education sciences

MDPI

Article

Fostering Critical Thinking Through Interdisciplinary and Transdisciplinary Education—A Boundary-Crossing Approach in Biomedical Science Education

Elianne M. Gerrits *, Cathelijne M. Reincke, Annelies Pieterman-Bos and Marc H. W. Van Mil

Center of Education and Training, University Medical Center Utrecht, 3584 CS Utrecht, The Netherlands; c.reincke-2@umcutrecht.nl (C.M.R.); j.e.bos-11@umcutrecht.nl (A.P.-B.); m.h.w.vanmil@umcutrecht.nl (M.H.W.V.M.)

* Correspondence: e.m.gerrits-3@umcutrecht.nl

Abstract

Critical thinking (CT) is essential for navigating the complex socio-scientific issues in contemporary biomedicine. These issues cross disciplinary boundaries and involve multiple societal stakeholders. Interdisciplinary and transdisciplinary (ITD) education therefore provides a valuable context for developing CT by confronting students with diverse forms of knowledge and prompting reflection on their disciplinary assumptions. In this study, boundary crossing is used as a pedagogical framework, with a focus on identification (understanding alternative perspectives) and reflection (examining one's own assumptions). We examine how such ITD education can foster CT by enhancing students' appreciation of disciplinary and societal viewpoints. Data from a pre- and post-course assignment were analyzed using a convergent mixed-methods approach. Students ranked the relevance and effectiveness of sessions engaging with different perspectives and identified educational design elements that contributed to broadening their biomedical outlook. Findings indicate shifts in how students perceived the relevance of different perspectives. Particularly, appreciation of the legal perspective increased. Sessions were considered most effective when involving interaction with perspective owners, interactive learning methods, and clear instructional design. The results suggest that boundary-crossing pedagogies can support CT in higher education by engaging students in reflective engagement with different disciplinary and societal perspectives.

Keywords: critical thinking; transdisciplinary education; boundary crossing; biomedical education

Check for updates

Academic Editors: Jordi Solbes and Teresa Lupión-Cobos

Received: 10 January 2026
Revised: 14 February 2026
Accepted: 19 February 2026
Published: 22 February 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

1. Introduction

Contemporary scientific practice increasingly requires researchers to navigate complex socio-scientific issues. These issues emerge from both groundbreaking innovations and routine scientific practice. Developments such as gene editing, artificial intelligence, and synthetic biology generate ethical, legal, and social questions that extend well beyond the laboratory. At the same time, more subtle and systemic concerns, such as privacy risks in data sharing, sustainability challenges related to laboratory waste, and biases in study design or participant recruitment, shape the societal impact of scientific work. Because these socio-scientific issues are inherently multifaceted and span disciplinary boundaries, addressing them requires integration of expertise from diverse disciplinary fields (i.e., interdisciplinary collaboration). Moreover, given their impact on patients, communities,

and society at large, addressing these issues effectively also demands moving beyond disciplinary perspectives and engaging stakeholders and the wider public (i.e., transdisciplinary collaboration). Interdisciplinary and transdisciplinary (ITD) collaborations are therefore acknowledged as imperative to contemporary research practice, including biomedicine. Consequently, there is growing recognition that biomedical science students should receive training to prepare them for future ITD collaboration (Boon & Van Baalen, 2019; Tripp & Shortlidge, 2019).

Key competencies associated with ITD collaboration include the ability to compare perspectives, evaluate the credibility of different knowledge sources, and make well-reasoned judgments in contexts marked by uncertainty and controversy (Daneshpour & Kwegyir-Afful, 2022). These competencies align closely with critical thinking, defined as the process of purposeful, self-regulatory judgment involving the well-reasoned evaluation of evidence, assumptions, and alternative viewpoints (Davies, 2015; Facione, 1990). ITD collaboration therefore constitutes a particularly valuable educational context for development of critical thinking, as students are required to engage with multiple, and sometimes competing, forms of knowledge. This positions critical thinking as a central competency in university-level biomedical education, and underscores ITD education as a particularly effective context in which it can be cultivated.

