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Bridging the gap: integrating One Health and Responsible Research and Innovation into medical education in Chad

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Abstract

In Chad, where daily interactions among humans, livestock, and ecosystems are central to livelihoods, health challenges require integrated and context-sensitive approaches. The burden of infectious diseases, including malaria and zoonoses, is compounded by environmental changes and fragile health systems. This paper proposes a structured framework for integrating One Health (OH) and Responsible Research and Innovation (RRI) into medical education. Beyond conceptual integration, it emphasizes the governance, institutional transformation, and contextualization of RRI within local socio-cultural realities. By combining the 5 RRI keys (public engagement, gender, open access, ethics, science education) with its four strategic dimensions (anticipation, reflexivity, inclusiveness, responsiveness), the proposed framework promotes a shift toward socially embedded, transdisciplinary, and ethically grounded medical training. The expected outcomes include improved clinical reasoning, stronger research relevance, enhanced community trust, and the development of health professionals capable of navigating complex socio-ecological systems. Ultimately, this approach contributes to strengthening health system resilience and advancing equitable, sustainable healthcare delivery in Chad and similar Sahelian contexts.

Key words: One Health; Responsible Research and Innovation; medical education; Chad; zoonoses.

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Introduction

The imperative for a transdisciplinary shift

Chad faces a complex and evolving public health landscape characterized by a dual burden of communicable diseases and emerging threats driven by environmental, demographic, and socio-economic changes. Malaria remains the leading cause of morbidity and mortality, accounting for more than 30% of healthcare consultations in several regions and disproportionately affecting children under 5 and pregnant women.[1] Alongside malaria, zoonotic diseases such as rabies, brucellosis, bovine tuberculosis, and viral hemorrhagic fevers continue to pose significant but often underrecognized public health challenges.[2,3]

The epidemiological profile of Chad is deeply shaped by its socio-ecological context. A large proportion of the population relies on pastoralism and agro-pastoralism for subsistence, resulting in constant and close interactions between humans, livestock, and wildlife. This dynamic creates a high-risk zoonotic interface, facilitating the transmission of infectious agents across species barriers.[4] In Sub-Saharan Africa, it is estimated that over 60% of emerging infectious diseases are zoonotic in origin, highlighting the critical importance of integrated surveillance and response systems.[5] Environmental changes further exacerbate these risks. The progressive shrinking of Lake Chad, coupled with recurrent droughts and climate variability, has led to population displacement, increased competition for natural resources, and the concentration of humans and animals around limited water sources.[6,7] These conditions favor the spread of zoonotic and waterborne diseases and contribute to the growing threat of antimicrobial resistance (AMR), driven by the widespread and often unregulated use of antibiotics in both human and veterinary sectors.[8,9]

Despite this complexity, medical education in Chad remains largely hospital-centered and discipline-specific, with limited integration of environmental and animal health considerations into clinical reasoning. This siloed approach is increasingly inadequate for addressing complex or "wicked" health problems that require coordinated, multisectoral responses.[10]

In this context, the One Health (OH) approach provides a relevant framework by promoting an integrated understanding of the interconnections between human, animal, and environmental health. Complementing this, Responsible Research and Innovation (RRI) introduces an ethical and societal dimension, ensuring that research and innovation processes are aligned with local needs,

cultural values, and societal expectations. Promoting RRI was a major strategy of the *Science with and for Society* work program of the European Union's Horizon 2020 Framework Programme for Research and Innovation. Beyond its global definition, RRI must be understood as a contextualized approach, particularly in Chad, where traditional knowledge systems, cultural beliefs, and community practices significantly shape health behaviors. Therefore, integrating RRI into medical education requires not only adopting international frameworks but also adapting them to local epistemologies and societal expectations. Furthermore, RRI operates at multiple levels: conceptual, operational, and governance-related, and represents a paradigm shift in how knowledge is produced, shared, and applied within society.

The integration of RRI into medical education can be structured around its 5 foundational keys: public engagement, gender equality, open access, ethics, and science education (Figure 1),[11] often integrated with the sixth overarching key of governance.

