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Abstract

This study explores how One Health, which connects human, animal, and environmental health, can be integrated into Austrian secondary education through interdisciplinary lessons combining biology and English. Three lessons on microbes, infections, and antibiotic resistance were developed and implemented in five classes. Using action research, materials were adapted based on student feedback, with scaffolding and digital tools supporting comprehension and engagement. Results suggest that both younger and older students benefited, highlighting the potential of interdisciplinary teaching to foster scientific literacy and awareness of global issues. The study also emphasizes the importance of embedding One Health in teacher education to support sustainable, transdisciplinary learning.

Keywords: One Health; action research; CLIL; biology education; scaffolding; teacher education

1. Introduction and Overview of the Study

1.1. Positioning the Study Within the Landscape of Science Teacher Action Research

Despite widespread recognition of One Health as a framework for addressing interconnected global challenges, from zoonotic disease to antimicrobial resistance, its integration into secondary school curricula remains limited (Hobusch et al., 2024; Villanueva-Cabezas et al., 2022). This represents a significant educational gap: students are rarely given the opportunity to engage with the interdisciplinary thinking that One Health requires, and teachers are seldom equipped to facilitate it (Haxton et al., 2015). At the same time, research shows that secondary students commonly hold misconceptions about core One Health topics such as microbiology and antibiotic use, misconceptions that go unaddressed when these topics are not part of the curriculum (Byrne & Grace, 2018; Carson et al., 2018; Cals et al., 2007).

This project addresses two further significant gaps identified in recent literature on science teacher Action Research (AR). Feldman et al. (2024) highlighted the disproportionate emphasis on interactive and technical approaches in published AR, while teacher-centered projects remain underrepresented. Furthermore, there is a notable lack of AR projects with political purposes, despite calls to foster science education that not only informs but also



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empowers students to engage critically with issues of equity, justice, and sustainability (Feldman et al., 2024; Grundy, 1987).

This study contributes to both areas. First, it is distinctly teacher-centered: the teacher-researcher (first author of this paper) independently initiated the project, designed the interdisciplinary One Health lessons, conducted the classroom implementation, and led the data collection and reflection processes. The integration of biology and English through a CLIL (Content and Language Integrated Learning) approach, while also creating scaffolding materials, further supports its categorization as teacher-centered research. Second, the study is explicitly political. It addresses pressing socio-scientific issues, such as antibiotic resistance, industrial farming, and global health inequities, through the lens of One Health and Education for Sustainable Development (ESD). In doing so, it aligns with the vision of AR that seeks not only to improve practice, but also to transform educational structures and empower learners to become agents of change (Grundy, 1987; Hobusch et al., 2025).

By centering health literacy and ecological responsibility within the curriculum, this project demonstrates how teacher-led AR can support both pedagogical innovation and political consciousness, which contributes to a necessary shift in science education towards more transformative practices (Feldman et al., 2024).

1.2. Aim and Contribution of the Study

This study aims to investigate how the One Health concept can be integrated into Austrian secondary school education through interdisciplinary, CLIL-based lessons combining Biology and English. Specifically, it develops, implements, and evaluates three lessons addressing microbiology, infection prevention, and antibiotic resistance across two implementation rounds in five classes. By doing so, it contributes to both educational practice and research in three interrelated ways.

First, it provides one of the few empirically documented examples of One Health being embedded in a secondary school curriculum in the German-speaking context. Despite its recognized importance, One Health remains largely absent from Austrian school curricula (Hobusch et al., 2024), and teacher education programs play a pivotal role in changing this (Haxton et al., 2015; Hobusch & Froehlich, 2021). A handful of classroom initiatives in Austria illustrate that One Health themes can be flexibly embedded across a range of subjects and school types, underscoring the approach's curricular adaptability (Hobusch et al., 2023). By developing and testing materials aligned with existing curricula, this study addresses the gap between One Health's recognized relevance and its limited classroom presence and contributes to broader efforts to integrate One Health into school-based ESD (UNESCO, 2020).

Second, the study exemplifies a teacher-centered and politically purposeful form of action research, two qualities that Feldman et al. (2024) identify as underrepresented in published science education AR. The project was initiated by a pre-service teacher who designed, implemented, and evaluated the lessons during her practicum and first year of regular teaching, demonstrating how early-career teachers can use AR not only to improve individual practice but to contribute to broader curricular change.

Third, by situating the project within the Teaching Clinic framework at the University of Vienna (Froehlich et al., 2021; Hobusch et al., 2025), this study illustrates a replicable model through which teacher education can institutionalize reflective, inquiry-based curriculum innovation. The findings aim to inform both the future design of One Health lesson materials and the integration of research-oriented teaching formats into pre-service teacher education, with implications for the broader D.A.CH. (Germany, Austria, Switzerland) context and beyond.

1.3. Research Questions

Building on the identified gap and the study's aims, three research questions guide this inquiry:

- RQ1: How does the implementation of cross-curricular One Health lessons influence students' understanding and awareness regarding microbiology and antibiotic resistance?
- RQ2: To what extent do learning outcomes differ between classes, and what factors may account for these differences?
- RQ3: What is the impact of CLIL-based teaching materials on students' engagement with One Health topics?

2. Theoretical Background

2.1. One Health as an Integrative Approach for Sustainability in Education

The One Health concept views human, animal, and environmental health as interconnected, emphasizing interdisciplinary collaboration (Hayman et al., 2023; Jørgensen & Neves, 2020; Redican & Akpınar-Elci, 2021; Ruckert et al., 2020; Wilkes et al., 2019). Particularly in education, its integration offers a promising approach to raising awareness of global health challenges and promoting holistic thinking (Atusingwize et al., 2020). These challenges, among others, include zoonoses and antimicrobial resistance (D. C. Jones et al., 2023; Mettenleiter, 2021). The COVID-19 pandemic exposed weaknesses in healthcare systems and environmental policies, emphasizing the importance of early education in fostering informed citizenship (GPMB, 2024; UNESCO, 2020).

Addressing these complex issues requires education that moves beyond mere knowledge transmission and promotes critical thinking and sustainability-oriented action (Hobusch et al., 2025; Sandri, 2022; Steiner & Rauch, 2013). At the same time, the pandemic revealed the fragility of public trust in science, caused by flawed science communication and the rise in misinformation (Eitze et al., 2021; Kanning, 2022; Schröder & Eckstein, 2022). However, public trust is essential for effective prevention (Eitze et al., 2021; GPMB, 2024).

International organizations such as the World Health Organization (WHO), Food and Agriculture Organization of the United Nations (FAO), United Nations Environment Program (UNEP), and World Organization for Animal Health (WOAH) have developed a joint action plan to strengthen global health capacities and support the achievement of the Sustainable Development Goals (SDGs) (Pitt & Gunn, 2024; Zaman et al., 2023). These goals are closely linked to Education for Sustainable Development (ESD), which encourages critical thinking, and future-ready competencies among learners (Riess et al., 2022; UNESCO, 2020). As part of SDG 4, ESD seeks to promote lifelong learning and global responsibility through interdisciplinary curricula and participatory teaching methods (Lotz-Sisitka et al., 2022; Shapiro Ledley et al., 2017).

