



Perspective

Braiding Two-Eyed Seeing and Education for Sustainable Development in science teacher education: The One Health Teaching Clinic model

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ABSTRACT

Science education increasingly requires integrative approaches that bridge scientific knowledge with cultural, ethical, and societal perspectives to effectively address sustainability and global health challenges. In response, this article presents the One Health Teaching Clinic, an innovative educational model specifically designed for science teacher education. Grounded in the principle of Two-Eyed Seeing—a framework that combines Indigenous and Western epistemologies—the One Health Teaching Clinic systematically incorporates Education for Sustainable Development using the Synoptic Transfer Framework. Within the One Health Teaching Clinic, pre-service science teachers collaborate intensively with interdisciplinary subject-matter experts to co-design and implement lesson plans centered on contemporary One Health issues, such as pandemic preparedness, ecosystem health, and sustainable food systems. Drawing from detailed qualitative analyses of four exemplary case studies, we illustrate how this structured co-design process enables educators to navigate the complexity of socio-scientific issues by balancing rigorous scientific accuracy, cultural relevance, practical applicability, and value-driven narrative shaping. Our findings highlight how integrating Two-Eyed Seeing through the One Health Teaching Clinic model effectively promotes transdisciplinary competencies, epistemic pluralism, and transformative pedagogical practices among future science educators. We argue that embedding Two-Eyed Seeing within structured, collaborative frameworks significantly enhances the ability of teachers to serve as empowered sustainability change agents, ultimately fostering secondary students' holistic understanding and critical engagement with pressing health and environmental concerns.

1. Introduction

Research in science education has increasingly grappled with the complex interdependence of environmental and human health issues. A

prominent example is the Science|Environment|Health (S|E|H) paradigm, which over the past decade has evolved within a Special Interest Group of the European Science Education Research Association (ESERA) toward embracing complexity and uncertainty in learning settings

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(Zeyer and Dillon, 2019). The initial S|E|H pedagogy (Zeyer and Kyburz-Graber, 2012) integrated socio-scientific issues to enhance relevance and engagement. By 2021 this approach had advanced further, embedding complexity theory and structural uncertainty into pedagogy (Zeyer and Kyburz-Graber, 2021; Zeyer et al, 2021). Such developments challenge deterministic teaching models and argue for transdisciplinary, holistic strategies to foster scientific literacy and informed citizenship (Osborne, 2023). This pedagogical transition parallels trends in the sciences themselves—exemplified by the One Health (OH) framework introduced in 2004—which emphasizes the interconnectedness of human, animal, and environmental health in addressing global challenges (Cook et al, 2004; Zinsstag et al, 2023). Recent crises like COVID-19 have underscored these interconnections, reshaping our scientific understanding of how climate change, ecosystem disruption, and human activity drive disease emergence (Ellwanger et al, 2022; Gibb et al, 2024).

OH is indispensable for addressing complex health problems that transcend disciplinary boundaries (Allen-Scott et al, 2015; Bronzwaer et al, 2024). To embed this perspective early—already at school level—we introduce the One Health Teaching Clinic (OHTC): a university-based, design-based model in which pre-service science teachers (PS-STs) co-create OH lessons with subject-matter experts (SMEs; physicians, veterinarians, environmental scientists) and science-education researchers, thereby fostering transdisciplinary thinking in classrooms and, ultimately, in society (Hobusch et al, 2024). By positioning learning at the interface of scientific evidence and societal perspectives, the OHTC integrates S|E|H pedagogy, the OH approach, and Education for Sustainable Development (ESD) principles (Heuckmann and Zeyer, 2022). The model equips future teachers with competencies for navigating complexity, uncertainty, and value-laden health–environment issues (Heuckmann and Zeyer, 2022). In doing so, it supports global agendas such as the UN 2030 Agenda and its 17 Sustainable Development Goals (SDGs; Colglazier, 2015), and aligns with the ESD for 2030 roadmap objectives (Bylund et al, 2022).

