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Bridging the knowledge gap: capacity building and education on antimicrobial resistance (AMR)

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Abstract

Purpose – The paper explores how the development of sustainability competences as key components in antimicrobial resistance (AMR) education can contribute to the implementation of AMR policies in practice.

Design/methodology/approach – Higher education is key to promoting sustainability, including sustainable health. Meanwhile, its role and impact are often complicated by unclear educational objectives and a lack of effective strategies. Interdisciplinary, competence-centred education provides a way to address these gaps. AMR presents a sustainability challenge that impacts health, food security and healthcare systems. Using transformative learning theory and a One Health approach, we conducted two participatory research workshops at Zimbabwean universities with researchers and students. The workshops applied UNESCO's sustainability competencies to explore how participants discussed AMR and how these competencies were expressed in practice.

Findings – Findings indicate that effective AMR education and policy implementation include a multifaceted approach, focusing on interdisciplinary collaborations. Efforts need to go beyond minimising antimicrobial use and engage communities and farmers in addressing everyday economic and social challenges. Integrating interdisciplinary collaborations throughout higher education becomes key in creating sustainable and effective AMR education and policy implementation.

Originality/value – The paper contributes original insights on how sustainability competencies can structure AMR education and provide educational objectives for the often underdeveloped aspect of AMR policy. Competence-focused health education can enable the implementation of policy into practice in ways that are contextually relevant and sensitive to local conditions.

Keywords Sustainability, AMR, Education for sustainable development, Sustainable development goals, Policy, Global health

Paper type Research article

Introduction

While higher education has been outlined as key in sustainability educational efforts, including sustainable health, and for achieving the sustainable development goals (SDGs) (Sachs *et al.*, 2019), a recurring challenge is how to realise this potential through clear educational objectives and effective strategies as highlighted by Isac *et al.* (2022) and Muchira *et al.* (2023)

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and referenced in Xiaojing and Chinaza (2024). Competence-centred education has been identified as crucial for enabling students to engage with sustainability challenges (including sustainable health) and the SDGs and to relate these wicked problems to their everyday lives by understanding and critically analysing key concepts in an effort to inform practice (Olsson *et al*., 2020; Xiaojing and Chinaza, 2024). Meanwhile, discussions of the transformative potential of competences have rarely included sustainable health challenges. As interdisciplinary collaborations are argued to be a condition for establishing holistic approaches to address sustainability challenges (Isac *et al*., 2022), competence-centred education faces challenges from the traditional disciplinary silos of higher education as well as the lack of resources and programs supporting educators to develop interdisciplinary skills and engagements around sustainability (Goller and Rieckmann, 2022).

Antimicrobial resistance (AMR) is a growing sustainable health challenge with serious implications for public health, food security and health-care systems, emerging when microbes develop resistance to antimicrobial pharmaceuticals due to overuse of antimicrobials in medicine, veterinary practice, agriculture and livestock raising (Jasovský *et al*., 2016). AMR poses a risk to modern medicine, with higher mortality and morbidity and increased pressures on healthcare systems (O'Neill, 2016; Laxminarayan *et al*., 2016). The World Health Organization (WHO) identifies AMR as a major health threat, predicting that by 2050, mortality will increase to 10 million deaths annually unless addressed comprehensively (WHO, 2021; Jonas *et al*., 2017; Murray *et al*., 2022). AMR poses a significant risk to multiple SDGs, undermining effective treatment of infections and common diseases (SDG 3: Good Health and Well-being) and threats to food security and safety of resistant infections in livestock (SDG 2: Zero Hunger) (UN, 2021). While AMR is increasingly recognised as a sustainability challenge, educational efforts have predominantly focused on individual behaviour and compliance in human health, with less attention given to structural aspects of AMR (Dixon *et al*., 2021; Mickelsson and Simbini, 2025). The prevalence of antimicrobial stewardship, prescription and public awareness campaigns are examples of this tendency. This creates a knowledge gap in terms of the potential role of sustainability competencies in AMR education and an implementation gap in how AMR policy is connected to educational practice. Comprehensive efforts are thus needed globally and nationally to address AMR, including education, working with health practitioners and communities based on a One Health approach interconnecting human, animal and environmental health (WHO, 2021; Velazquez-Meza *et al*., 2022). Educational efforts drawing on a One Health framework have leaned towards coordination and knowledge sharing between different health sectors and knowledge dissemination, while not fully exploring the potential of how to develop competencies of critical reflection and joint action across sectors. Focus has often been on the educational content with less emphasis on how learning can happen ways to support agency to realise change. This paper addresses the identified knowledge and implementation gaps through the integration of transformative learning theory (TLT) with UNESCO's eight sustainability competencies as part of how AMR education can enable the translation of policy objectives into practice.

There is a need to adapt AMR policy and relevant health education to local contextual conditions and needs, particularly in low-resource settings (Chandler *et al*., 2016). In Southern Africa, antimicrobial resistance is disproportionate to actual use and driven by the spread of resistant microbes through underwhelming water and sanitation infrastructure, further exacerbated by the use of antimicrobials in farming, such as small-scale poultry (Murray *et al*., 2022; Moyo *et al*., 2023; Mshana *et al*., 2021). In response to these challenges and calls from the WHO expressed in the Global Action Plan on AMR (WHO, 2015), national action plans have been developed in many countries (ZMHCC, 2017). To implement key objectives of these plans, educational efforts are a foundational pillar for other efforts in addressing AMR, promoting awareness, behaviour changes and equipping societal actors with the knowledge and skills needed to address AMR. Developing competencies among health practitioners and communities to understand, critically engage with and address sustainability challenges is a key part of AMR education and the successful implementation of AMR policies in diverse cultural,

economic and infrastructural contexts (Pacis and VanWynsberghe, 2020). There is thus a need to move research on AMR education beyond descriptive accounts, including investigating how sustainability competencies can enable bridging the implementation gap between AMR awareness and action (Mickelsson and Oljans, 2025b; Oljans and Mickelsson, 2025).