Despite its potential, One Health remains underrepresented in educational contexts, as is the case in Austria (Hobusch et al., 2024). Nonetheless, a handful of classroom initiatives in Austria illustrate that One Health themes can be flexibly embedded across a wide range of subjects and school types, underscoring the approach's curricular adaptability (Hobusch et al., 2023). Educational institutions, especially teacher training programs, play a crucial role in introducing the One Health concept into future curricula (Haxton et al., 2015). Thus, preparing teachers to integrate One Health into school curricula can foster cross-disciplinary learning and strengthen the interconnectedness of health, environmental protection, and education (Hobusch & Froehlich, 2021; Lotz-Sisitka et al., 2022; Riess et al., 2022).

2.2. One Health as a Framework for Global Health

One Health, through its interconnectedness of human, animal, and environmental health, emphasizes the need for interdisciplinary collaboration across sectors such as public

health, veterinary medicine, agriculture, and environmental science (Hayman et al., 2023; Jørgensen & Neves, 2020; Redican & Akpınar-Elci, 2021; Ruckert et al., 2020; Wilkes et al., 2019). This integrated approach seeks to sustainably balance and optimize the well-being of all three domains (Mackenzie & Jeggo, 2019).

It operates across three interconnected levels: individual, population, and ecosystem (Lerner & Berg, 2015). At the individual level, it encompasses issues such as zoonotic transmission from pets or contaminated food; at the population level, it includes public health and herd immunity; and at the ecosystem level, it emphasizes biodiversity, water systems, and habitat integrity (Fletcher et al., 2009). Coordinated action across these levels (locally, nationally, and globally) is at the heart of the One Health vision (Aslam et al., 2021; Hayman et al., 2023).

The increasing urgency of climate change and its health implications has made this interdisciplinary collaboration more critical than ever. Environmental changes contribute to rising zoonotic risks, linking the well-being of ecosystems, wild and domestic animals, and humans (Rushton et al., 2018). Effective surveillance of emerging diseases and zoonoses is therefore essential for preventing future pandemics (Atusingwize et al., 2020; Vicente et al., 2021), alongside the development of research programs, policy frameworks (Baum et al., 2017) and educational efforts that promote early awareness and understanding of One Health.

2.3. Environmental and Social Drivers of One Health

To appreciate the importance of One Health education, it is first necessary to understand the environmental processes that drive many contemporary global health threats. Human activity, including deforestation, urbanization, and pollution, has reshaped landscapes and increased contact between humans and wildlife (GPMB, 2024). Such changes raise the risk of zoonotic spillover events. The COVID-19 pandemic served as a global wake-up call, showing how quickly pathogens can spread in a globalized world (Gallagher et al., 2021; Jørgensen & Neves, 2020).

It is estimated that roughly 75% of emerging infectious diseases originate in animals, particularly wildlife (Redican & Akpınar-Elci, 2021; Strupat & Marschall, 2020). Climate change also contributes to disease spread, as temperature and humidity shifts create favorable conditions for disease vectors like mosquitoes (Pitt & Gunn, 2024).

Moreover, unequal access to healthcare, safe food, and hygiene, often due to socioeconomic disparities, further heightens vulnerability to zoonoses (GPMB, 2024). Gender inequality compounds these challenges. During pandemics, women face increased exposure as caregivers and suffer more from economic disruption and lack of medical access (GPMB, 2024). Thus, social justice and equity are crucial dimensions of One Health (United Nations, 2015). These examples also illustrate why One Health is inherently political, as addressing such challenges requires policy decisions on public health, environmental protection, food systems, climate action, and the equitable allocation of resources.

This interconnected nature of One Health challenges underlines the importance of equipping future generations with the scientific literacy, systems thinking, and awareness needed to understand and address complex global health issues. Education therefore plays a central role in preparing students to contribute to more informed and sustainable decision-making.

2.4. Antimicrobial Resistance (AMR) and One Health

One of the most pressing examples of the interconnected challenges addressed by the One Health approach is antimicrobial resistance (AMR). It poses a global threat similar to pandemics. It results from the over- and misuse of antibiotics in both human medicine and animal husbandry, which drives bacterial evolution and increases treatment failures (Aslam et al., 2021; D. C. Jones et al., 2023). This problem is worsened by factors such as

wastewater contamination, antibiotic overuse in livestock (D. C. Jones et al., 2023; McEwen & Collignon, 2018), as well as uncontrolled use of antibiotics by humans (Aslam et al., 2021). Even in countries where antibiotics are prescription-based, improper application is widespread: patients often discontinue treatments prematurely or self-medicate later, which promotes the development of resistance (Schulz & Nakamoto, 2012).

Antimicrobial resistance has therefore been classified by organizations such as the WHO and the International Monetary Fund (IMF) as one of the greatest global health challenges of the 21st century (Aslam et al., 2021). It also threatens food safety and progress toward achieving the Sustainable Development Goals (McEwen & Collignon, 2018; WHO, 2024). The situation is especially alarming given estimates that global antibiotic consumption could double by 2030 if no major changes are made (D. C. Jones et al., 2023; Klein et al., 2018). Moreover, AMR is estimated to cause over a million deaths annually and could lead to 10 million deaths per year by 2050 if left unaddressed (WHO, 2024).

Preventive strategies are crucial and include the development and use of vaccines and comprehensive public education campaigns on hygiene and the responsible use of antibiotics (Aslam et al., 2021; Lipsitch & Siber, 2016). Given the role of human behavior and decision-making in the spread of resistance, it is essential to educate the public about AMR, starting in schools, raising awareness, fostering responsible practices, and empowering future generations to contribute to a sustainable and health-conscious society.

2.5. One Health in Education and Sustainable Development

Embedding One Health into education is therefore central to fostering long-term resilience. It supports the United Nations Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being), SDG 4 (Quality Education), and SDG 13 (Climate Action) (Strupat & Marschall, 2020; UNESCO, 2020; United Nations, 2015). Education for Sustainable Development (ESD) promotes critical thinking, interdisciplinary learning, and action competence (Lotz-Sisitka et al., 2022; Riess et al., 2022). For this, schools and universities are key to raising awareness and instilling systems thinking. As Hobusch et al. (2025) argue, developing these competencies requires practical, inquiry-based learning formats like the Teaching Clinic, where future teachers engage directly with real-life challenges and learn to think in complex, interconnected ways.

However, One Health is often perceived as a high-level or purely scientific concern, with limited integration into school curricula (Hobusch et al., 2024). Yet, early engagement, particularly through interdisciplinary modules, could prepare students to grasp the complexity of health and environmental interrelations (Haxton et al., 2015; Hobusch et al., 2024). Haxton et al. (2015) and Villanueva-Cabezas et al. (2022) argue that One Health education should begin in school, not only at university, and should be holistic and inclusive in its design, reaching students across subjects and grade levels.

CLIL (Content and Language Integrated Learning) models offer a promising approach to this challenge, as students develop subject knowledge and language skills simultaneously (Hemmi & Banegas, 2021). This enhances both motivation and perceived relevance, particularly when students engage with socio-scientific issues such as pandemics or antimicrobial resistance (Anastácio et al., 2022; Simonneaux & Legardez, 2010).