2. Conceptual background: Two-Eyed Seeing and the Synoptic Transfer Framework

Effectively addressing sustainability and health challenges in education requires bridging empirical scientific knowledge with normative societal values. The Two-Eyed Seeing (TES) concept, articulated by Mi'kmaw Elders Albert and Murdena Marshall, provides a guiding heuristic for such a bridge (Bartlett et al, 2012) and was recently applied by the ESERA S|E|H Special Interest Group to accommodate diverse research interests (Zeyer et al, 2023). In philosophical terms, TES aligns with Wilfrid Sellars' distinction between the *scientific image*—grounded in empirical, objective facts—and the *lifeworld image*—grounded in personal experience, values, and social context (Esfeld, 2020). Rather than collapsing one into the other, TES seeks a reflective equilibrium between these perspectives (Roher et al, 2024). This guards against two classic fallacies: deriving *ought* from *is* (the naturalistic fallacy) (Frankena, 1939) and imposing *is* from *ought* (the moralistic fallacy) (Moore, 1957). Recent developments in S|E|H pedagogy have given rise to the Synoptic Transfer Framework (STF) as a practical model to implement the Two-Eyed Seeing heuristic in educational design (Zeyer and Aikenhead, 2025). The STF can be envisioned as a *braid* that intertwines the lifeworld and scientific perspectives through iterative cycles of explanation and interpretation. It delineates four critical educational “hotspots” – Engagement contexts (ENG), Scientific integrity (ISC), Scientific application (APL), and Narrative shaping (SNR) – each accompanied by guiding questions for educators (see Fig. 1).

These hotspots mark points in the teaching–learning process where knowledge must be translated between scientific and lifeworld domains. The approach treats health and the environment as inherently transdisciplinary themes that lie between societal narratives (e.g., the SDGs, the 2030 Agenda, public values) and individual-level factors (e.g., personal beliefs and experiences). For example, ENG asks how learners' everyday experiences and prior knowledge can be connected to the topic at hand; ISC asks what core scientific principles and evidence are crucial for understanding the issue; APL asks how knowledge can be applied to