In addition, the four dimensions of RRI – anticipation, reflexivity, inclusiveness, and responsiveness – provide a strategic framework for guiding educational reform and institutional transformation in dynamic contexts such as Chad.[10,12,13]

This combined OH-RRI framework is particularly relevant in malaria-endemic settings, where host genetics and environmental exposure interact. In addition to zoonotic diseases, antimicrobial resistance is another critical challenge that requires an integrated, context-sensitive approach. Together, these frameworks provide a foundation for an interdisciplinary (among scientific disciplines) and transdisciplinary (among scientific disciplines and other local knowledge) approach to health, enabling the training of future physicians who are not only clinically competent but also capable of addressing the broader socio-ecological determinants of health in Chad and similar Sahelian settings. Furthermore, in the field of biosciences, RRI offers a valuable framework to better understand and manage the complex interactions among scientific knowledge, societal needs, and local contexts. Through public engagement, interdisciplinary collaboration, and advanced research training, such as PhD programs, RRI contributes to strengthening the capacity to anticipate, understand, and respond to emerging health challenges.

Materials and Methods

A phased curricular integration model

This study adopts a conceptual and implementation-oriented methodological framework aimed at integrating OH and RRI into undergraduate medical education in Chad. The proposed approach is based on a phased curricular integration model that combines curriculum analysis, faculty capacity building, and pilot implementation, while taking into account the constraints and opportunities of a resource-limited setting. To operationalize the proposed OH curriculum, a structured semester-based training program is outlined in Table 1.

The first phase involves a systematic curriculum mapping and needs assessment. This process consists of reviewing the existing medical curriculum to identify potential entry points for the integration of OH and RRI concepts, particularly within core disciplines such as infectious diseases, parasitology, microbiology, public health, and medical ethics. The analysis aims to highlight gaps in current training, especially regarding zoonotic diseases, environmental determinants of health, and ethical considerations in research and innovation. In parallel, consultations with key stakeholders, including faculty members, curriculum committees, and relevant institutional authorities, are essential to ensure alignment with national health priorities. This phase also supports the development of a competency-based framework to define expected learning outcomes, such as the ability to understand the human-animal-environment interface, apply RRI principles, and engage in transdisciplinary collaboration.

The second phase focuses on faculty development and capacity building, which are critical for the successful implementation of curricular reform. Interdisciplinary training workshops should be organized to bring together educators from medical, veterinary,

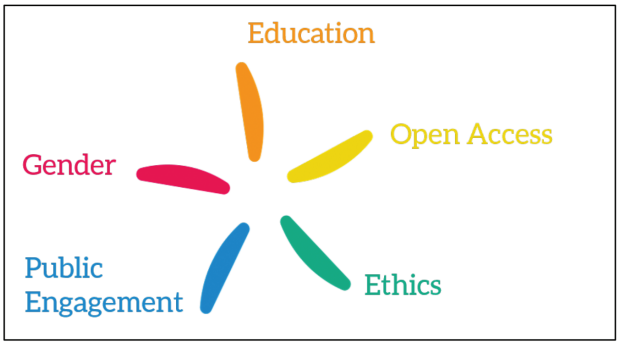

Figure 1. Five key pillars of RRI as depicted in the Structural Transformation to Attain Responsible BIOSciences (STARBIOS2) logo. *Retrieved from: https://starbios2.eu/*

Table 1. Proposed One Health and RRI integrated curriculum.

Week	Module topic	Key concepts	RRI/OH integration
1-2	Foundations	History of One Health in Africa; keys and dimensions of RRI	Defining the Chadian health landscape
3-4	Zoonotic interface	Epidemiology of brucellosis and Rift Valley fever	Ethics: management of shared human/animal data
5-6	AMR & innovation	AMR in humans and livestock	Innovation: local antibiotic stewardship strategies
7-8	Climate & health	Impact of Lake Chad recession on waterborne diseases	Public engagement: community-led water management
9-10	Field rotation	Mixed human-veterinary health post-exposure	Gender: roles in pastoralist health systems
11-12	Research seminar	Thesis design using RRI principles	Open access: publishing for the Global South
13-14	Final assessment	Transdisciplinary case study defense	Joint evaluation (medical and veterinary faculty)