Anastácio et al. (2022) demonstrated that a structured biology and health course could shift pre-service teachers' understanding of vaccination and infectious disease, underscoring the potential of content-integrated approaches for conceptual change on One Health topics. If teachers are equipped with the necessary competencies and supported in their role as multipliers for socio-scientific issues through teacher education, similar conceptual shifts can also be fostered among school students, highlighting the importance of introducing One Health early and systematically across school education.

2.6. Preconceptions in Microbiology

For teachers to successfully introduce One Health-related socio-scientific issues, such as antimicrobial resistance, into classroom practice, understanding students' pre-existing conceptions becomes equally important. Students often hold the belief that microorganisms are inherently harmful, overlooking their beneficial roles in ecosystems and human health (Carson et al., 2018; M. G. Jones & Rua, 2006). A widespread misconception is that antibiotics are effective against viruses, not just bacteria (Byrne & Grace, 2018; Cals et al., 2007). Such misunderstandings may be reinforced by media representations that emphasize danger and disease (Byrne, 2011; Byrne & Grace, 2018). Addressing these preconceptions early on is essential, especially in education on global health issues, where misinformation can easily spread. Microbiology provides an opportunity to foster scientific literacy and connect curriculum content to students' everyday lives (Carson et al., 2018). These findings highlight the importance of instructional approaches that not only address students' misconceptions but also support them in developing a deeper, interconnected understanding of complex health issues.

2.7. CLIL as an Approach to One Health Education

CLIL (Content and Language Integrated Learning) offers a particularly promising approach, because it enables students to develop subject knowledge and language skills simultaneously (Hemmi & Banegas, 2021). This not only supports language acquisition but also enhances students' motivation and perceived relevance of the content, particularly when engaging with socio-scientific issues (Anastácio et al., 2022; Simonneaux & Legardez, 2010), such as pandemics, infectious diseases, or antimicrobial resistance. One Health topics are particularly suitable for this approach because they require learners to understand complex interactions between science, society, and sustainability and to communicate these relationships across disciplinary boundaries. Moreover, as a substantial proportion of scientific publications, international reports, and policy documents addressing global health challenges are published in English, developing scientific and linguistic competencies in parallel may strengthen students' ability to access, interpret, and critically evaluate relevant information. More broadly, Piacentini et al. (2022) suggest that CLIL-based science teaching may benefit science education and students' conceptions of science.

2.7.1. Evidence from School-Based Research

Although the available literature does not appear to include a directly comparable study combining One Health with an explicit CLIL approach across secondary school Biology and English, related school-based research supports the separate components of this approach. In a qualitative case study of a Portuguese lower-secondary CLIL program, Piacentini et al. (2022) found that teaching science through English increased teachers' awareness of the linguistic demands involved in science learning. The additional language encouraged teachers to reflect more closely on scientific terminology, students' comprehension difficulties, and the ways in which content was communicated. It also prompted the adaptation of instructional strategies and resources, including greater use of visual, multimodal, interactive, and learner-centered activities. The presence of English was further described as a potential motivational factor. These findings suggest that CLIL may function not only as a means of developing foreign-language proficiency but also as a language-aware approach to science education.

Complementing these findings, Martínez-Pena et al. (2026) investigated a five-session teaching sequence in which ninth-grade students addressed antimicrobial resistance, microplastic pollution, and avian influenza as One Health-related socio-scientific issues. The sequence was designed to progressively foster systems thinking, critical evaluation, and the

application of a One Health perspective. While most students did not initially demonstrate a critical position when evaluating information about antimicrobial resistance, the majority did so at the end of the sequence. Students who developed critical positions also displayed the most comprehensive One Health views, suggesting a possible relationship between the critical evaluation of socio-scientific information and a more systemic understanding of human, animal, and environmental health. However, the exploratory design and small sample require these findings to be interpreted cautiously.

Together, these studies indicate that language-aware science teaching and One Health-related SSI instruction may support complementary competencies. CLIL can make the linguistic demands of science more visible and encourage teachers to provide more deliberate forms of support, while One Health-related SSI instruction may create opportunities for students to develop critical thinking, perspective-taking, and systems-oriented understanding. Combining these approaches may therefore offer a meaningful way of supporting scientific communication and critical engagement with complex global health challenges.

2.7.2. Teacher Education and the Research Gap

Further evidence from teacher education reinforces the potential of content-integrated approaches. [Anastácio et al. \(2022\)](#) found that a structured biology and health course contributed to conceptual change concerning vaccination and infectious diseases among pre-service teachers. At the same time, research on school-based health education suggests that increasing knowledge alone is often insufficient to produce lasting behavioral changes. Educational approaches should therefore also foster critical reflection, self-regulation, and action competence ([Laschke et al., 2023](#); [Weber et al., 2022](#)). This requires teachers who possess the knowledge, confidence, and pedagogical skills needed to address health-related socio-scientific issues meaningfully. Teacher education consequently plays a central role in preparing future educators for this responsibility ([Hobusch & Poelzl-Hobusch, 2022](#); [Steiner & Rauch, 2013](#)). Teachers' reflection on their own sustainability-related values and practices may also be important if they are to serve as authentic role models within Education for Sustainable Development ([Ernst & Dunker, 2022](#); [Sandri, 2022](#); [UNESCO, 2020](#)).

Existing One Health initiatives have primarily focused on higher education, where interdisciplinary programs have promoted systems thinking, collaboration, and global health competencies among university students ([Basarir & Sari, 2022](#); [Porta et al., 2020](#); [Vicente et al., 2021](#); [Villanueva-Cabezas et al., 2022](#); [Wilkes et al., 2019](#)). Comparatively less attention has been given to translating One Health into regular school education, particularly through foreign-language instruction. The present study contributes to bridging this gap by combining One Health, CLIL, and action research within interdisciplinary secondary school biology and English lessons. Rather than viewing teacher education as the final target, this approach considers it the starting point of a multiplier process. Teachers who are prepared to integrate One Health-related socio-scientific issues into their classroom practice may create opportunities for the next generation to develop scientific literacy, global health awareness, systems thinking, and sustainable action competence from an early stage.

3. Methodological Approach

3.1. Research Design

This study explores how the One Health concept can be meaningfully integrated into Education for Sustainable Development (ESD) and teacher education through an action research (AR) approach. Design-oriented methodologies such as AR and Design-Based Research (DBR) are well-suited for educational innovation and systemic change because they enable researchers and teachers to collaboratively develop, implement, and iteratively

refine educational interventions in authentic classroom settings (Burns, 2009; Wilhelm et al., 2014). In teacher education, AR encourages pre-service teachers to address real-world classroom challenges while critically reflecting on their own practice (Altrichter et al., 2018; Dosemagen & Schwalbach, 2019). This iterative and practice-oriented approach is particularly appropriate for implementing interdisciplinary frameworks such as One Health, which itself requires transdisciplinary collaboration and cross-curricular learning to reflect the complexity of real-world sustainability challenges (Villanueva-Cabezas et al., 2022). Insights generated through this practice-oriented approach aim to promote innovation and implementation of One Health into existing curricula.

This section outlines the study's research design, data collection methods, teaching implementation, and analytical framework.