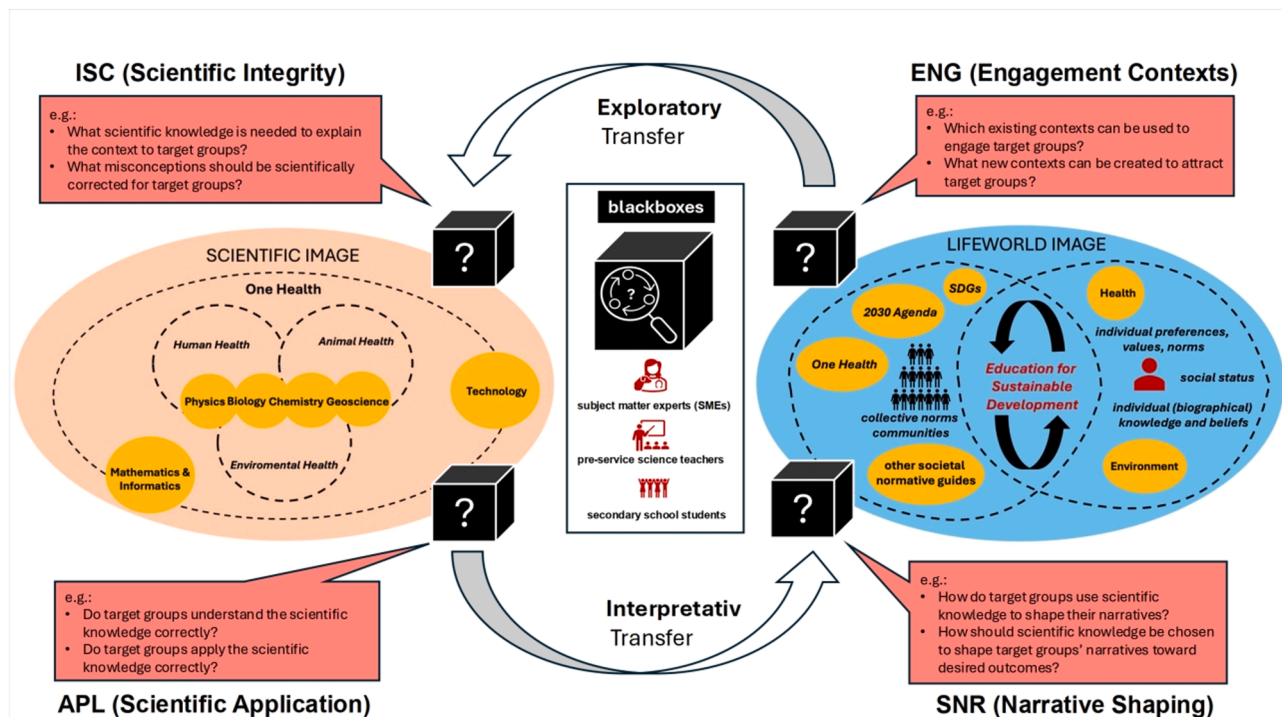


Fig. 1. Synoptic Transfer Framework (STF) applied to the One Health Teaching Clinic (OHTC). The model operationalizes the Two-Eyed Seeing heuristic across four educational hotspots — Engagement Contexts, Scientific Integrity, Scientific Application, and Narrative Shaping — to foster epistemic balance and alignment with Education for Sustainable Development. Adapted from Zeyer & Aikenhead (2025) and Heuckmann & Zeyer (2022).

real-world contexts or problem-solving; and SNR asks how learners can construct meaning and values, shaping a narrative around the issue. By structuring reflection around these questions, the STF provides a systematic way for teachers to integrate evidence-based reasoning with culturally and ethically grounded perspectives. In essence, the STF operationalizes Two-Eyed Seeing within the ESD framework, emphasizing the co-construction of meaning without sacrificing scientific accuracy. It thus supports a pedagogy of epistemic plurality, wherein multiple ways of knowing inform each other to address complex OH challenges in a manner that is both contextually relevant and scientifically sound. In science classrooms, this approach encourages critical thinking, systems thinking, and ethical reasoning coupled with solid scientific understanding (Heuckmann and Zeyer, 2022). Notably, ESD is interwoven with TES as a transformative paradigm rather than an add-on, fundamentally redefining the aims of science education to include sustainable futures and global citizenship competencies (Heuckmann and Zeyer, 2022; Vare and Scott, 2007). By learning to “keep both eyes open,” teachers and secondary students avoid conflating facts with values while engaging with complex socio-scientific issues in a holistic yet analytically rigorous way.

3. Bridging theory and practice: The One Health Teaching Clinic

The OHTC is a 13-week co-design “teaching clinic” that pairs pre-service science teachers (PS-STs) with OH subject-matter experts (SMEs) to create a lesson intertwining scientific evidence and lifeworld relevance around current health–environment issues. The “teaching clinic” sequence mirrors hospital training, rotating through planning, SME-expert discourse, classroom trial, and reflection, and deliberately fosters transdisciplinary and Two-Eyed-Seeing competences (see Table 1).

The process is scaffolded by Zeyer and Aikenhead’s Synoptic Transfer Framework (2025) (see Fig. 1), which articulates four educational hotspots that balance ways of knowing: Engagement Contexts (ENG), Scientific Integrity (ISC), Scientific Application (APL), and Narrative Shaping (SNR). Guiding questions at each hotspot keep disciplinary rigor and learner relevance in equilibrium throughout the clinic-like setting.

4. Design and implementation of the One Health Teaching Clinic

The analysis in this perspective article draws on the implementation of four OHTC cases (conducted in 2024/2025) corresponding to four distinct OH topics. Each project involved one SME (content expert) and a team of 4–6 PS-STs enrolled in a science teacher education program (OHTC). Over the course of each project, three SME–PS-ST sessions (see Table 1) were video-recorded, yielding a rich body of qualitative data on the collaborative knowledge-building process. In total, 12 interaction sessions (3 per project) were recorded, with a cumulative duration of about 677 min (11.3 h) of video screencasts. These recordings were transcribed verbatim in the original languages of communication (primarily German, with occasional English technical terms). The full transcript corpus amounted to approximately 250 pages of text. All personal identifiers (participant names, school names, etc.) were replaced with pseudonyms to ensure anonymity. The four projects, which we refer to by thematic focus, were as follows: (1) *One Health and the Berlin Principles* (Gruetzmacher et al, 2021) – a global OH policy framework; (2) *Plant Health – Ash Dieback Disease* (Langer et al, 2024) – forest pathology and ecosystem health; (3) *Protecting Our Future – One Health Approaches to Pandemics* (Ceruti et al, 2023) – zoonoses and public health; and (4) *One Health and Sustainable Food Production* (Espinosa-Marrón et al, 2022) – sustainable agriculture and nutrition.