Utilising health education in developing sustainability competencies (UNESCO, 2015) among health practitioners and communities becomes key in contextually relevant implementation of AMR policies in diverse cultural, economic and infrastructural conditions (Sartelli *et al*., 2020). Such health educational efforts come to encompass the raising of awareness among communities to the risk of antimicrobial abuse and the need for preventive practices and strengthening the understanding among health practitioners and policy makers regarding the importance of proper use of antimicrobials in human and animal health as well as the need for water and sanitary infrastructure in limiting the spread of resistance (Rocha *et al*., 2022). Without health education, even the most well-designed AMR action plans risk failing, as the success of AMR action plans hinges on education being fully integrated into the implementation, as educational programs help translate scientific guidelines into practical actions through higher education and social institutions into the everyday practices of health practitioners and communities (WHO, 2015; Fletcher-Miles *et al*., 2020). As such, education as a key component in AMR policy implementation highlights the relevance of SDG 4, Quality education, for addressing AMR as a sustainability challenge (United Nations, 2021). This paper seeks to contribute with a framework that connects AMR educational efforts to sustainability competencies as a comprehensive way to integrate knowledge, critical skills and value reflections to enable engagement with AMR as a complex sustainability challenge.

Key for AMR policy is to strengthen knowledge and agency around sustainability challenges on the part of health practitioners and communities, which can be achieved through education. To make progress towards the policy objectives of addressing the sustainability challenge, AMR education, as health education, focuses on the challenge of AMR need to equip health practitioners and communities with competencies to contribute to addressing AMR in their everyday practices (Glasser and Hirsh, 2016; Sterling *et al*., 2017). Our understanding of competencies draws on Glasser and Hirsh (2016), as constellations of values, skills and knowledges that provide societal actors with needed understandings and abilities to be active participants in critical and futures-oriented transformations in a more sustainable world. These knowledges, skills and values developed as part of such competencies are thus key for societal actors to become drivers and "change agents" in addressing the sustainability challenge of AMR (Wiek *et al*., 2011).

There is thus a gap in how change can be enacted, especially in contexts of limited resources and prevalent structural barriers, making AMR educational policy implementation complex (Mickelsson and Oljans, 2025b). Drawing on sustainability education research and particularly sustainability competencies, we seek to contribute to AMR education, which supports critical reflection and transformative change.

The aim of this paper is to explore how the development of sustainability competences as key components in AMR education can contribute to the implementation of AMR policies in practice. Two research questions are formulated,

(1) What aspects of sustainability competencies are highlighted in workshop participants' discussions on AMR?

(2) How could these competencies, as key components of AMR education, contribute to the implementation of AMR policies in practice?

Theory

In framing the paper, we draw on TLT (Mezirow, 1997, 2000), which provides a robust framework for understanding how individuals develop the competencies necessary for

sustainable development. The WHO's sustainability competencies, such as systems thinking, normative competence and self-awareness, are not only outcomes of transformative learning (TL) but also serve as catalysts for deep personal and societal change. By aligning these competencies with the phases of TL, this study situates and orders them within a progressive pedagogical process that fosters critical reflection, dialogue and strategic action. Such integration is essential for equipping learners to navigate the complexities of global health and sustainability challenges. This framework details how critical reflection can enable deep perspective shifts in learners and provides key tools for engaging with challenging topics (Mezirow, 1997, 2000). Taking TLT further, Clark and Wilson (1991) and Scott (2003) argue for the need to consider how TL occurs in context. The behavioural change thus goes beyond the acquisition of new knowledge to include fundamental revisions of beliefs, attitudes and perceptions on the part of the learner, changing how they act based on these transformed understandings of themselves and the world (Merriam, 2004).

As highlighted by Alam (2021), TLT can contribute with insights regarding the design and implementation of educational interventions and evaluations of learning towards sustainability through the analysis of learning processes, results, and contextual conditions. TL becomes the process of facilitating learners to engage in deep changes to thinking, behaviour and practice that are essential for achieving sustainable development. Learners go from understanding sustainability challenges to taking practical actions that contribute to real-world sustainability. Through developing competencies such as critical reflection, ethical decision-making and collaborative problem-solving, learners are empowered to engage in behavioural change towards more sustainable behaviours, making decisions that are aligned with the SDGs (United Nations, 2015; UNESCO, 2017). These competencies are supported by TL as it enables learners to reflect on deeply held beliefs and adapt them in line with sustainable thinking (Mezirow, 2000; Merriam, 2004; Alam, 2021). To this end, TLT offers an analytical approach to understand how critical reflections can support AMR education and policy implementation, as part of examining how individuals and communities can adopt new practices and attitudes towards the conditions that drive the emergence and spread of resistance as a global health crisis (WHO, 2015; UNESCO, 2017; WHO, 2023).

TLT, coupled with UNESCO's key competences for sustainable development, provides a theoretically deep, critical and action-oriented framing for AMR education and policy implementation. Facilitating the development of competencies, such as critical reflection, systems thinking, collaboration and futures thinking, health practitioners and communities are able to shift their perspectives, generating transformative practices that contribute to addressing AMR. This framework thus links theory and practice through the use of competence-based TL.

Methodology

The study operationalised participatory research workshops as its principal method (Ørngreen and Levinsen, 2017) and used case vignettes as the tool to structure the discussions and promote interdisciplinary collaboration within the workshops.

Case vignettes

Working with case vignettes selected for their narrative potential in exploring dimensions of AMR and AMR policy implementation, participants engaged in interdisciplinary knowledge co-creation (Converse *et al.*, 2015; Payton and Gould, 2022). Vignettes drew on relevant research and real-world experiences with antimicrobial use and resistance in Zimbabwe, with initial drafts of the vignettes being shared with interdisciplinary colleagues familiar with AMR in Zimbabwe. Their feedback was used to improve the vignettes for greater contextual relevance and linguistic clarity. The case vignettes focused on the impacts on health and food security from the usage of antibiotics (AB) and antiretrovirals (ARV) in beef cattle and poultry raising (See Mickelsson and Oljans, 2025a). As such, the two case vignettes addressed

different aspects of the intersections between health, food and AMR, highlighting the use of antibiotics and antiretroviral drugs respectively by small-scale farmers in the line of food production and their impact on the health of humans, animals and ecosystems. The vignettes were closely aligned with the aim of the study, as it facilitated discussion around the complexity of sustainability challenges related to AMR. By presenting case scenarios, the vignettes enabled participants to reflect on and explore how key competencies in AMR education could contribute to the practical implementation of AMR policies.