3.2. Study Context and Participants

This study is rooted in practical experiences gathered in 2021 during a seminar led by Froehlich et al. (2021) at the University of Vienna. It originated within the framework of the Teaching Clinic (TC), an innovative model in which student teachers address authentic classroom challenges through action research projects, thereby fostering systems thinking, practical problem-solving, and transformative action in line with Education for Sustainable Development (ESD) (Hobusch et al., 2025). Within this framework, an action research (AR) project was developed to implement cross-curricular One Health lessons in Austrian secondary schools. Preliminary findings were presented at the 2022 STEMS² Symposium in Honolulu, where expert feedback informed the further refinement of the project (Hobusch et al., 2022).

The intervention consisted of three CLIL lessons integrating biology and English, focusing on microbes, infections, and antibiotic resistance. The lessons were implemented in two iterative rounds, the first during the first author's teaching practicum and the second during her first year of teaching. Following the principles of action research, student feedback collected after each lesson was used to revise and refine the teaching materials before the next implementation.

Furthermore, the intervention was conducted in five classes across three school levels (grades 8–10; students aged approximately 14–16 years). In the Austrian school system, grade 8 corresponds to year 4 of lower secondary school (classes 4B and 4D), grade 9 to year 5 (classes 5A and 5B), and grade 10 to year 6 (class 6A). Classes 5A, 5B, and 6A participated in the first implementation round, while classes 4B and 4D participated in the second. Participation varied slightly across lessons. In the first round, 46 students attended lesson 1 and 39 attended lessons 2 and 3, with the decrease resulting from a class language trip. In the second round, 50 students attended lesson 1, 46 attended lesson 2, and 47 attended lesson 3. Overall, the study comprised 267 lesson participations across both implementation rounds (124 in round 1 and 143 in round 2).

To support students in managing both subject content and the English language, the lessons incorporated scaffolding materials such as vocabulary handouts and sentence starters. To ensure comparability between the two implementation rounds, the same three lesson plans were used throughout.

3.3. Lesson Content and Pedagogical Design

The lesson series focused on three main topics: microbes, infections, and antibiotic resistance. Tables 1–3 provide an overview of the lesson plans designed for the three interdisciplinary One Health sessions, outlining the activities, interaction formats, and additional notes.

The instructional approach was grounded in the CLIL framework, combining content from Biology and English language acquisition. Scaffolding materials, including vocabulary handouts, sentence starters, and topic-specific expressions, were provided to support students' understanding and communication. Lessons were designed to foster interdisciplinary thinking, promote scientific literacy, and raise awareness of health-environment interdependencies.

Table 1. Overview of One Health 1 (introduction to microbes).

Note	Interaction Format	Activity
Guessing game about statements related to microbes as an introductory activity	Partner work, whole class discussion	Guessing Game
Read an introductory text about microbes, exchange with a partner, then answer questions	Individual work, partner work	Reading about microbes and partner exchange to answer questions
	Discuss results of reading and answering questions	Whole class discussion
In groups of 4: two students read about helpful microbes, two students read about harmful microbes, exchange information, and create a mind map	Group work	Reading texts and group activity about helpful and harmful microbes
Discuss infection prevention measures and write down the results	Group work	Group discussion about infection prevention
	Joint discussion about hygiene measures	Whole class discussion about infection prevention

Table 2. Overview of One Health 2 (preventing infections).

Note	Interaction Format	Activity
"Did you know that...?"—Reading and briefly discussing facts about hygiene to spark interest as an introductory activity	Whole class	Fun facts about infections and hygiene
Read a short text about infection spread, research how far microbes can travel through the air when sneezing/coughing, exchange briefly with a partner, and write down results	Individual work, partner work	Reading about infection spread and online research on microbe load distance during sneezing and coughing
	Briefly discuss results	Whole class discussion
Read a short second text about hand hygiene, discuss with a partner, and briefly summarize both texts	Individual work, partner work	Reading about hand hygiene and summarizing both texts
	Briefly discuss results	Whole class discussion

Table 3. Overview One Health 3 (antimicrobial resistance and household remedies).

Note	Interaction Format	Activity
Watching a TED Talk video on antibiotic resistance on YouTube (with English subtitles) video: Kullar (2018). Antibiotic Resistance: What You Can Do to Prevent a Future Pandemic [Video]. TEDxBend. YouTube. https://www.youtube.com/watch?v=tGtYvQCSfFA (accessed on 30 January 2025)	Whole class	TED Talk Video
Short discussion/takeaways of the video's content	Whole class	Whole class discussion
Answering questions about the video (only in the second cycle, via Google Forms)	Individual work	Questions about the video
Short interactive brainstorming on the question: "Which antimicrobial household products do you know?"	Individual work, whole class	Brainstorming about antimicrobial household products in Mentimeter
Discussing common household products like chamomile, sage, coconut oil, and honey	Whole class	Discussion about antimicrobial household products using a prepared PowerPoint presentation
Final task: answering how the three One Health dimensions—wildlife, humans, and the environment—are interconnected	Individual work	Answering a question about the One Health connection

3.4. Student Feedback and Iterative Development

Student feedback played a central role in the refinement of the lessons. After each session, learners completed anonymous forms containing both open-ended questions and Likert-scale items. These assessed the perceived clarity of the content, level of interest, and the usefulness of the scaffolding tools. Based on this feedback, the lessons were then revised to better meet the students' needs. Adjustments included incorporating additional digital tools and adding more interactive activities. This iterative process enabled the continuous improvement of the teaching materials and was essential for maintaining student engagement.

3.5. Curricular Integration and Interdisciplinarity

The lesson plans were carefully aligned with the Austrian secondary school curriculum for both English and Biology. In English, the focus was on language production, vocabulary development, and the use of scaffolding tools. In Biology, emphasis was placed on understanding microbial life, infectious diseases, and behavioral aspects of sustainability.

These interdisciplinary lessons also reflected key competencies outlined in Austria's national education standards for Education for Sustainable Development (ESD), particularly regarding critical thinking, problem-solving, and participation in sustainable development initiatives (Steiner & Rauch, 2013). Here, the One Health concept served as a thematic bridge, linking natural science knowledge with real-world societal challenges.

3.6. Data Collection and Evaluation Strategy

To evaluate the effectiveness of this interdisciplinary and curriculum-aligned approach, a mixed-methods design was employed, combining qualitative and quantitative data sources (Wilhelm et al., 2014). Qualitative data was collected through open-ended feedback responses and student handouts. Moreover, during the second round of implementation, pre- and post-tests were designed to assess knowledge gains, including multiple-choice and short-answer items addressing the contents of the lessons.

These data were then analyzed using a coding framework (as summarized in Table S1 in the Supplementary Materials) that combined deductive codes (based on predefined categories) and inductive codes (emerging from the data) across three domains: biological knowledge, English language skills, and pedagogical effectiveness. Each code was rated on a three-point ordinal scale of 1 to 3. This scale applies both to student task responses (codes B1–B2 for Biology, E1–E5 for English, P1–P5 for Pedagogy) and to student feedback items (codes FB1–FB2, FE1–FE2, FP1–FP5). The analysis focused on three main domains: biological knowledge, English language skills, and pedagogical effectiveness. The full coding system is provided in the Supplementary Materials. For biological content, the coding categories included conceptual understanding, accuracy, and application to everyday life. In the English domain, grammar, spelling, vocabulary use, and overall language production were assessed. Pedagogical indicators involved clarity of instruction, activity choices, and the effectiveness of scaffolding and feedback. The coding system enabled a nuanced analysis of how students engaged with the interdisciplinary material, how effectively they understood the key messages of One Health, and how the teaching design supported their learning process.