Our analytic strategy was informed by the Synoptic Transfer Framework. We employed a qualitative thematic analysis (Braun and Clarke, 2006), using the four STF hotspots (ENG, ISC, APL, SNR) as an a priori coding schema. Initially, two researchers independently reviewed

Table 1
OHTC detailed 13-week workflow.

Week	Task (guided by workbook)	Description
1	Engagement with Disciplinary Expertise	Pre-service science teachers (PS-STs) are provided with selected scientific literature curated by One Health subject matter experts (SMEs) to build a foundational understanding of the topic. This establishes a common ground of current scientific knowledge.
2	First Concept Map (Science Lens)	The PS-STs in teams draft an initial concept map representing the scientific aspects of the One Health issue (e.g. key biological, environmental, and health concepts and their interrelations).
3	Expert Feedback Session 1 (~60 min, recorded)	In an online videoconference, PS-STs present their first concept map to the SME. The SME offers feedback to ensure scientific integrity – correcting inaccuracies, filling knowledge gaps, and deepening content understanding.
4	Refinement of First Concept Map	Incorporating the SME’s feedback, PS-STs revise their concept map so that it accurately reflects the state of the science. This iteration reinforces the importance of evidence-based accuracy in the lesson’s foundation.
5	Introduction to Two-Eyed Seeing	The instructors introduce the PS-STs to the Two-Eyed Seeing framework (Sellers’ two images and Marshall’s TES). This expands the teachers’ perspective beyond the scientific content, prompting them to consider everyday-life relevance and socio-cultural dimensions of the topic.
6	Second Concept Map (Lifeworld Lens)	Guided by the TES approach, PS-STs develop a second concept map focusing on learners’ lifeworld connections – such as students’ prior experiences, local context, and societal implications of the One Health issue.
7	Synthesis and Lesson Planning	The PS-STs merge insights from both concept maps to design a comprehensive lesson plan. Using a digital workbook scaffold (developed for OH-TC) and drawing on ESD competence models, they outline lesson objectives, learning activities, and assessment strategies. The emerging lesson is intended to bridge scientific content with real-world contexts, reflecting the TES balance.
8	Design Iteration with SME (Feedback Session 2) (~60 min, recorded)	The PS-STs reconvene with the SME to present their draft lesson design. The SME provides critique and suggestions, for example on the scientific feasibility of a proposed experiment or the appropriateness of a case study. This collaborative tuning ensures the lesson is both scientifically robust and pedagogically meaningful.
9	Instructional Approval	The refined lesson plan is reviewed by university science teacher educators (the course instructors) and, if needed, further adjustments are made. The goal is to ensure the plan meets curriculum standards and is ready for classroom implementation.
10 & 11	Implementation in Schools	The PS-STs carry out the lesson in a partner secondary school classroom.

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Table 1 (continued)

Week	Task (guided by workbook)	Description
12	Reflection and Dissemination (Feedback Session 3) (~60 min, recorded)	usually with their peers observing and the SME and teacher educator occasionally present. They collect any data planned (e.g., student work, feedback) and note critical incidents during teaching. After teaching, the PS-STs meet once more with the SME in a recorded session. They present the lesson outcomes and reflect on what was successful or challenging. Together, the group discusses implications for future practice and even potential follow-up research questions. This debrief helps consolidate learning and closes the loop by revisiting the One Health issue in light of the classroom experience.
13	Scientific Communication	In parallel with the final reflection, PS-STs (with their university mentors) distill their project into a scholarly output, such as a conference poster or short paper. This step encourages them to articulate the theoretical underpinnings and practical results of their work to a broader audience. It also reinforces the notion of teachers as contributors to educational research and innovation.

each transcript to identify segments corresponding to each hotspot – for instance, discussions where participants tried to connect the topic to secondary students’ everyday life were marked as ENG, exchanges ensuring accuracy of science content as ISC, and so on. We then compared and reconciled our coding (using QualCoder for qualitative data analysis) through discussion, achieving a high level of agreement on hotspot identification. Next, for each project, we constructed an analytic narrative (or vignette) that synthesizes how one particular hotspot played out saliently in that case. In doing so, we attended to both the diagnostic dimension (e.g., what challenges or prior conceptions were revealed) and the design dimension (e.g., what instructional moves were planned to address them), as prompted by the STF guiding questions.