In this study, we discuss the design and implementation of an undergraduate course offered at the end of the first year of a biomedical science bachelor's program at Utrecht University (UU). The course, entitled "Eye for Impact," aims to broaden students' perspectives on socio-scientific issues in biomedical research and innovation. Additionally, it aims to introduce students to the relevance of ITD collaboration and diverse forms of knowledge for solving these socio-scientific issues. This course fosters critical thinking by encouraging students to evaluate the added value of incorporating different viewpoints, including disciplinary and societal perspectives, in solving socio-scientific issues. This use of different perspectives and disciplinary approaches in education teaches them to critically reflect on diverse sources of information as well as to reflect on their own assumptions (Wansink et al., 2023).

To effectively harness the potential of incorporating different viewpoints in education, students must be actively involved in selecting relevant perspectives on the societal issues that are discussed (Vereijken et al., 2023). Such involvement requires students to evaluate the relevance of different perspectives. Therefore, this study aims to (1) identify which perspectives students consider relevant to broaden their outlook as future biomedical scientists and (2) characterize educational design features that support students in critically appraising these perspectives as relevant. To this end, we examined how students perceived the relevance of the various perspectives addressed in the course, both before and after the course. Furthermore, we invited students to suggest additional perspectives they considered relevant. Finally, we explored whether and how any shifts in perceived relevance could be attributed to specific elements of the course's educational design.

2. Theoretical Background

2.1. Critical Thinking Through Interdisciplinary and Transdisciplinary Education

Socio-scientific issues (SSIs) in biomedical research are inherently complex because scientific questions are intertwined with ethical, legal, and societal considerations. Such SSIs cannot be adequately addressed within a single disciplinary framework; they demand engagement with multiple disciplinary and societal perspectives. Interdisciplinary and transdisciplinary (ITD) collaboration is therefore essential to address these complex issues. In interdisciplinary collaboration insights from multiple disciplines are integrated to develop a more comprehensive understanding of a problem (Boix-Mansilla, 2017; Klein, 1996;

Newell, 2013; Repko & Szostak, 2020; Spelt et al., 2009). Transdisciplinary collaboration goes further by incorporating diverse forms of knowledge beyond academia, including societal perspectives, as well as input from non-academic stakeholders (Alvargonzález, 2011; Daneshpour & Kwegyir-Afful, 2022; Guimarães et al., 2019; Klein, 1996).

To effectively participate in future ITD collaborations, students need to develop capacities such as openness to alternative viewpoints, tolerance of ambiguity, reflexivity, and awareness of the broader implications of one's work (Augsburg, 2014; Boon et al., 2019; Fortuin et al., 2024; Giri, 2002; Godemann, 2008; Vogel & Hunecke, 2024). These capacities resemble competencies and skills central to critical thinking, including open-mindedness, intellectual humility, and respect for alternative perspectives (Davies, 2015; Ennis, 2011; Fisher, 2003; Waite & Davis, 2006). Consequently, ITD education offers a particularly suitable context for cultivating critical thinking, as it exposes students to diverse forms of knowledge and requires them to evaluate, compare, and reflect upon competing perspectives in a socio-scientific context.

In response to the growing appreciation for ITD competencies in higher education, a wide range of ITD educational approaches has been introduced, most of which emphasize experiential learning, where students collaborate with peers from different disciplines, societal stakeholders, or the broader public (Daneshpour & Kwegyir-Afful, 2022; Gulikers et al., 2025; Horn et al., 2023). While such experiences provide valuable exposure to ITD practices, they possibly fall short in addressing the cognitive and epistemological challenges researchers face when engaging in ITD research (Agustian, 2023; Boon & Van Baalen, 2019; Fortuin et al., 2024; Oonk et al., 2022; van Baalen & Boon, 2024). Students may benefit most from advanced forms of ITD education when they already possess relevant competencies (Horn et al., 2024). This underscores the importance of preparatory ITD education that supports students in becoming aware of and reflecting on their emerging disciplinary assumptions at an early stage of their undergraduate studies.