Participatory research workshops

Two one-day participatory research workshops were held at the Midlands State University, Gweru (provincial capital) and the University of Zimbabwe, Harare (national capital). The study involved 60 interdisciplinary participants, with 10 university lecturers and 20 university students conveniently and purposively sampled from each university (Bryman, 2017). They were recruited based on their experiential encounters from being part of physical, social and institutional environments across such diverse fields as education, veterinary science, medicine, pharmacy, agriculture and environmental science. The selection of participants was considered representative, as it included individuals from institutions and faculties relevant to food safety and public health in relation to AMR. Participants brought expertise from fields such as nutrition, microbiology, veterinary medicine, food technology and public health, ensuring a diverse and thematically appropriate range of perspectives. The selection of participants was based on a holistic understanding of sustainability and health, and encompassing participants from a range of departments and academic disciplines, all sharing an interest in the intersections of health, food, food security, sustainability and antimicrobial resistance. The development and organisation of the workshops focusing on exploring AMR education as a sustainability challenge was built on previous use of the participatory research workshop in research (Mickelsson *et al.*, 2019). The authors co-facilitated the workshops, with note-taking to support transcription provided by colleagues from the respective universities. The vignettes were in the form of written stories that the participants listened to, while the text was displayed on a screen. The workshops followed a protocol of first introducing an overview of AMR as a wicked problem, followed by a first discussion where participants in small groups analysed the vignettes using guiding questions. During a second discussion, participants in the same groups revisited the vignettes using ethical/policy questions, including ethical considerations, responsibility, trade-offs and opportunities for systemic actions to identify interdependencies enacted in the vignettes. The workshops were audio-recorded and transcribed by the authors, supplemented by contemporaneous notes to support the transcription process and enhance the depth and accuracy of the transcripts.

As part of strengthening reliability, both authors coded the transcripts independently using the same analytical framework, supported in transcription and analysis by the contemporaneous notes taken during the workshops. This was followed by joint sessions in which coding was compared, and any differences were discussed with the aim of reaching an agreement for the analysis. Through this process the themes and especially sub-themes were provided further analytical nuance and clarity. To ground the analysis and interpretations in the empirical data, illustrative quotes were used for each theme and sub-theme.

Analytical framework

The analysis utilised a combined deductive-inductive approach, where the deductive top-down approach was used in analysing the collected data, guided by the eight UNESCO key competences for sustainability (UNESCO, 2017), to explore how the development of sustainability competences can contribute to AMR education and policy implementation. Deductive qualitative content analysis is a theory-driven approach, starting with a pre-existing

framework which is applied systematically to the data, allowing for the exploration of specific, predefined themes (Elo and Kyngäs, 2008; Lundy, 2007). In studying the interview transcripts, the analysis draws on previous knowledge and conceptual frameworks, identifying key concepts. In this case, the analysis is grounded in the eight UNESCO sustainability competencies, providing a structured lens through which to examine how participants discuss aspects of these key competencies in developing and implementing AMR policies. Simultaneously, to avoid limiting the analysis to just pre-defined categories, we used an inductive approach to capture unexpected insights in the data. This included conditions specific to the Zimbabwean context that were not accounted for by the sustainability competencies, including concepts of responsibility and gaps between AMR policy and everyday experiences and practices in engaging with AMR. Through the inductive analysis, we were able to characterise partially unexpected aspects as outlined in the 12 sub-themes in Table 2, which provides further nuance to the main themes of the sustainability competences. The UNESCO competencies are interrelated and cut across the SDGs, allowing citizens to interconnect the SDGs as part of efforts in the 2030 Agenda for sustainable development, and encompassing what citizens need in dealing with current complex sustainability challenges (UNESCO, 2017). Through our analysis, we identify aspects of the UNESCO key sustainability competencies, *Systems thinking*, *Anticipatory*, *Normative*, *Strategic*, *Collaboration*, *Critical thinking*, *Self-awareness*, *Integrated problem-solving*, including inductive sub-themes relevant to developing and implementing AMR policies (see Table 2). This combination of deductive and inductive analysis ensures that the analysis remains focused on understanding how aspects of these competences become key parts in AMR education while at the same time identifying unexpected, contextually relevant aspects of AMR education and meaningful implementation of AMR policies. By applying this framework, the analysis seeks to identify both the strengths and gaps in current AMR-related education and policy implementation, offering insights into areas where further development of aspects of these key competences is needed.

The deductive-inductive analysis follows six consecutive steps outlined in Table 1, providing a systematic, theory-driven and contextually relevant analysis. This meant that results are both linked to the global context through the deductive use of the UNESCO sustainability competencies and grounded in the Zimbabwean AMR education context through the inductive analysis.

Ethical considerations

Ethical approval for the study was received from the Medical Research Council of Zimbabwe (MRCZ/A/2920). Principles of informed consent and voluntary participation were adhered to by seeking permission from researchers and students at respective universities, providing them with a consent form and information sheet. These outlined the purpose of the study and workshop as well as the workshop process, including how research data would be collected, documented and managed after the workshop. Furthermore, the voluntary nature of the workshop and study was emphasised, giving the participants the freedom to leave at any point without having to justify their decision. Before signing the consent form, participating researchers and students were provided opportunities to raise questions regarding the research and workshop, with further opportunities offered during the workshop. The study adheres to the global code of conduct for research in resource-poor settings (TRUST, 2018). To provide confidentiality, no participant names were recorded as part of data collection and participant codes were used instead.