We illustrate these vignettes with condensed excerpts from the transcripts, providing original quotations (translated into English) in the running text. Time-stamped references to the video data (in the format [Project, Session, hh:mm:ss]) are included for transparency. These vignettes are not exhaustive accounts of each project, but rather *zoom in* on critical moments that exemplify each STF hotspot in action. By presenting the data in this way, we aim to show concretely how the Two-Eyed Seeing approach, structured by the STF, informed both the process and content of PS-STs’ learning in the OHTC.

5. Results: STF hotspots in four One Health projects

Although all four STF hotspots naturally appear across each OHTC project, we highlight one particularly salient hotspot per case in the following vignettes, providing diverse insights into the application of the OHTC model across various OH contexts.

5.1. Engagement (ENG): connecting to people’s lives

In the OH *Pandemics* project, the planning discussions centered on choosing an example that would resonate with secondary students’ experiences. Early on, the SME encouraged the PS-STs to focus on a disease scenario that secondary students could readily relate to, given the recency of COVID-19. For instance, in debating whether to introduce a less familiar zoonotic disease (like rabies or avian influenza) versus the

coronavirus, the SME highlighted the importance of topical relevance: “That’s a really exciting example, primarily because it is highly topical...”. She pointed out that today’s secondary students, having lived through the pandemic, already possess significant prior knowledge: “The students can of course remember the COVID-19 pandemic and have more prior knowledge because of it” [Project 3, Session 1, 00:10:22]. This guided the PS-STs to design their lesson around a current and concrete context – in this case, comparing avian influenza and SARS-CoV-2 as emerging infectious diseases. By tapping into secondary students’ firsthand experience with pandemic disruptions, the lesson could more effectively engage interest and elicit discussion. Indeed, the PS-STs planned to begin by asking learners what they remembered about living through a pandemic, thereby validating the relevance of their personal experiences. This ENG-stage emphasis on lived experience aligns with the TES principle of starting from the lifeworld image. It ensured the lesson would not launch straight into abstract science, but rather build on the “everyday” awareness that even secondary students now carry about public health threats. The outcome was a more relatable entry point into complex content (virus reservoirs, transmission chains, etc.), illustrating how engagement context can catalyze motivation.

5.2. Scientific integrity (ISC): ensuring disciplinary rigor

The *Plant Health – Ash Dieback* project provided a clear illustration of how maintaining scientific integrity was paramount in the collaborative design. Ash dieback (caused by the fungus *Hymenoscyphus fraxineus*) is a complex phenomenon at the intersection of plant pathology and ecology. In the first SME feedback session, the conversation focused on getting the science right – correcting misconceptions and highlighting key causal relationships. The subject-matter expert, a forest ecologist, walked the PS-STs through the pathology step by step. At one point, he explained the invasive fungus’s interaction with native species: “...that *H. fraxineus* is pathogenic to the European ash, whereas the native fungus *H. albidus* is not pathogenic, but *fraxineus* displaces *albidus* in our forests.” He went on to describe the dire consequences of the infection: “The result is that ash trees decline... and there is a very high mortality of the trees.” [Project 2, Session 1, 00:21:30]. These detailed explanations (delivered in German with Latin species names) ensured the PS-STs understood the *scientific image* of the issue – an essential foundation before considering any societal or pedagogical angles. The PS-STs asked clarifying questions, for example, about how the fungus spreads and why Asian ash trees are resistant, to which the SME provided evidence-based answers. Maintaining this level of scientific integrity (ISC) was crucial not only for the accuracy of the eventual lesson but also for the PS-STs’ confidence. Only after solidifying the factual storyline – the introduction of an exotic pathogen leading to local biodiversity loss and safety hazards from dying trees – did the group feel ready to brainstorm teaching approaches. In terms of STF hotspots, the ISC phase in this project was about aligning the lesson content with up-to-date science: definitions of the disease, life cycle of the pathogen, ecological impacts, and potential mitigation measures. By front-loading scientific rigor, the OHTC format helps prevent the propagation of misconceptions in the classroom, addressing a core challenge in sustainability education where issues are often riddled with misinformation. Here, Two-Eyed Seeing acted as a check: even as the team would later discuss cultural values (such as the significance of ash trees in local folklore) or personal feelings about dying trees, those discussions rested on a bedrock of scientific understanding vetted by an expert.