In our efforts to develop such preparatory ITD education, we drew on the framework of boundary crossing, which approaches ITD teaching by focusing on learning at the intersections of disciplines (Akkerman & Bakker, 2011). At these boundaries the following four learning mechanisms take place: students are (1) gaining insight into their own disciplinary perspective and how other disciplines approach an issue (identification), (2) reflecting on their own discipline through the lens of another (reflection), (3) coordinating collaboration through shared tools and procedures (coordination), and (4) integrating new ways of thinking and acting into their evolving professional identity (transformation) (Akkerman & Bakker, 2011; Fortuin et al., 2024; Oonk et al., 2022; Vereijken et al., 2023). Of these mechanisms, identification and reflection are particularly relevant to the development of critical thinking, as they closely align with core components of critical thinking such as appreciating alternative perspectives and critically appraising one's own and others' views.

In the context of this preparatory ITD course, we deliberately focused on identification and reflection as the primary learning mechanisms. Coordination, which presupposes active interdisciplinary or transdisciplinary collaboration through shared tools and procedures in collaborative practice, was not a central component of the course design. Likewise, transformation, understood as the integration of new ways of thinking and acting into a stable professional identity, was not an explicit learning objective at this stage. Rather, the course aimed to create conditions for future transformation by fostering epistemological awareness and reflection on emerging disciplinary and personal positions.

The present study therefore examines how an educational design centered on identification and reflection supports students in recognizing the relevance of multiple perspectives and, through this process, fosters critical engagement with complex socio-scientific issues in biomedicine.

2.2. Recognizing and Integrating Multiple Perspectives

Within the framework of boundary crossing, developing the capacity to work across disciplinary boundaries begins with becoming aware of one's own disciplinary perspective. ITD collaboration requires researchers to not only have a deep understanding of their own disciplinary perspective but also to recognize the value of other perspectives.

A disciplinary perspective is the cognitive framework through which a discipline approaches problems, generates knowledge and interprets phenomena. It encompasses a discipline's key concepts, theories, methodologies, and epistemological assumptions (Repko & Szostak, 2020; van Baalen & Boon, 2024; Vereijken et al., 2023). This perspective is typically shaped through formal education but often remains implicit, leaving students unaware of how it influences their reasoning.

For first-year students, such disciplinary perspectives are not yet fully developed or explicitly articulated but are nevertheless present. Making these emerging perspectives explicit is a critical first step in developing the reflective capacities required for later ITD collaboration. In the boundary-crossing framework, making one's disciplinary assumptions explicit in relation to other disciplines is described as identification. Identification involves two processes, (1) othering: recognizing one's own identity by defining differences and similarities between one's own discipline and other disciplines, and (2) legitimate coexisting: acknowledging and accepting different disciplinary practices as valid and meaningful (Akkerman & Bakker, 2011; Oonk et al., 2022; Vereijken et al., 2023).

A second learning mechanism described in the boundary-crossing framework is reflection, which refers to expanding one's perspective by engaging with those of others (Akkerman & Bakker, 2011; Oonk et al., 2022; Vereijken et al., 2023). Reflection encompasses both perspective-making and perspective-taking. Perspective-making involves critically examining one's own disciplinary perspective, while perspective-taking entails understanding and integrating how others interpret a given situation (Akkerman & Bakker, 2011; Boland & Tenkasi, 1995; DeZure, 2017; Fortuin et al., 2024; Szostak, 2024).

In ITD education, perspective-taking is often described as the practice of adopting multiple disciplinary perspectives, leading to a more thorough understanding of complex problems. However, perspective-taking can also be understood more broadly, as the capacity to adopt another person's viewpoint, including their thoughts, feelings, and motivations. Effective perspective-taking, in this broader conceptualization, is linked to empathy (Nussbaum, 2003) and moral reasoning (Gerrits et al., 2023; M. Johnson, 1993).

