics/alternative antibiotics to overcome the infection, as they now have resistant strains of bacteria. This merely perpetuates antibiotic resistance, and leads to individuals then using different antibiotics (seen in ‘shifting the burden’ archetype) (Created by Rebecca Wardell).
Figure 10: The ‘shifting the burden’ archetypical behaviour that has in the past been inherent to stakeholders contributing to AMR. Essentially, when antibiotic resistant bacteria are causing disease in an individual, the disease is treated using an alternative antibiotic. This removes the infection in an individual, and also reduces the incentive to look for fundamental solutions to AMR. Consequently, a multifactorial strategy to combat AMR has not been developed by world governments. Given we are now in an era where we can no longer ‘shift the burden’ of antibiotic usage, new strategies including behaviour modification needs to be adopted (4). (Created by Rebecca Wardell).

Figure 11: Trends in the sales of the last resort antibiotic Carbapenem in a number of countries. Note how sales have dramatically increased in India, Pakistan and Egypt (Obtained from Laxminarayan et. al 2013).
D. A way forward: Limiting and preventing AMR in the future.

Clearly AMR resistance is occurring and has spread globally due to the behaviour of stakeholders driven by lack of education and economic incentives. Because of the severe implications and burden of AMR on our lifestyles, action needs to be taken to curb AMR and develop alternative treatments (4). Behaviour modification will not only limit the spread of AMR, but to some extent may reverse resistance, with three nationwide interventions targeting antibiotic misuse and infection control seeing reductions in levels of some resistant bacteria (42). However, this appears to be highly community and strain dependent with further research required (43). Additionally, with the possibility of new antibiotics and new antibiotic alternatives in the future, improving behaviours should ideally reduce resistance to these new drugs (4).

The need for a global solution

A Global initiative targeting a range of factors including behaviours is required to limit the spread of AMR strains. This is because the spread and development of resistance is dependent upon space and time and involves multiple stakeholders at different levels. The interconnected factors leading to the development and spread of AMR coupled with globalisation means that if action to curb AMR occurs in one country but not another, AMR will still spread. This can be described by the prisoner’s dilemma in game theory, in which two or more countries can either ‘cooperate’ and aggressively fight AMR, or ‘defect’ and invest little in strategies to prevent AMR (eg. hospital infection control) (44). If each country cooperates, all will win. If one defects and free rides on the efforts of other countries, in the short term the defecting country wins. However, in the long term this will lead to other countries ‘defecting’ and efforts to reduce AMR being defeated– a concept known as the Nash equilibrium (44). Therefore, a global initiative is needed, with all countries needing to contribute.

Developing a global strategy with a region based approach

I believe there is a need to develop a global initiative to monitor AMR, but ultimately a region specific approach should be taken. A multi-level, integrative approach suggested by Professor Gabrielle Brammer in her panel would be best, however such an approach must account for the large regional variation in factors contributing to AMR. Currently, there is large variation in resistant strains, antibiotic usage and importantly antibiotic access across the world (5). There is also regional variation in relation to the influence of each stakeholder, as highlighted by prescribers in LMIC being given financial incentives to supply specific antibiotics (4). In the short term, a regional approach would not necessarily be seen as equitable, as it would allow some regions more leniency than others. Importantly however, as Dr. Wayne Morgan asserted in his panel, acknowledging regional ‘difference’ is likely beneficial, as we can then address the needs of each region to ultimately

Coursework links:

- Space and time, stakeholder engagement and behaviour of complexity to assert why a regional approach is necessary.

- Towards a balance and establishing an evidence base to argue for a regional approach.
allow a balance to be achieved. For example, in LMIC that do not have prescription only antibiotic regulations, enforcing stringent regulations currently in place in affluent countries such as Australia would be disastrous. This is because the economic and healthcare feasibility consequences of these regulations may severely limit an individual’s access to antibiotics (24). Therefore, for such regions perhaps instead of applying prescription regulations, other strategies such as hygiene and counterfeit drugs may best be first targeted (4). In the long term, as each region is contributing to stem the spread of AMR, this regional based initiative can balance the usage of antibiotics and therefore limit the spread of resistance. Additionally, global monitoring and initiatives to develop new or alternative antibiotics are also required (4).