RRI, Responsible Research and Innovation; AMR, antimicrobial resistance.

environmental, and social science backgrounds. These workshops aim to strengthen understanding of OH and RRI principles while promoting collaborative teaching approaches. Training-of-trainers programs are particularly important to ensure sustainability and local ownership of the initiative. In addition, the development of innovative teaching tools, such as eco-clinical case studies and simulation exercises, will facilitate the practical integration of these concepts into teaching activities. Given infrastructure limitations, the use of digital platforms and open-access educational resources is recommended to support continuous professional development and improve access to up-to-date scientific knowledge. The third phase consists of a pilot implementation through the introduction of structured "One Health Tracks" within the clinical years of medical training (years 4-6). This phase integrates OH and RRI principles into existing clinical rotations using active and experiential learning approaches. Students are engaged in case-based and problem-based learning activities that incorporate clinical, veterinary, and environmental perspectives, using locally relevant scenarios such as zoonotic outbreaks, antimicrobial resistance, and climate-related health issues. Furthermore, community-based research and field exposure are central components of this phase, allowing students to observe the human-animal-environment interface directly in rural and peri-urban settings. Through supervised field placements, students conduct health assessments and interact with local communities, including pastoralists and traditional leaders. Interdisciplinary clinical rotations, involving collaboration among medical, veterinary, and environmental students, further enhance the development of teamwork and systems thinking. To ensure the effectiveness and sustainability of this integration, a monitoring and evaluation framework is incorporated into the methodology. This includes the assessment of student knowledge and competencies before and after implementation, evaluation of interdisciplinary collaboration, and measurement of student and faculty satisfaction. Continuous feedback mechanisms are also essential to refine the curriculum and adapt it to evolving local needs and constraints.

The proposed model not only targets curricular reform but also requires organizational transformation within academic institutions. Educational innovation must be supported by institutional policies, governance structures, and incentive systems that promote interdisciplinary teaching and socially responsible research.

Finally, the entire integration process is guided by RRI principles. This includes respect for cultural diversity, recognition of local knowledge systems, and active community engagement in both educational and research activities. Particular attention is given to promoting equity, including gender-sensitive approaches, to ensure that the benefits of this educational reform are inclusive and socially responsive.

Implementing responsible research and innovation in the Chadian context

In the Chadian healthcare and research landscape, the integration of RRI is not merely a theoretical consideration but a practical necessity. Incorporating RRI into medical education provides a framework through which future physicians and researchers can develop context-sensitive solutions that respond to the country's specific health challenges. Within this framework, the central elements are ethics and local ownership. In Chad, research activities have historically been influenced by external actors, sometimes resulting in what is described as "parachute science", where data are collected without sustainable benefits for local communities. RRI addresses this issue by promoting research practices that prioritize national health priorities and strengthen local capacity. Medical students should therefore be trained to design and conduct research protocols that respect cultural norms, ensure equitable partnerships, and contribute to long-term health system strengthening. This approach fosters a sense of responsibility and ownership among local researchers and institutions, thereby enhancing the relevance and sustainability of scientific outputs.[14]

Other key components are public engagement and science literacy. In many regions of Chad, biomedical knowledge coexists with traditional beliefs and practices, which significantly influence health-seeking behaviors. As such, future physicians must be equipped not only with scientific knowledge but also with strong communication skills to engage effectively with diverse populations. Medical education should emphasize the role of the physician as a mediator between scientific evidence and community perceptions and knowledge. This includes the ability to explain complex concepts such as zoonotic transmission or antimicrobial resistance in culturally appropriate ways. Furthermore, RRI encourages the co-creation of health interventions, where communities are actively involved in the design and implementation of research and public health programs, thereby increasing their acceptability and impact.