5.3. Application (APL): bridging knowledge to action

A hallmark of ESD is empowering learners to apply knowledge to real-world problems and actionable solutions. This was exemplified in the *Sustainable Food Production* project, where the PS-STs designed a highly interactive lesson to convey the environmental footprint of

different protein sources. In their planning meeting, they enthusiastically described a hands-on simulation activity aimed at translating abstract data (land use, water use, CO₂ emissions) into tangible form for secondary students. One pre-service teacher explained how each secondary student group would visualize a specific resource use: “So they will use a box to represent the 5 square meters of land used... for water we planned blue styrofoam balls..., for CO₂ we planned to visualize with balloons...” followed by “...so that they have a direct visualization: ‘Okay, this is how much the beef uses, this is how much the pork uses.’” [Project 4, Session 2, 00:13:30]. By building towers of boxes and cylinders of balls, secondary students could literally see the comparative impacts of dietary choices. This creative idea impressed the SME, who noted that such tactile visualization is not only pedagogically engaging but also mirrors methods used by experts: “So you’re using a method that is actually used in real-world practice.” [Project 4, Session 2, 00:14:10]. She introduced the term “proportional piling,” a technique in community development where people use piles of objects (beans, stones, etc.) to represent data for decision-making. The PS-STs were thrilled to learn that their classroom idea had a direct analog in professional practice, reinforcing the authenticity of their approach. In STF terms, this vignette highlights the APL hotspot – the translation of knowledge into practice. The PS-STs weren’t content with secondary students simply *knowing* that, say, beef has a larger water footprint than chicken; they wanted secondary students to experience the magnitude of difference through activity. This application-oriented mindset is vital for sustainability education, which aims to spur learners toward *action competence*. By the end of the project, the implemented lesson saw secondary students building the proposed models and discussing why these differences arise (e.g., feed conversion ratios, life-cycle energy use). The APL focus thus not only reinforced scientific concepts (through applied math and modeling) but also empowered secondary students with a systems perspective on a daily-life issue (food choices). The OHTC setting, by enabling PS-STs to collaborate with an SME and iterate on such ideas, ensured that the application was both imaginative and scientifically grounded.

5.4. Narrative shaping (SNR): integrating values and meanings

The *Berlin Principles* OH project operated at a broad policy level, which naturally led to discussions about values, priorities, and the “big picture” narrative of health and sustainability. Here, the PS-STs had engaged with texts on the Berlin Principles on OH – a set of guidelines linking human, animal, and environmental health – and were eager to translate this global framework for a high school audience. A critical moment in the second session occurred when a PS-ST asked the SME (an expert in wildlife conservation and OH policy) how priorities might have shifted in the past decade regarding sustainable development goals. This prompted a rich reflection by the SME on the fluidity of societal narratives. She explained that the weight given to different aspects (environmental, social, animal welfare, etc.) can change rapidly with events and context. For instance, climate concerns were front and center until the COVID-19 pandemic hit; then suddenly the public narrative pivoted to health security. Later, the war in Ukraine introduced new priorities, affecting energy and food discussions. Such context-setting underscored that there is no single static narrative in OH – instead, educators must help secondary students appreciate the dynamic interplay of factors. She emphasized the need to “keep everything in view” and be ready for priorities to “flip” with changing circumstances [Project 1, Session 2, 00:39:00]. This exchange set the stage for the PS-STs to consider a classroom activity where secondary students debate scenarios that pit one priority against another (e.g., wildlife conservation vs. public health in disease outbreaks), thereby practicing the weighing of trade-offs. The narrative-shaping role of the teacher here is to facilitate understanding that OH issues involve ethical and societal choices, not just technical solutions. As the SME put it, the whole point of OH is to highlight “the connections and interdependencies between the health of humans, other

animals, and ecosystems” [Project 1, Session 2, 00:13:03]. She noted that the Berlin Principles emerged to broaden OH beyond just zoonotic diseases, explicitly incorporating ecological justice and sustainability. For the PS-STs, this clarified that their lesson should not only impart knowledge about the Berlin Principles but also engage secondary students in thinking about how those principles play out in real-world contexts (for example, how preventing the next pandemic might require rethinking land-use practices, or how Indigenous knowledge could inform wildlife health monitoring). In the enacted lesson, secondary students ultimately worked on creating their own “One Health charter” for their community, effectively shaping a narrative that mirrored the Berlin Principles but in locally meaningful terms. This SNR vignette illustrates how the OHTC model supports pre-service teachers in navigating the values-laden dimension of sustainability education. Through expert modeling and dialogue, the teachers learned to openly discuss uncertainties and value judgments, and to guide learners in constructing a coherent narrative that links personal actions to global health outcomes. In other words, they practiced the art of storytelling in science education – framing scientific facts within contexts of purpose and meaning, a skill essential for motivating sustainable action.