Finally, the resulting data was analyzed using SPSS (IBM SPSS Statistics, Version 29.0.0.0) applying non-parametric tests to identify significant learning effects. To provide a clearer structure of the approach and its focus areas, Table 4 summarizes the evaluation framework, outlining the data sources, assessment domains, and representative indicators.

Table 4. Overview of Data Collection and Evaluation Framework.

Example Indicators/Codes	Evaluation Focus	Data Sources	Domain/Subject
Correctness of facts; Use of scientific terminology; Everyday relevance	Conceptual understanding, accuracy, and real-world application of biological content	Pre- and post-tests; Student handouts	Biology
Sentence structure; Correct vocabulary use; Spelling errors	Grammar, spelling, vocabulary use, and language production	Student handouts; Open-ended responses	English
Clear task instructions; Use of scaffolding tools; Student motivation	Clarity of instruction, scaffolding effectiveness, engagement with tasks	Open-ended feedback; Teacher observations	Pedagogy
Reflections on One Health; Language-content balance	Interdisciplinary integration and engagement with One Health themes	All above	Cross-cutting Analysis
Kruskal–Wallis and Mann–Whitney U Tests (SPSS)	Statistical analysis of knowledge gains	Pre-/post-tests (round 2)	Quantitative Data

Data was analyzed using SPSS with non-parametric tests, as the coded data are ordinal and normality assumptions were not met (confirmed via Shapiro–Wilk tests). Kruskal–Wallis tests were applied to compare outcomes across the five classes (OH1 and OH2) and across lessons over time (OH1 → OH2 → OH3). Mann–Whitney U tests were used for pairwise comparisons involving two groups; Wilcoxon signed-rank tests were used for pre/post comparisons within individual classes. Where Kruskal–Wallis tests indicated overall significant differences, pairwise post hoc comparisons were conducted. It should be noted that the lesson-to-lesson comparisons (e.g., OH1 vs. OH2 vs. OH3 within a class group) involve the same students at successive time points, which would theoretically call for a repeated-measures approach such as the Friedman test. However, because student participation varied between lessons due to absences and anonymity (making pairings impossible), the groups were treated as independent samples. We acknowledge this as a limitation.

4. Results

This section summarizes the findings from non-parametric analyses conducted with SPSS. Because the coded data are ordinal and normality could not be assumed (Shapiro–Wilk tests), Kruskal–Wallis tests were used to compare multiple independent groups, Mann–Whitney U tests for two-group comparisons, and Wilcoxon Signed-Rank Tests for paired pre- vs. post-test comparisons within lessons. Where Kruskal–Wallis tests were significant, Dunn’s pairwise post hoc tests with Bonferroni correction were applied. Effect sizes are reported as η^2H for Kruskal–Wallis and as $r = Z/\sqrt{N}$ for Mann–Whitney U and Wilcoxon tests. All responses were coded on a 1–3 ordinal scale (1 = incorrect, 2 = partially correct, 3 = fully correct; see Table S1 in the Supplementary Materials).

4.1. Performance Differences Between Classes

One Health (OH) 1: An Independent-Samples Kruskal–Wallis Test revealed significant differences in Biology scores across the five classes ($H(4) = 140.258$, $N = 2544$, $p < 0.001$, $\eta^2H = 0.054$). Mean scores on the 1–3 scale were: 4B ($M = 2.32$), 4D ($M = 2.33$), 5A ($M = 2.73$), 5B ($M = 2.70$), and 6A ($M = 2.89$). Dunn’s post hoc comparisons (Bonferroni-corrected) showed that younger classes performed significantly below class 6A: 4B vs. 6A (mean rank difference = -390.93 , $Z = -9.41$, $p_{\text{adj}} < 0.001$) and 4D vs. 6A (mean rank difference = -385.75 , $Z = -9.40$, $p_{\text{adj}} < 0.001$). The mean rank difference is a post hoc test statistic based on ranked scores, not a raw score difference; the actual mean score gap between 4B and 6A is approximately 0.57 points on the 1–3 scale. No significant differences were found among the 8th- and 9th-grade classes themselves, indicating relatively similar performance within those levels. Moreover, for English, an Independent-Samples Kruskal–Wallis Test found no significant differences in scores between classes ($H(4) = 4.122$, $N = 2912$, $p = 0.390$), indicating that performance was more evenly distributed regardless of grade.

One Health (OH) 2: An Independent-Samples Kruskal–Wallis Test again revealed significant between-class differences in Biology ($H(4) = 13.221$, $N = 849$, $p = 0.010$, $\eta^2H = 0.011$). However, no pairwise post hoc comparisons reached significance after Bonferroni correction, indicating a more uniform performance distribution than in OH1. Furthermore, a significant between-class difference in English was found (Independent-Samples Kruskal–Wallis Test: $H(4) = 21.055$, $N = 346$, $p < 0.001$, $\eta^2H = 0.050$). Dunn’s post hoc comparisons showed class 6A significantly outperforming 4B (mean rank difference = -58.45 , $p_{\text{adj}} < 0.001$) and 4D (mean rank difference = -47.87 , $p_{\text{adj}} < 0.001$). No significant differences were found among 8th- and 9th-grade classes, again indicating more homogeneity within those levels.

One Health (OH) 3: As only the two second-round classes (4B and 4D) were available for this lesson, an Independent-Samples Mann–Whitney U Test was used. Here, class 4D significantly outperformed 4B ($U = 174,574.5$, $Z = 3.40$, $N = 1136$, $p < 0.001$, $r = 0.10$), but no such difference was found in English.

The results of this section are summarized in the Supplementary Materials, in Table S2.

4.2. Performance Differences Across Lessons

As previously noted, lesson-to-lesson comparisons treat each lesson session as an independent group, because varying student attendance across lessons, as well as the anonymity of students' responses, impeded pairing. This represents a methodological limitation that should be considered when interpreting these results.

Round 1 (classes 5A, 5B, 6A), OH1 → OH2: An Independent-Samples Mann–Whitney U Test detected no significant difference ($U = 33,272$, $Z = 0.20$, $N = 923$, $p = 0.839$, $r = 0.007$), indicating no overall Biology improvement between the two lessons for these classes. However, an Independent-Samples Mann–Whitney U Test found a significant improvement in English scores for class 6A between OH1 and OH2 ($U = 21,360.5$, $Z = 4.13$, $N = 592$, $p < 0.001$, $r = 0.17$), with mean scores increasing from 2.40 to 2.79.