Open access and gender equality represent additional critical aspects of RRI, particularly in low-resource settings such as Chad. Access to scientific knowledge remains uneven, limiting the ability of students and researchers to engage with global scientific discourse. Promoting the use of open-access resources and encouraging local publication practices are essential steps toward democratizing knowledge and strengthening research autonomy. At the same time, gender equality must be integrated into both research design and healthcare delivery. This involves ensuring equitable participation of women in research activities, as well as addressing gender-specific health needs that are often overlooked. By incorporating these principles into medical education, RRI contributes to a more inclusive and socially responsive health system.[13]

Institutional and organizational transformation

The integration of OH and RRI into medical education cannot be achieved solely through curricular reform; it requires a broader transformation of research and teaching organizations. Such transformation is essential to ensure coherence between educational practices, research priorities, and institutional governance.

This transformation includes several interrelated elements. First, institutional alignment is necessary to ensure that teaching, research, and governance share common objectives and are guided by national health priorities. Second, consensus-based planning plays a critical role, requiring the active engagement of faculty members, administrators, and external stakeholders in the design and implementation of educational reforms. Capacity building is another central component, focusing on the development of interdisciplinary competencies among educators and students. In parallel, the establishment of incentive systems is essential to support sustainable change. This includes the recognition of transdisciplinary teaching, the integration of RRI criteria into academic evaluation frameworks, and the creation of career incentives for community-engaged and socially responsive research.

From an RRI perspective, these elements contribute to strengthening governance, inclusiveness, and reflexivity within academic institutions, thereby facilitating a more responsible and context-adapted approach to medical education. In resource-limited settings such as Chad, approaches like the responsible management approach can support implementation by optimizing the use

of existing resources, reinforcing institutional commitment, and promoting adaptive and sustainable organizational practices.

Pedagogical strategies for One Health integration

The effective integration of OH and RRI into medical education in Chad requires a shift from traditional didactic teaching toward active, learner-centered, and transdisciplinary pedagogical approaches. These strategies are essential to equip students with the competencies needed to understand and address the complex interactions between human, animal, and environmental health.

Problem-based learning represents a central component of this pedagogical transformation. By using eco-clinical case studies that reflect real-life situations in the Chadian context, students are encouraged to move beyond a purely biomedical perspective and adopt a systems-thinking approach. These cases integrate clinical symptoms with environmental exposure and animal health factors, enabling students to analyze health problems through the lens of the human-animal-environment interface. This approach enhances critical thinking, diagnostic reasoning, and collaborative problem-solving skills, which are essential for managing zoonotic diseases and emerging health threats. An example of a transdisciplinary case-based intervention plan is presented in Table 2.

In addition, the integration of RRI principles within these pedagogical approaches strengthens the ethical, social, and participatory dimensions of medical training, and students are encouraged to critically assess their role as future healthcare professionals and to engage with communities in a culturally sensitive and socially responsible manner.

Changing teaching methods represents a focused "grounding action", but it inevitably triggers broader transformations. These include improved access to scientific knowledge, strengthened national and international collaborations, integration of theoretical and applied learning, and the development of hybrid teaching models combining academic instruction with field-based experience. These transformations highlight the interdependence between educational reform and institutional evolution, emphasizing that pedagogical innovation must be supported by organizational change to ensure long-term sustainability. Field-based interdisciplinary rotations further strengthen this learning process by providing students with direct exposure to the zoonotic interface in rural and peri-urban settings. Through supervised placements, students observe firsthand the interactions between communities, livestock, and ecosystems, particularly in pastoral and agro-pastoral environments. These experiences allow them to contextualize theoretical knowledge, understand local health practices, and engage with community stakeholders. Such immersive learning is particularly valuable in Chad, where socio-cultural and environmental factors play a major role in disease transmission dynamics.

In addition, interdisciplinary seminars serve as a platform for fostering dialogue and collaboration across different fields of expertise. Regular seminars involving medical professionals, veterinarians, environmental scientists, and social scientists allow students to explore complex health challenges from multiple perspectives. Topics such as AMR, which lies at the intersection of human health, animal health, and environmental factors, are particularly relevant in this context. These seminars not only enhance students' understanding of transdisciplinary health issues but also promote the development of a common language across disciplines, which is critical for effective collaboration in real-world health systems.[6] A practical example of an AMR stewardship strategy integrating One Health and RRI principles is shown in Table 3.