Within this broader context, Kahn and Zeidler (2019) introduced the concept of socio-scientific perspective-taking (SSPT), a form of perspective-taking specifically aimed at recognizing societal perspectives, especially in contexts characterized by conflicting values, interests, and ethical uncertainty. Crucially, SSPT identifies a moral context and a moral compass as a prerequisite for perspective-taking to solve socio-scientific issues (Kahn & Zeidler, 2019). This broader conceptualization of perspective-taking closely relates to multiperspectivity, which emphasizes the importance of understanding and appreciating multiple, often contrasting, viewpoints (Wansink et al., 2023). Employing different perspectives in education about controversial and even polarizing topics can stimulate self-awareness of a personal perspective on the topic as well as acknowledgement and appreciation of different perspectives (M. R. Johnson et al., 2017; Parker, 2016).

3. Rationale for the Course and Current Study

Building on insights from boundary crossing, this study approaches critical thinking as a process that is fostered through students' engagement with multiple perspectives on complex socio-scientific issues. Within this context, we distinguish four categories of perspectives that are central to such engagement: students' personal perspectives (shaped

by lived experience and values), their disciplinary perspectives (formed through academic training), other disciplinary perspectives (with distinct conceptual and methodological approaches), and societal and stakeholder perspectives grounded in contextual and experiential knowledge. Engaging with these perspectives creates structured opportunities for identification and reflection, supporting students in evaluating relevance, integrating viewpoints, and developing critical engagement with complexity.

Rather than conceptualizing critical thinking as a directly measurable skill, this study approaches its development as a process shaped through engagement with multiple perspectives, reflection, and reconsideration of assumptions. Accordingly, students' judgments about the relevance of diverse perspectives are used as a meaningful but indirect indicator of critical thinking development.

From an educational design perspective, this raises the question of how learning environments can support students in recognizing, valuing, and engaging with diverse perspectives. This effectiveness of perspective-based education may depend on which perspectives are introduced, how they are connected to students' personal and disciplinary frames, and how relevant they are perceived in relation to real-world socio-scientific challenges. This study therefore examines how students evaluate the relevance of different perspectives and which educational design elements shaped their perception of relevance. In doing so, we aim to identify which approaches may best support students in their development of critical thinking.

4. Educational Design of the Course Eye for Impact

4.1. Course Objective

The course described in this study aims to broaden students' perspective by encouraging them to reflect on biomedical research through other disciplinary and societal perspectives. The educational design is grounded in the first two learning mechanisms of boundary crossing: (1) identification, to gain insight into how biomedical science and diverse other perspectives approach issues that impact society, and (2) reflection, to examine SSIs in which biomedical research plays a central role, both from students' own personal and disciplinary perspectives and from the perspectives of other disciplinary and societal stakeholders.

4.2. Bioethics, Philosophy of Science and Science Communication

The course begins with two introductory sessions and culminates in a final session designed to provide students with a strong foundation in three fundamental (non-biomedical) disciplines. The initial sessions focus on bioethics and philosophy of science, while the final session centers on science communication. We consider these disciplines essential for fostering critical reflection on biomedical science by helping students become aware of their emerging disciplinary perspectives while also encouraging them to explore how their backgrounds and values shape their personal perspectives (Gerrits et al., 2022; Pieterman-Bos & van Mil, 2023; Reincke et al., 2024). Each session consists of a lecture, where students are introduced to foundational theories from the relevant disciplines, followed by a seminar in which they apply these theories to reflect on the societal impact of biomedical research and innovation.

In the bioethics sessions, students discuss how to navigate the ethical dilemmas inherent in biomedical advancements, ensuring they consider societal and moral implications. To identify and discuss these societal and moral implications, students reflect on the four principles of Beauchamp and Childress; respect for autonomy, non-maleficence, beneficence, and justice (Beauchamp & Childress, 2001). In the seminar, students reflect on how these principles might be upheld or compromised in a particular case and on how

considering various perspectives on the case can help in balancing competing principles (Gerrits et al., 2023).