Round 2 (classes 4B, 4D), OH1 → OH2 → OH3: For Biology, an Independent-Samples Kruskal–Wallis Test showed significant improvement across all three lessons ($H(2) = 57.547$, $N = 3606$, $p < 0.001$, $\eta^2H = 0.015$). Dunn's post hoc tests revealed significant gains from OH1 to OH2 ($Z = -3.36$, $p_{\text{adj}} = 0.002$), OH1 to OH3 ($Z = -7.55$, $p_{\text{adj}} < 0.001$), and OH2 to OH3 ($Z = -3.08$, $p_{\text{adj}} = 0.006$). If examined separately by class:

- Class 4B: An Independent-Samples Kruskal–Wallis Test was conducted, $H(2) = 11.675$, $N = 1693$, $p = 0.003$, $\eta^2H = 0.006$. Post hoc testing showed a significant improvement only between OH1 and OH3 ($Z = -3.41$, $p_{\text{adj}} = 0.002$).
- Class 4D: Again, an Independent-Samples Kruskal–Wallis Test was conducted, $H(2) = 53.814$, $N = 1913$, $p < 0.001$, $\eta^2H = 0.027$. Post hoc testing showed significant step-wise gains: OH1 → OH2 ($Z = -3.64$, $p_{\text{adj}} = 0.001$), OH1 → OH3 ($Z = -7.25$, $p_{\text{adj}} < 0.001$), and OH2 → OH3 ($Z = -2.63$, $p_{\text{adj}} = 0.026$), suggesting a gradual learning curve.

However, no significant changes across lessons were found for English in round 2, indicating more stable performance in language-related outcomes.

The results of this section are also summarized in the Supplementary Materials, in Tables S2 and S4.

4.3. Student Feedback and Researcher Evaluation

Round 1 (5A, 5B, 6A): Student feedback also improved across lessons. An Independent-Samples Kruskal–Wallis Test revealed significant differences in feedback scores across the three lessons ($H(2) = 23.732$, $N = 673$, $p < 0.001$, $\eta^2H = 0.032$). Dunn's post hoc comparisons showed feedback after OH1 was significantly lower than after both OH2 ($p_{\text{adj}} < 0.001$) and OH3 ($p_{\text{adj}} < 0.001$). No significant difference emerged between OH2 and OH3.

Round 2 (4B, 4D): A similar trend was observed in the second round. An Independent-Samples Kruskal–Wallis Test again revealed significant improvement in feedback across lessons ($H(2) = 24.817$, $N = 820$, $p < 0.001$, $\eta^2H = 0.028$). Post hoc testing showed significant gains between OH1 and OH3 ($p_{\text{adj}} < 0.001$) and between OH2 and OH3 ($p_{\text{adj}} = 0.009$), but not between OH1 and OH2.

The results for this section are summarized in the Supplementary Materials, in Table S3.

4.4. Alignment Between Student Performance and Perception

To examine whether student perceptions aligned with their actual performance, Independent-Samples Mann–Whitney U Tests compared feedback scores with student task outcomes for each class and lesson (15 comparisons in total). In 13 of 15 cases, no significant differences were observed. However, discrepancies were found in 4B (OH1, $p = 0.007$) and 5B (OH2, $p < 0.001$), where feedback ratings were slightly more favorable than actual outcomes. These outliers may reflect overestimation of performance or disengagement due to contextual factors (e.g., low attention).

4.5. Consistency Between Researcher and Student Evaluations

Finally, Independent-Samples Mann–Whitney U Tests compared researcher evaluations with student feedback in the pedagogical category across all classes and lessons. No significant differences were found, indicating a shared perception of lesson clarity, scaffolding, and overall instructional quality.

4.6. Addressing Preconceptions

The analysis of student pre- and post-test responses revealed significant improvements in addressing two prevalent misconceptions about microbes and antibiotics.

4.6.1. Preconception 1: Antibiotics Are Effective Against Viruses

The first preconception addressed the effectiveness of antibiotics against bacteria. In the second implementation round (classes 4B and 4D), students completed pre- and post-tests at the beginning and end of each lesson. They were asked whether antibiotics only work against bacteria (Question 1 = Q1) and whether antibiotics also work against viruses (Question 2 = Q2). The results of these questions are summarized in Table 5.

Table 5. Results of the pre- and post-tests on the preconception “antibiotics are effective against viruses”.

Q2 Post False	Q2 Post True	Q2 Pre False	Q2 Pre True	Q1 Post False	Q1 Post True	Q1 Pre False	Q1 Pre True	
75%	25%	59.10%	40.90%	15%	85%	45.50%	54.50%	4B
87.50%	12.50%	80%	20%	4.20%	95.80%	24%	76%	4D
81.25%	18.75%	69.55%	30.45%	9.60%	90.40%	34.80%	65.30%	total

Initially, a substantial proportion of students incorrectly believed that antibiotics are effective against viruses. In class 4B, 40.9% of students answered that antibiotics work against viruses in the pre-test, while in class 4D, this figure was 20%. Following the intervention, the proportion of incorrect answers dropped to 25% in 4B and 12.5% in 4D. Similarly, understanding that antibiotics act only against bacteria improved. In 4B, correct answers to the statement “antibiotics only work against bacteria” rose from 54.5% (pre-test) to 85% (post-test). In 4D, the correct response rate increased from 76% to 95.8%. These findings indicate a marked conceptual shift, particularly in clarifying the boundaries of antibiotic effectiveness.

4.6.2. Preconception 2: Microbes as Beneficial Organisms

Another common misconception addressed was the belief that all microbes are harmful. Pre-test data showed that 40% of students in 4B and 24% in 4D agreed with this incorrect statement. After the lesson, only 4.8% of students in class 4B maintained this belief, in comparison to 0% of students in 4D. This substantial reduction demonstrates that the lessons seem to have successfully conveyed the complexity of microbial life, emphasizing

both beneficial and harmful roles of microorganisms. The results are summarized in Table 6 below.

Table 6. Results of the pre- and post-tests on the preconception “all microbes are harmful”.

Q3 Post False	Q3 Post True	Q3 Pre False	Q3 Pre True	
95.20%	4.80%	60%	40%	4B
100%	0%	76%	24%	4D
97.60%	2.40%	68%	32%	total

Related-Samples Wilcoxon Signed-Rank Tests confirmed that pre-to-post improvements were statistically significant across all six lesson–class combinations: 4B OH1 ($W = 15,943$, $Z = 2.76$, $N = 426$, $p = 0.006$, $r = 0.13$); 4B OH2 ($W = 1518$, $Z = 3.35$, $N = 147$, $p < 0.001$, $r = 0.28$); 4B OH3 ($W = 2202.5$, $Z = 4.61$, $N = 176$, $p < 0.001$, $r = 0.35$); 4D OH1 ($W = 21,152.5$, $Z = 5.27$, $N = 475$, $p < 0.001$, $r = 0.24$); 4D OH2 ($W = 2059$, $Z = 5.50$, $N = 175$, $p < 0.001$, $r = 0.42$); 4D OH3 ($W = 478.5$, $Z = 4.60$, $N = 114$, $p < 0.001$, $r = 0.43$). Effect sizes increased across the lesson series for both classes (4B: $r = 0.13 \rightarrow 0.28 \rightarrow 0.35$; 4D: $r = 0.24 \rightarrow 0.42 \rightarrow 0.43$), consistent with cumulative learning across the three sessions.

4.7. Effectiveness of Scaffolding Tools

The scaffolding materials, including vocabulary sheets, word banks, and sentence starters, seemed to have been crucial in bridging linguistic gaps. Their design aimed to reduce cognitive overload while maintaining content integrity.