Challenges and sustainability

The integration of OH and RRI into medical education in Chad faces several key challenges, particularly those related to limited resources and institutional resistance. Financial constraints, inadequate infrastructure, and restricted access to educational tools may hinder effective implementation. However, these barriers can be mitigated through context-adapted, low-cost strategies such as interdisciplinary partnerships, shared training programs, and the use of open-access digital resources.

Institutional resistance also represents a significant obstacle, as some faculty members may perceive OH as an additional burden rather than an added value. Reframing OH as an approach that strengthens clinical reasoning and improves diagnostic accuracy is therefore essential to facilitate its acceptance and long-term adoption.

Despite these challenges, sustainable integration is achievable through strong institutional commitment, continuous faculty development, and alignment with national health priorities. In this

Table 2. One Health transdisciplinary intervention plan (brucellosis case).

Sector	Action required	Responsible party
Medical	Initiate 6-week antibiotic treatment and monitor liver function	Medical student/physician
Veterinary	Test livestock for *Brucella melitensis* and implement vaccination	District veterinarian
Environmental	Assess water quality at shared water sources	Environmental officer
Sociological	Educate community on boiling milk and safe practices	Community health worker

Table 3. One Health-based AMR stewardship strategy.

Sector	Action required	Responsible party
Medical	Use WHO AWaRe "Watch" antibiotics only when necessary	Pediatrician/medical student
Veterinary	Train herders on antibiotic withdrawal periods	Veterinary officer
Policy/ethics	Establish a local antimicrobial stewardship committee	Public health researcher
Lab/innovation	Develop low-cost antimicrobial sensitivity tests	Biomedical engineer

AMR, antimicrobial resistance; AWaRe, Access, Watch, Reserve.

perspective, sustainability is not only a matter of resources but also of governance and collective engagement.

In this regard, RRI provides a relevant framework to support sustainability by promoting a shared governance model that involves not only researchers but also communities, policymakers, and civil society actors. This aligns with the "Quadruple Helix" model, where innovation emerges from interactions between academia, government, industry, and society. Furthermore, mutual learning processes and international networking play a crucial role in reinforcing this transformation. By fostering collaboration, knowledge exchange, and adaptive learning, these mechanisms contribute to the long-term sustainability and scalability of OH-RRI integration in medical education in Chad.

Expected outcomes

The integration of OH and RRI into medical education in Chad is expected to generate significant improvements at multiple levels of the healthcare system.

At the clinical level, one of the primary anticipated outcomes is improved diagnostic accuracy. By incorporating environmental and animal health considerations into clinical reasoning, future physicians will be better equipped to identify zoonotic diseases and complex infectious conditions that are often misdiagnosed in conventional hospital-centered approaches. This enhanced diagnostic capacity is particularly relevant in the Chadian context, where overlapping symptoms between diseases such as malaria, brucellosis, and other febrile illnesses frequently complicate clinical decision-making.

At the societal level, the integration of RRI principles is expected to foster increased trust between healthcare providers, researchers, and local communities. By promoting public engagement, transparency, and culturally sensitive communication, this approach encourages active community involvement in both healthcare delivery and research processes. As a result, medical interventions and research initiatives are more likely to be accepted, adhered to, and sustained over time, thereby improving their overall effectiveness. At the health system level, the combined OH-RRI framework is anticipated to strengthen national health systems through enhanced multisectoral collaboration. By training future physicians to work alongside veterinarians, environmental scientists, and public health professionals, this approach supports the development of integrated surveillance systems and coordinated responses to public health threats. Such collaboration is essential for addressing cross-cutting challenges, including zoonotic disease outbreaks, antimicrobial resistance, and the health impacts of climate change.

In addition to these clinical, societal, and systemic benefits, the integration of OH and RRI is expected to contribute to broader institutional and research-related outcomes. These include strengthening institutional resilience, improving research governance and accountability, and fostering locally driven innovation ecosystems that are better aligned with national priorities and community needs.