In the philosophy of science sessions, students reflect on the nature, origins, and history of science, helping them understand the underlying assumptions, methods, and limitations of scientific inquiry, fostering epistemological awareness. Major misconceptions about the nature of science (NOS) are discussed with students derived from the consensus framework of NOS (Abd-El-Khalick et al., 2008, 2024). In addition, different epistemologies are discussed to broaden students' views on what might constitute the nature of (rigorous) science (Pieterman-Bos & van Mil, 2023). In the seminar, students are stimulated to formulate and develop their own view of NOS.

In the science communication sessions, students learn about effectively conveying complex biomedical knowledge to diverse audiences, including policymakers, practitioners, and the public. In this session, the dialogue model of science communication is discussed in contrast to the deficit model. While the deficit model focuses on one-directional knowledge transfer from experts to a passive audience, the dialogue model emphasizes two-way communication, fostering mutual understanding between researchers and society (Dudo & Besley, 2016; Reincke et al., 2020). The seminar includes a project in which students have to develop a short explanatory video that discusses the ethical and societal impact of a recent biomedical innovation.

4.3. Reflecting on Six Perspectives Through Co-Creation and Perspective-Owner Interaction

In the remainder of the course, students are introduced to additional perspectives during six thematic sessions: the patient, the research participant, the legal expert, the pharmaceutical company, the planet (sustainability sciences), and the methodologist. These perspectives were carefully selected by the course development team, drawing inspiration from current socio-scientific issues (SSIs) where biomedical science plays a crucial role. In alignment with the ELSA framework (Zwart & Nelis, 2009), the course includes perspectives that help reflect on the ethical, legal, and social aspects of biomedical research and innovation. To develop these sessions, we collaborated with disciplinary experts and societal stakeholders (perspective owners) who provided specialized content. Each perspective owner was paired with a biomedical science teacher to co-create a session, ensuring that new disciplinary insights were accessible and relevant to biomedical students. To foster connections between different course components, the foundational theories discussed in the introductory sessions (see Section 4.2) were intentionally revisited and integrated into the thematic sessions. Each session combined short lectures with interactive discussions and assignments. In some sessions, the perspective owner and biomedical science teacher co-taught the session, while in others the perspective owner led the session independently. Students were actively encouraged to engage with each perspective by asking questions and exploring the stakeholder's core values, expectations, and concerns regarding the socio-scientific issues. Sessions featuring disciplinary perspectives (legal expert, planetary perspective, and methodologist) introduced prominent and relevant theories within this discipline and distinct methods to analyze and approach the discussed SSIs. Sessions focusing on societal and stakeholder perspectives (patient, research participant, and pharmaceutical company) encouraged students to engage with and consider the interests and values of the perspective in relation to the SSIs. A summary of the perspectives that were central in the thematic sessions and the SSIs that inspired the sessions can be found in Table 1.

Table 1. Overview of the six thematic sessions included in the course. These sessions explore three disciplinary perspectives (Planetary Perspective, Methodologist, and Legal Expert) and three societal (stakeholder) perspectives (Patient, Research Participant, and Pharmaceutical Company). Each session is framed around a socio-scientific issue in which both the biomedical disciplinary perspective and the respective societal or stakeholder perspective play a significant role.