The need to educate stakeholders so that a global strategy can occur

Such an initiative requires the commitment of all stakeholders to reduce their behaviours that contribute to the spread of AMR. However, to first develop a shared goal, the issue of AMR needs to be effectively communicated to each stakeholder. Based upon the evidence in table 1, there is a need to educate the public, healthcare workers and farmers about the implications of their actions. Lack of public education is highlighted by studies finding that 85% of individuals surveyed believe respiratory infections are caused by bacteria, and that of these 20% specifically asked their doctor to prescribe antibiotics (most respiratory infections are in fact viral and cannot be treated with antibiotics) (28). This problem with scientific communication extends far beyond antibiotic usage, with the recent science literary report in Australia finding inherent issues with communicating science to the public (45).

Given these limitations, a more humanised approach to this issue is required. One means to do this would be through videos and art, which as JR describes in his TEDtalk can be used to ‘turn the world inside out’ (30). Once the public, healthcare workers and agricultural industries collectively understand the need to change their attitudes towards antibiotics, developing a shared commitment between all stakeholders should theoretically become easier. This draws upon Peter Senge’s Shared Vision approach and also Social Identity Theory. Using social identity theory, if we can shift individual’s from having extrinsic, personal identities to develop a shared social identity, then there is a large opportunity to influence individuals and make wide-scale change. This is because you can develop a superordinate ‘in group’ that has a higher sense of purpose, with more people then wanting to join this ‘in group’ because this is seen as a positive social identity (46, 47). In the context of AMR, this social identity could be to develop positive behaviours to limit AMR development and spread, such as improving hygiene and reducing the use of antibiotics. Complementing this, you can actively pursue a ‘shared vision’ in order to get commitment from all stakeholders to reduce their behaviours (48). In the case of likely reluctant stakeholders such as agricultural and pharmaceutical industries, to obtain this commitment a range of subsidies and regulations in addition to educational approaches could be used (49).

Coursework links:

Here I have discussed why we first need to educate stakeholders about their behaviours contributing to AMR before any solution can be implemented.

- Evidence base, when discussing stakeholder awareness of using antibiotics.
- Communicating complexity, when acknowledging that science has failed to educate society on antibiotic usage. Also, when proposing alternative media for education.
- Stakeholder engagement when discussing how a shared commitment can be engendered through ‘Shared Vision’ and ‘Social Identity’ theories.
- Navigating the future by discussing strategies to develop stakeholder engagement.
**Concluding remarks**

Ultimately, navigating the future of this ‘wicked’ problem is inherently difficult and strategies are filled with uncertainty (49). Nevertheless, given the enormity and implications of AMR, in the coming decade practices and behaviours will likely have to change (5). The degree and rate at which change occurs will be driven by stakeholders, some of whom are currently unaware that AMR is an issue that is already having a detrimental impact upon society (4, 5). Therefore, alternative educational and awareness campaigns are likely the most effective strategy to begin to shift society’s behaviour (45). As new antibiotics or alternatives to them become available at some point in the future, hopefully society will modify its behaviours to prevent this situation occurring again (4).

**Course reflections**

Personally, the Unravelling Complexity course has equipped me with the skills to distil complex problems using a relatively methodological approach. In essence- it has given me methodologies to draw upon in order to accurately express my understanding of complex ideas. For example, before this course I could have explained how antibiotics select resistant strains of bacteria, but if the audience were not from a scientific background they would have been unlikely to understand. I believe that the systems approach has greatly improved my ability to articulate these concepts. I have also included many simplified diagrams throughout to help communicate this complexity. Considering feedback and time delay that Dr. Steve Cork discussed has improved my ability to comprehend the complexity of the problem. In the past I would often look at things as linear, causal factors, but when I add in dimensions of space and time I can quickly appreciate why systems become ‘wicked.’

Additionally, the interdisciplinary thinking and later navigating the future panels helped me recognise that no one problem is defined, devised and solved within one silo. I believe that I addressed this when I suggested that strategies need to humanise AMR, consider a range of factors for each region, and that strategies need to be effectively communicated to the public using alternative forms. This course has also made me reconsider what ‘equitable’ is, which has made me realise that in order to sometimes achieve a balance, equitable strategies do not work. Importantly, this course has helped me to become less naïve, accepting that some problems cannot be easily fixed and may not be fixed in our lifetime. I hope however, that AMR does not fall into this category.
References:

30. JR. 2011. My wish: Use art to turn the world inside out. TEDtalks
45. Wyatt N, Stolper D. 2013. Science literacy in Australia, Canberra
Figure A: How antibiotics used in the agricultural industry can impact on human AMR. Antibiotics fed to animals cause livestock to produce manure and biological solids containing antibiotic residues and AMR bacteria. Through environmental factors such as contaminated surface water, soil, wildlife or irrigation crops, these AMR bacteria can then spread resistance to human beings (Wellington et al., 2013).