Teacher observations confirmed that students used the scaffolds, especially during written tasks and group discussions. In post-lesson reflections, many students mentioned using the vocabulary handouts to formulate complete sentences or clarify meaning. The teacher-researcher noted that these tools reduced the need for code-switching into German and allowed more time for content-focused interactions.

5. Discussion

A central question underlying this study is whether interdisciplinary CLIL-based One Health teaching can foster students’ learning and thinking skills, concerning their capacity to build conceptual understanding, adopt systems thinking, use language as a tool for scientific reasoning, and engage critically with socio-scientific issues. This thread connects the three research questions and is reflected in the findings across both implementation rounds.

The following sections interpret the results against the existing literature on conceptual development, CLIL pedagogy, scaffolding, and action research to examine what the findings reveal about the conditions under which meaningful learning and thinking take place in a One Health education context.

5.1. Conceptual Development and Systems Thinking in One Health Education

The statistically significant pre-to-post gains across all three lessons, documented by Wilcoxon Signed-Rank tests with effect sizes ranging from small to moderate ($r = 0.134$ to $r = 0.430$), indicate that students made measurable progress in biological understanding. Yet the more theoretically important finding is the pattern of how those gains were distributed. In OH1, the gap between tenth-grade (6A) and eighth-grade students (4B, 4D) was substantial (mean rank differences of -390.93 and -385.75 in Dunn post hoc comparisons), reflecting the well-established role of prior knowledge as a driver of initial performance in novel topic areas (Carson et al., 2018). Crucially, however, this gap narrowed significantly by OH2 and OH3, and effect sizes for within-class pre-post gains were largest precisely for the younger classes (e.g., 4B OH3: $r = 0.348$; 4D OH3: $r = 0.430$). This suggests that

iterative, scaffolded instruction enabled students who began from a lower knowledge base to develop the conceptual frameworks necessary to engage with One Health as a systems-level concept.

This aligns with findings from [Anastácio et al. \(2022\)](#), who showed that structured content-integrated biology teaching could produce measurable conceptual shifts even within brief interventions, and with [Martínez-Pena et al. \(2026\)](#), who found that secondary students' ability to develop critical positions on One Health-related socio-scientific issues (SSIs), including antibiotic resistance, improved markedly over the course of a structured teaching sequence: while most students showed no critical stance at the outset, a majority did so by the sequence's end. The parallel to this study is instructive, as just as [Martínez-Pena et al. \(2026\)](#) observed that critical engagement with One Health SSIs develops through structured practice rather than passive exposure, the gains documented here emerged only when students were repeatedly asked to apply, extend, and articulate their understanding across consecutive tasks.

The preconceptions identified at baseline, particularly the belief that antibiotics are effective against viruses, and the tendency to frame microbes exclusively as threats, are consistent with patterns documented in the literature ([Byrne & Grace, 2018](#); [Cals et al., 2007](#)). [Byrne and Grace \(2018\)](#) note that the "microbes as threat" frame is particularly resistant to change because it is continually reinforced by everyday media. The deliberate inclusion of a mind-mapping activity in OH1, which required students to categorize microbes by function and role, directly targeted this frame. The significant pre-post improvements in both Q1 (microbial roles) and Q3 (antibiotic targeting) across classes suggest that explicit conceptual confrontation was responsible for the observed change. This finding supports the view that One Health education is most productive when it challenges students to revise their thinking, not merely to add information.

5.2. CLIL as a Language-Aware Approach to Scientific Thinking

The English-language outcomes reveal a more complex picture than simply whether students' language proficiency was sufficient to engage with the content. English performance showed significant class differences in OH2 ($H(4) = 21.055$, $p < 0.001$), largely driven by the advantage of older, more proficient students. However, the younger classes demonstrated comparable performance to one another and showed meaningful gains within rounds, indicating that the CLIL format did not systematically exclude less proficient learners.

This finding resonates with [Piacentini et al. \(2022\)](#), who investigated science teachers' experience of CLIL in a Portuguese secondary school and found that the presence of English prompted teachers to become more attuned to the linguistic demands placed on students, leading them to actively adjust their strategies and resources. In the present study, the same dynamic was observable, as the need to design English-language tasks on biological content required the teacher-researcher to attend explicitly to vocabulary load and support in ways that conventional monolingual biology instruction rarely demands. The result was a heightened pedagogical awareness that, as [Piacentini et al. \(2022\)](#) argue, constitutes one of the core benefits of CLIL as a language-aware approach that enriches science teaching itself.

This perspective shifts the interpretation of CLIL's contribution, because rather than viewing English merely as an added challenge to biology learning, the integration of language tasks required students to externalize and articulate their scientific thinking more carefully. Writing a sentence about how antibiotic resistance develops, using a targeted vocabulary frame, requires a qualitatively different kind of thinking than selecting a correct answer on a knowledge check. This aligns with [Karabassova's \(2022\)](#) observation that teacher-initiated CLIL tends to be more responsive to learners' actual needs, because

the teacher can continuously calibrate the language demands to the conceptual ones. In this study, the iterative AR design created precisely that responsiveness, and the teacher-researcher subject combination, English and Biology, helped to integrate both demands.

5.3. Scaffolding as a Mediator of Learning and Thinking

Teacher observations and student reflections consistently confirmed that vocabulary handouts with word banks and sentence starters were actively used, particularly during written tasks and group discussions. The reduction in code-switching into German and the ability of younger students to formulate complete scientific sentences in English suggest that scaffolding fulfilled its intended cognitive function, which is reducing extraneous load so that attentional and working memory resources could be directed toward conceptual engagement.

Hemmi and Banegas (2021) identify scaffolding as a critical enabler of content engagement in CLIL settings, especially for learners who are not yet fully proficient in the target language. However, the role of scaffolding can extend beyond language support, as vocabulary sheets and sentence starters can help structure the cognitive work of classification and causal reasoning that are central to One Health thinking. In this sense, scaffolding materials can function as thinking scaffolds, temporarily supporting the reasoning processes that students are still developing. This interpretation is consistent with the students' increase in cognitive autonomy across lessons in this study, because as students internalized the relevant concepts and vocabulary, their reliance on the scaffold materials decreased.

The relatively stronger gains in round 2 compared to round 1 for several classes, particularly visible in the larger Wilcoxon effect sizes, support the view that scaffolding design improves through reflective iteration. Adjustments made between rounds based on student feedback addressed specific weaknesses in task clarity and language support, resulting in more targeted cognitive scaffolding in the revised materials.

5.4. Action Research as a Framework for Teacher Knowledge Development

This study used AR not only as a research method but also as a way for the teacher-researcher to examine and improve her own practice alongside students' learning. The two-cycle structure of observing, reflecting, redesigning, and reimplementing produced not only improved lesson materials but also practitioner knowledge about what supports effective interdisciplinary One Health teaching in a specific school context.

Altrichter et al. (2018) describe AR as a form of professional learning in which knowledge develops through the ongoing cycle of planning, acting, observing, and reflecting alongside the improvement of teaching practice. The significant improvements in student outcomes between round 1 and round 2, particularly in the younger classes, suggest that this cycle produced real pedagogical gains. Feldman et al. (2024) note that teacher-centered AR remains disproportionately underrepresented in science education journals, even as researchers call for more politically engaged, practice-driven inquiry. This study contributes to addressing that gap by demonstrating how an early-career teacher, working within the Teaching Clinic framework at the University of Vienna (Hobusch et al., 2025; Froehlich et al., 2021), can generate curriculum knowledge that is simultaneously relevant to her own classroom and to the broader field.