	Perspective	Socio-Scientific Issue	Description
Disciplinary perspectives	Planetary perspective (Sustainability Sciences)	Climate change and sustainability in biomedical research	Climate change has a two-fold impact on biomedical research. Biomedical research has a significant environmental footprint, as laboratory research and pharmaceutical production contribute to carbon emissions, resource depletion, and waste generation. Furthermore, climate change influences our health, changing disease patterns in society. In this session, students reflect on the balance between planetary and societal health.
	Methodologist	Biomedical science misinformation	The rise in misinformation in science and medicine underscores the need for methodologic rigor as well as accurate and transparent public science communication. In this session, students discuss how they can critically assess data and how misinformation comes into being.
	Legal expert (legal studies)	Embryo research and the Dutch Embryo law	Legal and ethical considerations are central in embryo research in which scientific progress should be balanced with moral and societal concerns. In this session, students reflect on the legal status of an embryo, and the practical implications of the Dutch embryo law.
Societal Perspectives	Patient	Patient engagement and research priority setting	While patient engagement is often emphasized in clinical research and healthcare decision-making, its role in fundamental biomedical research is equally crucial. In this session, students reflect on the benefits of involving patients early in the research process to align scientific priorities with real-world health needs, ensuring that discoveries have meaningful translational potential.
	Research participant	Diversity and inclusivity in biomedical research	The inclusion of diverse populations in biomedical research is essential for ensuring generalizability and equity of scientific findings. In this session, students discuss historical and current biases and systemic exclusions in biomedical research and the impact this had on the validity and integrity of research.
	Pharmaceutical Company	Healthcare costs and accessibility	The rising cost of healthcare results in disparities in access to medical treatment, as well as economic challenges. In this session, students reflect on how economic evaluations regarding healthcare are made in the Netherlands.

4.4. Course Assessment

While the primary goal of the course is to expose students to diverse perspectives, successful completion required passing an exam. The exam was divided into two components: 50% of the grade assessed students' ability to apply the theories and insights discussed during the course, while the remaining 50% was based on an argumentative essay. In the open-ended questions, students were asked to apply the theories discussed during the course to short case descriptions. Examples include formulating moral arguments for and against a proposed study design, applying legal frameworks to concrete cases, or explaining how a patient perspective could be meaningfully integrated into a research design. In the essay, students had to critically evaluate whether the described innovation should be further developed. They were allotted 1.5 h to complete the essay, without access

to the internet or generative AI, ensuring that their responses were based solely on their own insights and the knowledge gained from the course. To help students prepare for writing the essay, two non-mandatory writing workshops were offered.

5. Methods

5.1. Context of Study and Participants

Eye for Impact is a mandatory, 5-week, half-time course offered at the end of the first year of the biomedical bachelor's program at Utrecht University. This bachelor's program is discipline-specific and highly research-oriented. Of the 175 students that start the program each year, approximately 97% of students continue with a biomedical research master after their bachelor's program. The participant group consisted of 173 students, 67.6% (117) women and 32.4% (56) men, with ages ranging approximately from 18 to 23 years.

5.2. Data Collection

Data were collected during the academic year 2023–2024. Data consisted of student responses to a course assignment that was taken prior to (pre-test) and after (post-test) the course. In both the pre-test and post-test assignment students ranked the six perspectives presented in the thematic sessions based on how they perceived their relevance for broadening their perspective. They were also invited to suggest additional perspectives they felt were missing from the course. In the post-test, students repeated the relevance ranking and additionally ranked the perspectives based on how effective they found the corresponding thematic sessions in broadening their perspective. Furthermore, they were asked to identify specific educational elements that contributed to this aim. The full assignment is provided in the Supplemental Materials (Supplementary Data S1). A total of 173 students registered for the course. For the pre-test, 118 students completed the online assignment, of whom 87 gave consent to use their responses for research purposes (response rate: 50%). For the post-test, 89 students completed the assignment, with 83 consenting to participate in the research (response rate: 48%).

Participants were presented with the assignment in an online environment (Qualtrics). After completion of the assignment, responses were automatically collected. Students who had not given consent were removed from the dataset. For students who had given consent, pre- and post-assignment responses were coupled (n = 62). Lastly, all data was pseudonymized by removing student numbers and replacing them with a unique identifier for each student.

5.3. Data Analysis

We adopted a convergent mixed-methods research design (Creswell, 2021). Data collection and analysis of both quantitative and qualitative data occurred simultaneously, and insights from these analyses were combined to answer the research questions.