6. Discussion

Across these four vignettes, we see a through-line of how the Two-Eyed Seeing (TES) approach and the Synoptic Transfer Framework (STF) jointly informed the design and facilitation of learning in the OHTC. Each vignette corresponded to a key STF hotspot, yet in practice all four hotspots are deeply interdependent. Taken together, they illustrate a holistic teaching model that is at once scientifically rigorous and richly contextual – a model we argue holds much promise for advancing Education for Sustainable Development (ESD) in teacher education.

6.1. Synthesis of vignettes through the TES/STF lens

In the engagement vignette, the focus was on forging connections to secondary students’ lifeworld experiences (ENG), which in TES terms means starting with the manifest image familiar to learners. The Pandemics project showed that by acknowledging secondary students’ lived experience (e.g., the COVID-19 pandemic), teachers can more effectively draw their attention to the scientific content. However, that engagement alone would not suffice without the scientific integrity (ISC) element – as the Ash Dieback case demonstrated, ensuring the factual and conceptual accuracy of the science content is non-negotiable. The ISC hotspot maintained the scientific image at a high standard, which actually empowered the teachers to be more creative later, knowing that their lesson rested on sound science. The application vignette then highlighted how bridging the two images can generate innovative pedagogy: the PS-STs translated scientific data into a tangible, embodied learning experience, effectively bringing the scientific and lifeworld perspectives together in a hands-on activity. This reflects what the STF describes as *interpretative transfer* – using lifeworld modes (boxes, balls, analogies) to interpret and internalize scientific knowledge. Finally, the narrative shaping vignette zoomed out to the ethical and societal storyline, reminding us that in sustainability and health education we ultimately aim to help learners construct meaning and a sense of agency about the problem. The Berlin Principles project underscored that shaping a narrative (SNR) involves grappling with shifting priorities and value judgments. Here, the TES dual perspective was crucial: the teachers had to present OH not just as a set of scientific facts (e.g., disease dynamics) but as a paradigm that includes Indigenous wisdom, environmental ethics, and global justice considerations. Through the OHTC process, the PS-STs practiced moving back and forth between these levels – one moment discussing the molecular biology of viruses, the next discussing how community values influence disease prevention. In doing so, they enacted what Zeyer and Aikenhead (2025) describe as the braiding of the two epistemological images. The STF’s structured

hotspots made this braiding more explicit and attainable by breaking the complexity into four manageable focal points. Notably, while each vignette emphasized one hotspot, elements of the others were always present (for instance, the Ash Dieback team, even while focused on science content, were implicitly considering how to engage secondary students with it later). This speaks to the iterative nature of STF: effective teaching may start at any hotspot, but it will cycle through all four in a dynamic equilibrium, much like repeatedly alternating between scientific explanation and contextual interpretation.

6.2. Contributions to science teacher education and classroom practice

The experience of the PS-STs suggests several implications for science teacher education. First, engaging PS-STs in authentic co-design with experts proved to be a powerful form of professional learning that also directly links the OHTC model with S|E|H pedagogy (Zeyer et al., 2021, 2023). Rather than passively learning about TES or ESD principles, the PS-STs actively applied them in a co-designed project. This mirrors a design-based approach for teacher education where theory is not taught in isolation but through its use in practice. Such an approach could be adopted more broadly in science teacher education programs – for instance, partnering PS-STs with community experts or scientists to develop interdisciplinary lessons on climate change, biodiversity, or other socio-scientific issues. It gives PS-STs a safe space to experiment with novel pedagogies (like those described above) while having a content safety net provided by the SME. Second, the STF hotspots can serve as a reflective checklist or scaffold for science teachers aiming to incorporate Two-Eyed Seeing in their teaching. As our cases illustrate, a teacher could ask themselves: Have I considered ENG? (Will this topic feel relevant to my secondary students' lives?); Have I ensured ISC? (Am I confident in the scientific accuracy and integrity of what I'm teaching?); What about APL? (Am I giving secondary students a chance to apply or do something with this knowledge?); and What is the SNR? (What broader meaning or narrative do I want secondary students to take away, and does it connect to their values?). These guiding questions, drawn from the STF, can help teachers design more balanced and impactful lessons. In our projects, when a hotspot was initially overlooked, the collaborative format and STF prompts helped bring it to light – for example, one group initially had a very research-heavy plan (strong on ISC) but realized through discussion that they needed to add an engagement hook and a concluding narrative to make it work for secondary students. Thus, incorporating the STF framework in teachers' professional development could strengthen educators' capacity to self-monitor and enhance their lessons' alignment with sustainability competencies.