Results

With ESD requiring more than the transmission of knowledge and transformation needed in how individuals perceive, reflect and act upon complex global challenges, our analytical

Table 1. Description of the steps of the analysis

Step number	Description of the steps of the analysis
Step 1	We read through the transcribed materials from the workshop discussion multiple times, focusing on poignant statements and interesting ideas expressed by the students
Step 2	In the transcribed Word documents, we identified recurring ideas of interest using systematic colour codes
Step 3	Reviewing the colour-coded documents, we compiled similar quotes from the discussions and used a theory-informed approach based on understanding how aspects of the eight UNESCO competencies for sustainability are expressed in participants' discussions on AMR education as addressing a pressing sustainability challenge. Using comparative readings, we considered the categorisation of quotes into the main theme of *AMR Sustainability Competencies* as well as primary themes and alternative categorisations
Step 4	8 primary themes of the workshop discussions were identified and used to categorise the discussion quotes: *Systemic AMR thinking, Anticipatory, Normative, Strategic, Collaboration, Critical AMR thinking, Self-awareness, Integrated AMR problem-solving*. These were further reviewed and refined in terms of nuance to conduct a more detailed analysis of the data. Through iterative coding and comparison, we distinguished twelve subcategories that reflect recurring patterns and variations within each theme, 12 sub-themes were furthermore identified, including 1) *Understanding of relationships in AMR*, 2) *Complex AMR systems analysis*, 3) *AMR risk assessment in future scenarios, 4) AMR envisioning, 5) Reflections on norms and negotiating sustainability values in AMR, 6) Developing and implementing innovative AMR actions, 7) AMR action at local levels, 8) Learning and empathy for AMR action, 9) AMR conflict resolution, 10) Reflecting on AMR perceptions and practices, 11) Reflecting on roles and responsibilities in addressing AMR, 12) Integrated AMR solutions*
Step 5	As part of this step, themes were re-checked against the empirical materials to make certain that no important aspects of the student's discussions were unaccounted for in the themes
Step 6	To provide readers with convincing arguments for our analysis, illustrative examples were selected from the coded empirical materials. These were aimed at justifying the themes and supporting our analytical results and conclusions. Throughout this final step, the paper's aim and research questions guided the analysis and writing of the analytical report

framework enabled us to operationalise TLT as a powerful pedagogical lens for the progressive cultivation of sustainability competencies. This included emphasising the progress from disorienting dilemmas, critical reflection and dialogic learning to perspective transformation that can lead to meaningful action and reintegration. Drawing from WHO, UNESCO and Wiek *et al*. (2011), the progressive and integrated order of sustainability competencies set by UNESCO was used to analyse workshop discussions on how participants identified and discussed what is needed for developing and implementing AMR in local contexts. Competencies are progressive in the sense that they are mutually supportive and part of an integrated whole, enabling educators to design for pedagogical progression moving from understanding, comprehension, through evaluation, collaboration towards action. The analysis, structured around the eight sustainability competencies, resulted in the categorisation of a main theme, eight primary themes and twelve sub-themes providing further depth and highlighting contradictions and tensions emerging in the discussions (see Table 2). This meant that participants articulated certain competencies as more foundational for AMR education, while others were more linked to specific contextual conditions. As highlighted by the sub-themes, participants highlighted emerging tensions of AMR education and policy implementation, such as between short-term individual needs and long-term communal sustainability and unexpected synergies between conventional and traditional medicine. These competencies are not isolated skills but transformative capacities that enable learners to engage with sustainability challenges in holistic, ethical and future-oriented ways. Transformative learning unfolds through a series of phases that align with the development of sustainability competencies.

Table 2. Outline of the thematisation process

Main theme	Primary themes	Sub-themes
AMR sustainability competencies	*Systemic AMR thinking:* as the ability to recognise and understand relationships; to analyse complex systems; to think of how systems are embedded within different domains and different scales; and to deal with uncertainty	*Understanding of relationships in AMR* *Complex AMR systems analysis*
	Anticipatory: The ability to understand and evaluate multiple scenarios for the future – possible, probable and desirable; to create one's own visions for the future; to apply the precautionary principle; to assess the consequences of actions; and to deal with risks and changes	*AMR Risk Assessment in Future Scenarios* *AMR envisioning*
	Normative: The ability to understand and reflect on the norms and values that underlie one's actions; and to negotiate sustainability values, principles, goals and targets, in a context of conflicts of interests and trade-offs, uncertain knowledge and contradictions	*Reflections on norms and negotiating sustainability values in AMR*
	Strategic: The ability to collectively develop and implement innovative actions that further sustainability at the local level and further afield	*Developing and implementing innovative AMR actions* *AMR action at local levels*
	Critical AMR thinking: The ability to question norms, practices and opinions; to reflect on one's own values, perceptions and actions; and to take a position in the sustainability discourse	*Reflecting on AMR perceptions and practices*
	Collaboration: The ability to learn from others; to understand and respect the needs, perspectives and actions of others (empathy); to understand, relate to and be sensitive to others (empathic leadership); to deal with conflicts in a group; and to facilitate collaborative and participatory problem solving	*Learning and empathy for AMR action* *AMR conflict resolution*
	Self-awareness: The ability to reflect on one's own role in the local community and (global) society; to continually evaluate and further motivate one's actions; and to deal with one's feelings and desires	*Reflecting on roles and responsibilities in addressing AMR*
	Integrated AMR problem-solving: The overarching ability to apply different problem-solving frameworks to complex sustainability problems and develop viable, inclusive and equitable solution options that promote sustainable development, integrating the above-mentioned competences	*Integrated AMR solutions*

Systemic AMR thinking

In the participants' discussions, systems thinking was one of the more recurring competencies. A theme related to systems thinking emerging from the participants' discussions is the *understanding of relationships in AMR*. The quote below highlights how the impact of antimicrobial use in livestock and small-scale farming needs to be understood in terms of how it affects the ecosystem as a whole.

> And also the fact that it also affected the nearby water bodies, the rivers, which ended up killing the fish and affecting the balance of the ecosystem. So, I think it was a disadvantage. I think you're supposed to research first, find out about the consequences. (Workshop 1, Participant 5)

> Yes, he was very much implementing or experimenting because he knew there was a probability in what he was doing. But he didn't know the danger of microbial resistance, which could affect the rest of the community, including people as well. (Workshop 2, Group 1, Participant 2)

As seen in the quotes, there is a need to understand relationships between the animals that are given antimicrobials and the environments they are part of. As these are closely linked, the use of antimicrobials affects more than the animals; it impacts the soil, the water and rivers and by extension the communities where the farmers live. Participants emphasised how antimicrobial use in animals could not be understood in isolation but must be analysed in relation to the ecosystem, water environments, human health and community livelihoods. To this end, developing and implementing AMR policies were framed as requiring the ability to identify and understand these interconnections and how actions and behaviours have results for human, animal and environmental health.