5.4. Quantitative Analysis

Our quantitative analysis concentrated on investigating three potential differences in mean ranking:

A. Differences in perceived relevance for broadening students' perspective between the six perspectives, assessed for both the pre-test and post-test.
B. Differences in perceived relevance for each perspective between the pre-test and post-test.
C. Differences in perceived effectiveness of the educational intervention between the six perspectives in the post-test.

For each perspective, the mean rank and standard deviation regarding relevance (A) and effectiveness (C) were calculated for both pre-test and post-test to understand the central tendency and variability of rankings. The non-parametric Friedman test was used to determine whether there were statistically significant differences in the perceived relevance (A) and effectiveness (C) among the six perspectives. If the Friedman test indicated significant differences, pairwise comparisons were conducted using the Wilcoxon signed-rank test to identify specific differences.

In addition, we determined whether there were significant differences in the relevance rankings of the six perspectives between the start and end of the course (B). Here, we followed two separate procedures: one for paired data from a subgroup of 62 participants for whom we had both pre- and post-test data, and one for unpaired data of the total group. For the paired data, we conducted a Wilcoxon signed-rank test for pairwise comparisons. For the unpaired data, we conducted a Mann–Whitney U Test to identify statistically significant differences in the relevance rankings between pre-test (n = 87) and post-test (n = 83). To assess the degree of agreement among participants regarding relevance (A and B) and effectiveness (C) rankings, Kendall's coefficient of concordance (Kendall's W) was calculated. To assess potential selection bias due to attrition, we compared baseline pre-test rankings between students who completed both pre- and post-tests (n = 62) and those who completed only the pre-test (n = 25). Mann–Whitney U tests showed no significant differences across any of the six perspectives (all $p > 0.05$), indicating that attrition was unlikely to have biased the results.

Although multiple comparisons were conducted (15 for between-perspective analyses and 6 for pre–post comparisons), we opted not to apply Bonferroni correction to the primary analyses. Bonferroni adjustment is highly conservative in settings with correlated outcomes, such as ranking data, which can substantially increase Type II errors. Given our focus on detecting changes in relevance rankings, we prioritized consistency and interpretability across analyses by the reporting of effect sizes to ensure robust conclusions. To support a more nuanced assessment of statistical significance while controlling for multiple testing, we provide False Discovery Rate (FDR)–adjusted *p*-values using the Benjamini–Hochberg procedure in Supplemental Tables S1–S4.

5.5. Qualitative Analysis

To analyze which perspectives students felt were missing (pre- and post-test), we categorized their responses by perspective and calculated the frequency rates. To analyze which educational design elements students felt contributed to the effectiveness of the thematic sessions in broadening their biomedical perspective, responses were analyzed using a collaborative, consensus-based coding procedure. Three members of the research team independently reviewed the responses and assigned a code based on whether it referenced:

1. Person-related elements ("who")—e.g., instructors or guest speakers.
2. Content-related elements ("what")—e.g., topics addressed.
3. Process-related elements ("how")—e.g., instructional design or teaching methods.

Following initial coding, the coders met to discuss discrepancies until full consensus was reached. Additionally, responses related to the perspective rated as most effective at the group level were further examined for in-group patterns or regularities.

6. Results

6.1. Perceived Relevance of Different Perspectives

6.1.1. Perceived Relevance Rankings of the Different Perspectives Before and After the Course

To determine whether there were statistically significant differences in students' relevance rankings among the six perspectives offered in the thematic sessions of the course, a Friedman test was conducted. The results revealed a significant difference in relevance rankings between perspectives both before the course (n = 87, $\chi^2(5) = 211.87$, $p < 0.001$) and after the course (n = 83, $\chi^2(5) = 119.93$, $p < 0.001$), indicating that some perspectives were ranked as more relevant than others. To identify which perspectives were ranked significantly higher or lower than others, post hoc Wilcoxon signed-rank tests were performed for both the pre-test and post-test rankings (Table 2 and Supplemental Tables S1 and S2). Perspectives sharing the same rank did not differ significantly in perceived relevance ($p > 0.05$).