6.3. Limitations and future research directions

This perspective is exploratory in nature, focusing on a small number of pilot cases in a specific context. One limitation is the sample size and diversity of cases – four project implementations in related cultural settings (Central Europe) may not capture the full range of how TES and STF could play out. As the OHTC initiative scales up to other institutions and countries (expansions to Sweden and Spain are planned), comparative research could examine how cultural and disciplinary differences influence the braiding process. For instance, would the approach work similarly in a social science teacher program or in a setting with a strong Indigenous secondary student presence? Another limitation is that we assessed the process primarily through teacher and expert discourse; we have not yet examined secondary student outcomes in the secondary classrooms. While our focus was on PS-STs' learning, ultimately the efficacy of this model should also be judged by what secondary students gain (in terms of knowledge, skills, and motivation for sustainable action). Future research should examine secondary students' data from OHTC-designed lessons: Do learners exhibit a greater ability to link science with societal issues? Do they show increased systems thinking or

empathy for other perspectives after being taught with a TES approach? Measuring such outcomes could involve pre/post assessments of secondary students' understanding of OH or sustainability concepts, or analyzing secondary student reflections for evidence of dual-perspective reasoning. Additionally, longitudinal studies could track the PS-STs into their early teaching careers to see if and how they carry forward the TES approach. Do alumni of the OHTC, now full-fledged teachers, design their curricula differently? What supports or hinders the sustained use of Two-Eyed Seeing in real school environments (e.g., curricular constraints, exam pressures)? Answering these questions would help determine the long-term impact of incorporating frameworks like STF in teacher education.

7. Conclusion

The OHTC model provides a fertile training ground for future educators to practice integrating multiple ways of seeing and knowing. By braiding Two-Eyed Seeing with Education for Sustainable Development through the structured guidance of the Synoptic Transfer Framework, the OHTC addresses a crucial application of S|E|H pedagogy for our education systems: preparing science teachers who can help learners navigate the complex, value-charged challenges of the 21st century. The four vignettes illustrate that when teachers learn to open both eyes – grounding themselves in solid science while also embracing socio-cultural insight – they are better equipped to foster secondary students who are not only scientifically literate but also socially and ethically aware. In a world where issues like pandemics, climate change, and food security dominate headlines and daily lives, such an integrative approach to science education is not just innovative but necessary. We encourage further experimentation and research in bringing Two-Eyed Seeing into classrooms, and we envision science teacher education as a critical leverage point for this transformation. By supporting teachers to become weavers of knowledge and perspective, we set the stage for the next generation of learners to approach global health and sustainability challenges with wisdom, creativity, and a profoundly two-eyed vision.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the first author used DeepL and ChatGPT to improve language. Literature search was supported by Elicit. After using these tools/services, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Data availability

Due to participant confidentiality, raw data are not publicly available but may be provided by the corresponding author under a data-sharing agreement.

CRediT authorship contribution statement

Ulrich Hobusch: Writing – review & editing, Writing – original draft, Visualization, Project administration, Conceptualization. **Petra Bezeljak Cerv:** Writing – original draft. **Uwe K. Simon:** Writing – original draft. **Benedikt Heuckmann:** Writing – original draft, Supervision, Conceptualization. **Gregor Torkar:** Conceptualization. **Sebastian Stuppan:** Conceptualization. **Dominik E. Froehlich:** Conceptualization. **Sascha Johann:** Conceptualization. **Franziska Messenboeck:** Visualization, Project administration, Conceptualization. **Noah S. Kluempfen:** Data curation. **Sandra A. Barilits:** Conceptualization. **Kerstin Kremer:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **Martin Scheuch:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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