Another theme from the discussion related to the UNESCO competency of systems thinking is *complex AMR systems analysis.* These reflections illustrate how the participants went beyond recognising AMR as a complex systemic challenge to reflect on this complexity and engage with the resulting uncertainty. While participants identified what they perceived as resistance pathways between livestock and humans, they also acknowledged that changes in practices could impact resistance in unexpected ways. As highlighted in the quote below, AMR education for effective policy implementation needs to consider the complexity of the sustainability challenges, which are both intersectoral, including management of healthcare, agriculture and environment, and multileveled, encompassing local, regional and global considerations.

> I think one of the measures that we need to put in is that these different disciplines, health, food, this agriculture should work hand in hand. Different disciplines should work hand in hand, give each other knowledge and pass on knowledge. (Workshop 2, Group 1 Participant 4)

> Even when we're talking about food security, yes, we do engage in those, because for us, in applied food science, it's all about food security, because we need to, like, save food. So, we need to, like, engage with other . . . (Workshop 2, Group 2, Participant 2)

Highlighted by the quotes, the key for AMR education and policy implementation is the ability to analyse the different levels of the intersectoral challenge while accounting for what is not yet known, i.e. new practices involving antimicrobials in humans or animals resulting in the emergence and spread of resistance. Participants framed systems thinking as foundational in the sense that without engaging with these interconnections, new practices and efforts to address AMR risked lacking contextual relevance. Simultaneously, for the participants, the competence also encompassed an emerging tension between acknowledging complexity in AMR education and the need for clear and practice-oriented recommendations for small-scale farmers, communities and policymakers.

Anticipatory AMR competence

Anticipatory competence was in the participants' discussions often linked to risk assessment and envisioning futures, forming the theme *AMR Risk Assessment in Future Scenarios*. As illustrated by the quote, participants discussed how ongoing practices, including antimicrobial overuse in animals, could be envisioned as creating long-term health risks through the spread of resistant microbes in the local community.

> This is because of AMR, when germs that cause disease or infection in humans and the ecosystem leads to change and become resistant to treatment like to those who are already consuming the ARVs for their immune systems. This will lead to the resistance for their medication in their bodies. (Workshop 1, Group 3, Participant 5)

As highlighted, these futures must then be assessed in terms of risks for health and sustainability. A second theme, identified in the participants' discussions, is *AMR envisioning* where communities are empowered to envision situations in which AMR has been successfully addressed.

> Communities need more education and education mainly is to empower them to know their power and value chain so that they can be on the lead to trace what are the inputs and how are they applying and what are the processes are they helping so that they can take the edge (Workshop 1, Gorup 2, Participant 29)

> If we educate our farmers on proper management of antibiotics and everything else in order to come up with good quality meats, we can also improve the health of our communities (Workshop 1, Group 4, Participant 1).

In line with the quote, such a competence encompasses identifying how education is likely to lead to certain desirable outcomes and developing strategies to work towards this vision of sustainable health. Importantly, participants highlighted how envisioning could encompass both futures of risk and futures of possibilities, including using education to empower farmers and communities to become healthier and take a greater role in antimicrobial stewardship. Meanwhile, the discussions highlighted how these more positive visions of the future existed in tension with the immediate conditions of economic pressure and food insecurity, constraining future possibilities. While not as key as systems thinking, participants framed anticipatory competence as necessary to avoid AMR education becoming reactive.

Normative AMR competence

In the participants' discussions, a theme related to normative competence was mentioned in the form of *reflections on norms and negotiating sustainability values in AMR*. The quote below highlights the need to be able to reflect on norms and navigate value trade-offs between long-term health risks and immediate food security, with participants emphasising competing priorities:.

> I think these people that are keeping chickens, they need to be educated on the consequences that they are putting on people, right? So I'm thinking, some people are just ignorant. Yes, you might tell them that these ARVs might cause such problems, but then they can still go on and do it. What people are thinking is we need money. So I think it's best to also talk to the consumers, people should be taught, those who are going to buy should know, don't just buy chickens from anyone, because it might cause this. (Workshop 2, Group 3, Participant 15)

As seen above, negotiating between norms regarding the emergence and spread of resistance (AMR) and the economic benefits of increased livestock growth or cheap meat becomes crucial for AMR education in effective policy implementation in context. This includes setting sustainability goals that are fair and understanding the ethical implications of practices and behaviours, and how different, sometimes conflicting, values are expressed through these practices and behaviours. Therefore, it becomes key to grasp conflicting interests and negotiate between these in situations of uncertainty to make AMR policy contextually relevant. Normative competence thus became, in the participants' discussions, more about ongoing value negotiation rather than specific skills, prompting AMR educational engagements to go beyond individual farmers to consider consumer practices, markets and social values.

Strategic AMR competence

Strategic competence was in the participants' discussions connected to the theme of *developing and implementing innovative AMR actions*. Illustrated by the quote below, participants saw potential for integrating traditional medicine with conventional medical approaches to AMR in creating contextually relevant approaches. Importantly, this did not represent a shift to traditional medicine but rather an effort to generate innovative and sustainable solutions adapted to community needs.

> But if you make a research on the right feeds, you can actually come up with something that can give the same results as the results you obtained from the antiretroviral [antimicrobial] feeds. I think that's a

> better idea than to just venture into something that will cause harm to the ecosystem, cause harm to people. But if you can just make a thorough research on things that do not cause harm, like on the feed, make a thorough selection, I think that's a better idea. (Workshop 1, Group 1 Participant 7)

> So one way which could also help is also to look at more traditional ways of rearing the chickens which do not require those antibiotics. Because definitely, if you're keeping a thousand chickens, ten thousand chickens, for you to actually realize a good profit, you'd have to rely on these antibiotics because of the conditions which are present. Because the health of the chickens will be very compromised by the squalid conditions. (Workshop 2, Group 3 Participant 34)

As seen, such innovative AMR actions respect and draw on the strengths of cultural practices in terms of healthcare access and trust for the community to address AMR. This highlights the necessity to engage and work with local communities in developing and implementing AMR policy to promote sustainable actions locally and nationally as part of AMR efforts. A further theme identified in the participants' discussions is *AMR action at local levels*. As seen in the following quote, AMR education and effective policy implementation involves the ability to act locally.