Critically, the AR framework also shaped how this study engaged with failure. Lessons that yielded smaller or inconsistent gains in round 1, for example, the limited pre-post progress in some classes in OH1, were not treated as deficits to be explained away but as diagnostic information prompting instructional revision. This is the kind of iterative, evidence-responsive practice that Design-Based Research principles emphasize (Wilhelm et al., 2014), and it produced tangible improvements in the second implementation cycle.

5.5. Toward Critical Thinking and One Health Literacy

Taken together, the findings point toward a broader goal that goes beyond any individual lesson outcome, which is the development of students' capacity to think critically about health as a systemic, interconnected phenomenon. [Martínez-Pena et al. \(2026\)](#) frame this capacity at the intersection of critical thinking and a One Health view. Their findings suggest that students who developed a critical position toward SSIs also tended to demonstrate more comprehensive One Health views. However, the study does not establish a causal or bidirectional relationship and instead highlights the need for further research into this association. One Health education may therefore support not only content knowledge but also opportunities to develop analytical, systems-oriented, and socially aware reasoning, which are central to scientific literacy and ESD ([Riess et al., 2022](#); [UNESCO, 2020](#))

In this study, this orientation was reflected in students' responses, which indicated a growing awareness of antibiotic resistance as a multifactorial and socially embedded problem rather than a purely biomedical issue. Although the study design does not permit strong conclusions about the development of critical thinking, the qualitative evidence suggests that some students began to connect the biological mechanisms addressed in the lessons with broader One Health dimensions. This apparent progression from factual misconceptions to more accurate conceptual understanding and, subsequently, to greater system-level awareness illustrates the type of learning that well-designed One Health education may support. Its implementation in an Austrian secondary school context, where One Health has so far received limited attention ([Hobusch et al., 2024](#)), further indicates the feasibility and educational potential of this approach.

Evidence from a closely related Austrian study further supports this. [Hobusch et al. \(2023\)](#) developed and evaluated One Health-informed lesson units centered on meat production and consumption in the context of vocational agricultural education. Their didactic design was grounded in action-oriented and competency-oriented principles, with the explicit pedagogical goal of enabling students to develop the capacity to reflect on systemic connections and to take self-directed, informed action regarding their own consumption behavior. Crucially, the authors conclude that only a multiperspective and interdisciplinary approach can generate constructive solutions to the challenges at the intersection of food systems, animal welfare, and human health. While the SSI context differs from the present study (meat production and consumption rather than antibiotic resistance and microbiology), the underlying pedagogical logic is overlapping: meaningful One Health education requires students not merely to acquire isolated factual knowledge, but to recognize and reason about the interconnections between human, animal, and environmental health as a basis for value-informed decision-making. Moreover, [Hobusch et al. \(2023\)](#) explicitly note that the teaching materials they developed hold potential beyond the agricultural school context and are relevant to secondary teachers across subjects more broadly, which is a finding that resonates with the present study's demonstration that One Health can serve as a flexible interdisciplinary anchor in mainstream biology and CLIL settings.

6. Conclusions

6.1. Insights on Integrating Sustainability and One Health into Classroom Teaching

This study focused on investigating interdisciplinary One Health lessons to make concepts such as microbiology and antimicrobial resistance tangible for students. The objective was to evaluate the effectiveness of an interdisciplinary One Health approach and to raise students' awareness of global health challenges. The results suggest that interdisciplinary teaching, combined with appropriate scaffolding materials, can significantly enhance students' understanding of One Health topics. This format made it possible to teach both biological content and English language skills simultaneously, reinforcing the

goals of interdisciplinary education and sustainable learning. It also encouraged the use of subject-specific vocabulary and expressions, which students were able to access more easily through scaffolding tools. Moreover, the interdisciplinary structure supported systemic thinking, a skill increasingly important in the face of global challenges such as climate change and pandemics.

The combination of quantitative and qualitative data also provided a nuanced understanding of the students' learning processes. Pre- and post-tests helped measure knowledge gain, while written feedback and observations revealed aspects of language use, motivation, and engagement. The mixed-methods approach ensured a holistic evaluation of the learning outcomes and contributed to the project's practical relevance.

Additionally, the use of digital tools proved beneficial in increasing student engagement, as reflected in the feedback from the first round of classes (5A, 5B, 6A). This underlines the importance of digitalization in education. At the same time, collecting feedback from students after each lesson was found to be an essential component of iterative teaching design and allowed for constant adaptation of the lesson plans to the learners' needs.

Furthermore, the AR methodology allowed the teacher-researcher to reflect critically on her own teaching practices. This iterative process enabled the development of practical insights that could inform the future design of similar educational projects.

In summary, the project demonstrates that implementing interdisciplinary One Health units in a CLIL format could potentially strengthen students' awareness of global health issues and promote sustainability in education. It also emphasizes the role of future teachers in shaping curricula that reflect pressing societal needs. Teacher education programs should provide more opportunities for pre-service teachers to conduct design-oriented projects in classrooms, enabling them to develop both pedagogical and research skills while addressing topics of global importance. By bringing the One Health perspective into the classroom, education becomes not only a place of knowledge transmission but also a space for societal transformation.

6.2. Limitations and Considerations

Despite its strengths, this study has several limitations mentioned here despite the acknowledgment that an AR study takes these limitations explicitly into account for the benefits of this approach. Firstly, the sample size was limited and included only five classes across two different teaching cycles, which restricts the generalizability of the findings. Secondly, the classes varied in age group and number of Biology lessons per week, which introduces potential variability in prior knowledge and cognitive development. Thirdly, the reliance on self-designed instruments and a coding system, although tailored to the context, may limit comparability with other studies. Fourthly, the dual role of the researcher as teacher and evaluator introduces a risk of observer bias inherent to action research designs. Finally, lesson-to-lesson comparisons treated groups as independent samples because incomplete participation across lessons precluded fully paired analysis.

Moreover, the intervention focused primarily on microbiology and antibiotic resistance. While these topics are highly relevant, the One Health approach covers a much broader range of themes such as food systems, biodiversity, and environmental justice, which could be explored in future implementations. Expanding the scope and integrating more participatory methods might further enhance student engagement and transdisciplinary learning.

6.3. Directions for Future Research

Future studies should aim to replicate and extend this work in several ways. Larger-scale studies involving multiple schools and teachers would allow for more robust general-

ization of the findings. Longitudinal designs could assess whether brief lesson series of this type lead to durable conceptual change over time. Comparative studies that contrast CLIL and non-CLIL delivery of One Health content could help disentangle the contribution of language integration from content design. Additionally, future research could explore how students' engagement with socio-scientific dimensions of One Health, such as the behavioral, policy, and equity dimensions of AMR, develops over extended instructional sequences. Finally, the development and validation of standardized instruments for assessing One Health literacy at the secondary level would greatly support future comparative research in this emerging field.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/educsci16091455/s1>. Table S1: Coding scheme; Table S2: Results of statistical tests for class differences; Table S3: Results of feedback comparisons; Table S4: Pre- and post-test results.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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