Discussion

The integration of OH and RRI into medical education in Chad represents a critical and timely response to the increasing complexity of public health challenges in the country. The Chadian context, marked by a strong interdependence between human, animal, and environmental health, highlights the limitations of traditional, discipline-specific medical training. Addressing these challenges requires a systemic transformation of educational approaches toward more holistic and transdisciplinary models.

The findings of this conceptual framework suggest that incorporating OH into medical curricula enhances students' ability to understand and manage diseases within their broader ecological and socio-economic contexts. In settings such as Chad, where zoonotic diseases and environmentally driven health risks are prevalent, this expanded perspective is essential for improving diagnostic accuracy and public health responsiveness. By integrating environmental and animal health considerations into clinical reasoning, future physicians are better prepared to identify complex disease patterns that may otherwise remain undetected in conventional clinical approaches.

In parallel, the integration of RRI provides an ethical and societal dimension to medical training, ensuring that research and innovation processes are aligned with local needs and values. In many low-resource settings, including Chad, there is a growing recognition of the need to move away from extractive research models toward more inclusive and participatory approaches. RRI addresses this by promoting principles such as public engagement, transparency, and local ownership of research. This not only enhances the relevance and acceptability of scientific outputs but also contributes to building trust between communities and healthcare systems. Similar applications of RRI in public health research have been reported in other settings, including genomic surveillance of arboviruses in Brazil, highlighting the global relevance of this approach.[15]

Importantly, the combined OH-RRI framework fosters the development of systems thinking among medical students. This cognitive shift enables them to move beyond reductionist biomedical paradigms and engage with the complexity of health determinants, including climate change, mobility, socio-economic inequalities, and cultural practices. Such competencies are particularly valuable in the Sahelian context, where health challenges are deeply intertwined with environmental and societal dynamics.

The implementation of transdisciplinary pedagogical strategies, such as problem-based learning, field-based training, and interdisciplinary collaboration, further reinforces these competencies. These approaches not only improve knowledge acquisition but also enhance critical thinking, teamwork, and communication skills, which are essential for effective health system functioning. Moreover, exposure to real-world contexts through community-based learning allows students to better understand local health realities and adapt their interventions accordingly.

Despite these promising perspectives, the integration of OH and RRI into medical education is not without challenges. Structural constraints, including limited financial resources, insufficient infrastructure, and restricted access to educational tools, may hinder implementation. In addition, institutional resistance to change may slow adoption, particularly when new approaches are perceived as additional burdens rather than enhancements. However, these barriers can be mitigated through context-adapted strategies, including faculty development, incremental curriculum integration, and the use of open-access resources and digital platforms.

Ultimately, this study underscores that integrating OH and RRI is not merely an academic innovation but a strategic investment in the future of healthcare in Chad. By training physicians capable of working across disciplines and engaging meaningfully with communities, this approach contributes to the development of more resilient, inclusive, and sustainable health systems. It also positions medical education as a key driver of health system transformation

in response to both local and global health challenges.

From this perspective, the integration of RRI further highlights the need for a renewed "grammar of responsibility"[16] within medical education and health systems. This involves clarifying key questions such as who is responsible, for what, at which level (individual, institutional, or systemic), and according to which criteria responsibility is assessed. In the context of medical training, this expanded notion of responsibility redefines the role of future physicians not only as clinicians but also as researchers, educators, and socially accountable actors operating within complex systems. It also calls for greater institutional accountability, where universities and research organizations actively support ethical, inclusive, and socially responsive practices. Embedding this broader understanding of responsibility into both educational and organizational frameworks ultimately strengthens the coherence, relevance, and sustainability of the OH-RRI approach in Chad.

Conclusions

In the context of Chad's complex and evolving health landscape, the physician of the 21st century must transcend traditional clinical boundaries and act as a bridge between biomedical practice, environmental realities, and societal needs. The integration of OH and RRI into medical education offers a strategic pathway to achieve this transformation. By fostering transdisciplinary competencies, ethical responsibility, and community engagement, this approach equips future physicians with the skills required to address emerging health challenges, including zoonotic diseases, antimicrobial resistance, and climate-related risks. Ultimately, the integration of OH and RRI is not only a pedagogical reform but also a transformative governance process, reshaping the relationship between science, society, and health systems in Chad.

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