> [. . .] when it comes to anti-microbial resistance, for us to be able to have good behaviour, it's individual, it's through feeding to the whole society. You find that these behaviours affect these others in particular, how we handle our water sources, our animals, etc. Our environment is affected by how we as a community decide to live in our territory, how we decide to grow our individual area, how we decide to have our health care systems (Workshop 1, Group 2, Participant 11).

> So it's critical what we do in terms of our individual health, in terms of global health, so I think the message, the top message is what we are doing. Is it the right thing? If it's not, we have seen it's not the right thing in some cases, how can we correct that so that we promote good health for our environment and ultimately for ourselves. I think we can move to identifying key knowledge content within your work out and discipline that is crucial in addressing challenges and highlighting issues (Workshop 2, Group 4, Participant 31).

The quotes show that reducing antimicrobial use in livestock animals can be a key local action that contribute to addressing the challenge of AMR both locally and as part of broader mitigation efforts. Strategic competence around AMR was thus more than abstract planning, including identifying practice pathways to enable communities in connecting their ongoing activities to national and global AMR educational goals.

Critical AMR thinking

Critical AMR thinking competence emerging from the participants' discussions in *reflecting on AMR perceptions and practices.* As illustrated by the quote below, participants view the ability to question the shared information, status quo and routine practices while reflecting on the broader impacts of these practices and being able to push for change when required as important.

> There is a lot of misinformation that is going around in this particular community where [the farmer] is located. You know, where people just exchange information informally and misinform each other that, you know, if you use the antimicrobials, chickens will grow. I think, regarding misinformation, maybe the idea is getting the information from social media platforms. (Workshop 2, Group 3, Participant 14)

> It comes with the issue of adopting a strategy without enough information. It's just like saying, oh, my neighbour is doing this, let me also do that. There's no scientific basis for what [the farmer] was doing. So in the long run, it's not just going to affect you and your family, it's now affecting the local communities, it's affecting the population. (Workshop 2, Group 3, Participant 3)

Highlighted is how the use of antimicrobials in healthy animals often have broader implications, making it essential to reflect on how we view the use of antimicrobials and their benefits and risks for not just ourselves but the communities we are part of. As such, being able to reflect on perceptions and practices is, according to the participants, key for both the

effectiveness and the ethical soundness of AMR education and policy implementation. Critical thinking becomes highly relevant because it involves the ability to question assumptions, evaluate evidence and make balanced judgments in complex and uncertain situations. It illustrates not only the intellectual skill of problem analysis but also the practical competence of making responsible, informed choices in situations where the consequences extend beyond the individual to national or even global health.

AMR collaboration

Collaboration competence was discussed by the workshop participants as encompassing *learning and empathy for AMR action*. As seen in the following quotes, they emphasised the necessity to engage diverse stakeholders, farmers, health practitioners, interdisciplinary academics, communities and government officials as part of AMR education and policy implementation.

> One of the measures that we need to put in is that these different disciplines, health, food, this agriculture should work hand in hand. Different disciplines should work hand in hand, give each other knowledge and pass on knowledge (Workshop 2, Group 1, Participant 14).

> So I'm thinking most probably [the farmer] was not aware of the consequences. So I think we should have people who go out there teaching people who are into farming. So they teach them on how they feed their cattle, what not to give their cattle, because it might not be a force. She was just trying to make her heard grow bigger. So we need people to be educating the farmers. (Workshop 2, Group 2, Participant 3)

Highlighted by the quotes, stakeholder engagements should be characterised by collaboration and mutual respect and empathy to be able to understand and integrate the different stakeholders' perspectives and needs regarding addressing AMR. Collaboration thus encompasses both co-learning among stakeholders and the facilitation of participatory knowledge creation and problem-solving to address AMR. However, in the emphasis on collaboration, there was also tensions as participants highlighted how uneven power relations between farmers, communities, academics and government officials impact collaboration on equal terms.

A second theme emerging in the discussion was *AMR conflict resolution*. As highlighted by the quote, to develop and implement AMR policy requires the ability to manage conflicts between more short-term individual needs for economic and food security and the longer-term health interests of both the individual and the community.

> I think [the farmer] is much worried about the short-term effects of what he is actually doing. So in the short-term, yes, she is managing the situation like she is preventing. He is working on the unknown future that probably the cattle will get this bacteria. So there is always a trade-off to this. He is improving the food security, the production of the meat and the like. But in the long run, it is going to be a challenge especially to the consumers. So in the short run, yes, he is doing fine from a business perspective. But looking at the sustainability issues, it is not sustainable health-wise. Because eventually it will have a trade-off effect to human health. (Workshop 2, Group 2, Participant 26)

As seen above, this illustrates an recurring tension with the immediate pressures of having food on the table and sending children to school, risking to crowd out the more societal challenge of reducing antimicrobial use and avoiding the emergence and spread of resistance. Based on participants' discussions, it is thus key for collaboration to include joint dialogues and negotiating trade-offs to find common ground, while simultaneously acknowledging that addressing AMR in ways that consider all stakeholders equally will sometimes be a challenge.

AMR self-awareness

Self-awareness competence was expressed by the workshop participants as a theme related to *reflecting on roles and responsibilities in addressing AMR*. Showcased by the following quote,

participants highlighted the key importance of understanding what one's own role is in driving resistance and responsibility to address AMR. From the discussion, this includes recognising the impact of decisions and practices beyond immediate surroundings.

> The consequences that are going in the name of competition, of wanting to have a bigger chicken and getting more money. Of the ethical consideration down in the community level, in houses, so that they can understand what they are doing to each other, because you're now affecting your own community, just because you're going to get more money. (Workshop 2, Group 3, Participant 18)

As seen above, participants emphasised a central tension in the need to weigh the immediate economic gains from giving antimicrobials to farming animals against long-term health risks associated with AMR for both the individual and society. This raised questions regarding accountability and shared responsibilities in AMR education. While it is important to recognise individual roles and responsibilities in addressing AMR, participants also brought attention to the role of communities and systemic factors to contextualise self-awareness and make it meaningful in relation to AMR. AMR self-awareness as a competence thus requires us all to engage in evaluation of our decisions and practices and to motivate ourselves to align these decisions and practices with the common good of addressing AMR.

Integrated AMR problem-solving

A theme related to critical thinking competence emerging from the participants' discussions is *integrated AMR solutions*. As highlighted in the following quote, the ability to integrate multiple ways of knowing AMR becomes key in AMR education and policy implementation

> Embracing different stakeholders. From medicine, from agriculture, from health. We come together as one group which we call a community of practitioners. Whereby each stakeholder brings in expertise about a component of what we want to solve. Be it a traditional medicine in order to cure whatever is being treated by the antibiotics. (Workshop 2, Group 3, Participant 1).

Participants emphasise the need to combine traditional and conventional medical knowledge and practice as the basis for collaborative approaches to address AMR and provide viable and sustainable solutions. Linked is the theme of locally adapted AMR approaches, which the participants express as considering community conditions, needs and priorities, illustrated in the quote below.

> Chicken is now in the backyard. Everyone owns a chicken business, almost everyone. I understand his frustration when you're saying that there was competition, because in the high density three, out of five houses sold chickens. That's when you can start addressing the ethical considerations. We need to get down into the community level, because that's where most chickens are being sold today. (Workshop 2, Group 3, Participant 18)

As seen, such approaches become important to AMR education and policy implementation as they offer holistic perspectives on problem-solving that consider the contextual conditions of communities in promoting effective AMR management. This theme can be described as the competence to connect knowledge across disciplines, stakeholders and levels of action in order to address the complexity of antimicrobial resistance. Furthermore, it highlights the ability to synthesise diverse sources of information, navigate conflicting interests and co-create strategies that are both scientifically sound and socially feasible. This competence illustrates not only technical problem-solving skills but also systems thinking and the capacity to collaborate across sectors, which is essential in tackling a "One Health" challenge such as antimicrobial resistance.

Discussion

The paper sought to explore how the development of sustainability competences as key components in AMR education can contribute to the implementation of AMR policies in

practice. We operationalised TLT to bridge the implementation gap between knowing and doing through the developing of a sustainability competence-based framework for AMR education.

The results outline a multifaceted approach to AMR education and policy implementation, built on interdisciplinary collaborations and deeply rooted in communities' contextual conditions and needs. Through the developing an understanding of how sustainability competencies can be integrate in AMR education the identified knowledge gap is addressed, while illustrating how these competencies, operationalised using TLT to support educational practice contributes to the closing the implementation gap. This was key for the paper intention to provide a framework that integrate TLT and UNESCO sustainability competencies. The paper thus makes a conceptual contribution in linking TL with sustainability competencies while also providing an framework for AMR education as a practical contribution. TL provides a pedagogical framework through which sustainability competencies can be cultivated. As learners encounter disorienting dilemmas and engage in critical reflection and dialogue, they begin to internalize sustainability values and develop the capacity to act strategically. As such, TLT guides the bringing of the knowledge gap by connecting AMR awareness and understanding with abilities of context-relevant and reflective decision-making. Each competency aligns with a phase of TL, reinforcing the need for educational approaches that foster deep, value-driven change. The paper is thus providing an framework for educators to use in operationalising sustainability competencies as part of transformative AMR education. Through the papers' framework, a structured approach is outlined which shifts AMR education towards competence building, emphasising how competences are build on the basis of systems thinking, collaboration and self-reflection while AMR policies are contextually adapted to educational practices through strategic and normative competencies. Three main outcomes from the results include a) the development of a competence-based framework for transformative AMR education and b) highlighting the possibilities of drawing on interdisciplinary collaborations and co-creation to bridge the implementation gap between knowledge and practice. While explorative, the results highlight how AMR education policies are shaped by contextual conditions, including water and sanitation and economic pressures. This indicates that these conditions need to be considered as part of developing sustainability competencies and interdisciplinary collaborations. Interdisciplinary collaborations throughout higher education, from medicine and veterinary sciences, through agriculture and dietetics, to education are thus all components of sustainable, effective and ethical AMR education and policy implementation (Wallace *et al*., 2016; Chandler *et al*., 2016; Rawson *et al*., 2020; Velazquez-Meza *et al*., 2022; WHO, 2021).

A key topic cutting across the themes identified in the results is the need for sustainable AMR efforts that take a long-term transformative perspective. TLT enables participants to shift from awareness to decision-making, fostering agency and critical reflection. Utilising a TLT framework (Mezirow, 1997, 2000), we argue that such sustainable efforts involve co-learners, academics across disciplines, critically reflecting on their knowledge and practices as part of societal norms. Transformative co-learning can thus generate shifts in perspectives on AMR and how the challenge can be addressed in practice (Clark and Wilson, 1991; Taylor, 2007; Scott, 2003). The results highlight how the implementation gap can be addressed through the integration of TL as part of AMR education, allowing the contextualisation of AMR challenges and co-creating ways to implement AMR policy. In the Zimbabwean case, the feasibility of such shifts in practice appears to rely on the ability to make affordances for structural challenges, including infrastructural limitations and resource scarcity. As highlighted in the paper, both agriculture and healthcare emerged as key in preventing the emergence and spread of resistance, addressing the underlying drivers of AMR (O'Neill, 2016). Crucially, these efforts need to go beyond prescriptive directives on minimising the use of antimicrobials by engaging communities and farmers around their everyday economic challenges (Goutard *et al*., 2017). The results highlights how sustainability competencies when integrated with TLT can contribute to bridging the implementation gap between

knowledge and practice and as a conceptual framework form the basis for developing competence-based AMR educational efforts. Systems thinking in relation to AMR thus becomes an emergent practice linking participants antimicrobial prescriptions, livestock use and the health of local water ecosystems and communities. This highlights the importance of engaging with local practices and practitioners, which form a key component of the everyday realities that form the context for AMR education. Furthermore, results suggested the value of drawing on interdisciplinary research to identify and explore alternative methods for health promotion and disease prevention in livestock animals, as well as futures thinking to envision future challenges and opportunities in addressing AMR (Littmann and Viens, 2015; Laxminarayan *et al*., 2016; United Nations, 2021).

Applied to health education as part of higher education, engagements beyond and across disciplinary silos and interdisciplinary collaborations could be enabled by operationalising TLand One health approaches as part of competencies-centred sustainability education, contributing to achieving SDG 2, 3 and 4 (Sachs *et al*., 2019; Goller and Rieckmann, 2022). As highlighted in the results, the identified aspects of the UNESCO competences provide educational objectives and effective strategies as part of the development of these competences (Isac *et al*., 2022; Muchira *et al*., 2023; Xiaojing and Chinaza, 2024). Furthermore, the results emphasise the role of competences in providing higher education students with concrete avenues for critically and reflectively engaging with AMR and how these reflections can inform their practices (Olsson *et al*., 2020; Xiaojing and Chinaza, 2024). While preliminary, the results illustrate the potential value of curricula that enable students to engage with structural aspects of AMR, including resource scarcity and health inequalities. As part of supporting novel cross-sectoral practices, curriculum and educational modules could be developed that connect case-vignette supported learning with interdisciplinary projects that include students from health, agriculture, veterinary sciences, as well as education. This could be productively supported by establishing interdisciplinary curriculum committees on sustainable health challenges, such as AMR, which encompasses agricultural and veterinary lecturers in addition to those working in medicine.

Related to the relevance for health education is the need for collaborative efforts where AMR education and policy implementation are a whole-society affair, involving stakeholders across disciplines and sectors. Through collaboration that is supported by the government and NGOs, AMR policies and by extension health policies, can become effective, inclusive and critically supported by the health practitioners, farmers and communities that are set to implement them (World Health Organization, 2015; Murray *et al*., 2022; WHO, 2021). The results indicate that policy adaptation would need to extend beyond technical solutions to developing sustainability competencies as capacity-building for health practitioners in navigating structural challenges of AMR. Based on the results, important policy contributions would include integrating sustainability competencies as part of the national AMR action plan, as well as drawing on these competencies in AMR policy implementation. In adapting policy to structural conditions in Zimbabwe, competencies could be used in training future practitioners to actively engage with the structural challenges of AMR, such as limited water and sanitation.

Furthermore, a community-centric approach is presented as crucial in AMR education and policy implementation. This includes developing an understanding of communities' incentives, needs and priorities, and how practices contribute to the emergence and spread of resistance, for human, animal and environmental health (Bloomfield *et al*., 2017). Communities thus develop agency in making responsible decisions on antimicrobial use (Chandler *et al*., 2016). The results highlight the potential value of engaging multiple ways of knowing and doing AMR as a productive starting point for furthering AMR education. An example would be to integrate traditional practices around raising livestock and the use of traditional medicinal plants to promote health and prevent disease in animals (Lam *et al*., 2021). A societal implication supported by the papers' results would be to couple sustainability competencies with community engagement approaches, to have universities working together with communities in co-developing locally relevant approaches to AMR (Khumalo *et al*., 2024).

From the previous cross-cutting topics, practical strategies for health policy implementation through health education focused on AMR can be outlined. Integrating traditional medical practices of health promotion and disease prevention with conventional AMR efforts in both humans and animals has the potential to constitute a comprehensive strategy for lessening the dependence on antimicrobials (Van Boeckel *et al*., 2019). Contextual adaptation of AMR policies in particular and health policies in general to fit the economic, social and environmental conditions of local communities would, for example, acknowledge and consider the practices of small-scale farmers and the challenges they face (Robinson *et al*., 2016). These can be brought together in AMR and health education and policy implementation by focusing on collaborative systems for monitoring antibiotic use and resistance patterns in local contexts, extending to traditional medical practitioners and local communities. Community-level monitoring and reporting would generate feedback loops in which information from the community level informs ongoing policy development, implementation and revisions (WHO, 2021). Such efforts could build on citizen science approaches that use low-cost digital reporting platforms (Mickelsson *et al*., 2024). This would enable communities, small-scale farmers and community health practitioners to document antimicrobial use, water and sanitation challenges and local cases of infections and resistance. Reporting could furthermore provide valuable input in adapting and developing national AMR efforts and priorities. These topics could provide generative avenues of further research.

To support replication and future development, the presented framework could be extended to different educational settings by mapping sustainability competencies to contextual AMR educational objectives, pedagogically designing educational activities informed by TLT and evaluating competence development among students and policy implementation as part of AMR education using participatory research methods. This approach would enable researchers and educators to adapt the framework to diverse settings thus testing the relevance of the proposed framework and further develop it.

Conclusion

This paper explored how the development of sustainability competencies as key components of AMR education can address identified knowledge and implementation gaps, contributing to the linking of AMR policies to practice. Drawing on the UNESCO key competencies for sustainability, the papers' results suggest that AMR education benefits from an sustainability competences-based interdisciplinary and inter-sectoral approach, where societal actors can collaborate to address the sustainability challenge of AMR. The paper illustrates how integrating sustainability competencies with TLT could inform and structure AMR educational objectives, informing how policy can be implemented as educational practices. TL is thus connected to sustainability competencies as part of the presented through educational competence development and policy implementation. By developing comprehensive sustainability competencies, including understanding relationships, risk assessment and envisioning, and reflections on norms and values, the identified knowledge gap can be addressed by providing conceptual depth regarding how sustainability competencies can be integrated with TLT as a conceptual framework for AMR education. The paper highlights ways to develop curriculum and educational modules across disciplines that embed sustainability competencies and TLT as part of addressing AMR challenges by developing and learners' critical reflection, collaboration and context-relevant decision making. In terms of policy, the paper indicates how integrating sustainability competencies and TLT as a key part of AMR national policy and action plans could further the adaptation of education to the structural conditions and realities in Zimbabwe, strengthening adaptive AMR policy implementation. Implications for the framework also extend to economic benefit of limiting antimicrobial dependency, improving animal health and supporting sustainable practices among small-scale farmers as part of AMR management. The research can inform AMR policy implementation by highlighting the importance of cross-sectoral competencies

and educational approaches that support sustainable decision-making. It can be used in teaching to develop critical thinking around AMR governance, guide policymakers in designing inclusive strategies and contribute to research by deepening understanding of the social dimensions of AMR challenges.

In terms of societal implications, linking sustainability competencies with community engagement and citizen science approaches could enable university-community partnerships to develop localised antimicrobial and AMR monitoring and reporting systems, with education facilitating action on AMR. Through explicitly outlining how transformative education centred on sustainability competencies can bridge the gap between AMR educational policy and practice, the paper outlines the potential for adaptive, contextually relevant and adaptive AMR policy implementation. These contributions suggest potential areas for further empirical and conceptual research, especially regarding how sustainability competencies are articulated in diverse contextual conditions.

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