Table 2. Mean rankings and standard deviations of perceived relevance of perspectives before (n = 87) and after the course (n = 83). Rankings were compared using the Friedman test, with pairwise differences assessed through the Wilcoxon signed-rank test. Lower mean rank values indicate higher perceived relevance.

Pre-Test Relevance Ranking				Post-Test Relevance Ranking		
Rank	**Mean Rank ± SD**	**Perspective**		**Perspective**	**Mean Rank ± SD**	**Rank**
1	1.48 ± 0.71	Patient	→	Patient	1.87 ± 1.31	1
2	2.37 ± 1.06	Research participant	→	Research participant	2.78 ± 1.33	2
3	3.82 ± 1.42 a	Planetary perspective	↘	Legal expert	3.51 ± 1.64	3
3	3.95 ± 1.34 a	Methodologist	↘	Planetary perspective	4.11 ± 1.45 c	4
4	4.52 ± 1.46 b	Pharmaceutical company	→	Pharmaceutical company	4.25 ± 1.36 c	4
4	4.85 ± 1.23 b	Legal expert	↘	Methodologist	4.47 ± 1.56 c	4

Rankings for a, b, and c were not significantly different ($p > 0.05$), resulting in shared final ranks.

6.1.2. Perceived Relevance of Perspectives Compared Between the Pre- and Post-Tests

To examine the significance of the shifts in relevance ranking between the pre- and post-tests, the primary analysis focused on students who completed both the pre-test and post-test (n = 62) to assess within-subject changes in relevance rankings. The Wilcoxon signed-rank tests revealed significant changes in perceived relevance for all perspectives except for the pharmaceutical company ($p = 0.05$) and the planetary perspective ($p = 0.08$). The legal expert perspective showed the most substantial change (r = 0.82), suggesting a strong positive shift in students' perception of its relevance. All other significant changes showed a decrease in perceived relevance of the perspectives, with the most notable decrease in the methodologist perspective (r = 0.48) (Table 3).

To assess the robustness of our findings, we conducted a supplementary analysis using the full dataset, comparing independent pre-test (n = 87) and post-test (n = 83) groups with the Mann–Whitney U test. The Mann–Whitney U test confirmed significant differences in mean ranking for two of the six perspectives. The legal expert perspective significantly increased in relevance perspective ($p < 0.001$), while the methodologist perspective significantly decreased ($p = 0.008$). No significant changes were observed for the other perspectives (all $p > 0.05$) (Supplemental Table S3).

The results of both analyses suggest the thematic sessions influenced the perceived relevance of the six perspectives. Expressed in mean ranking, the patient, research partici-

pant, planetary, and methodologist perspectives went down in perceived relevance, while the legal expert perspective moved up. Since it concerns relative ranking data, assumptions regarding whether our educational intervention influenced absolute relevance per perspective cannot be made. For instance, if students developed a more positive perception regarding the relevance of the methodologist perspective, but this change was smaller compared to other perspectives, the methodologist perspective would be considered more relevant in absolute terms but would still drop in the overall ranking of perspectives.

Table 3. Changes in mean rankings of perceived relevance of perspectives between Pre- and Post-Test (n = 62). Rankings across perspectives were compared using the Friedman test, with pairwise differences assessed through the Wilcoxon signed-rank test. Absolute effect sizes |r| were calculated based on Wilcoxon Z-values, with |r| < 0.3 considered small, 0.3–0.5 medium, and >0.5 large effect.

Perspective	Pre-Test (Mean ± SD)	Rank (Pre)	Post-Test (Mean ± SD)	Rank (Post)	*p*-Value	Effect Size |r|	Change in Mean Relevance
Patient	1.48 ± 0.76	1	1.81 ± 1.23	1	0.027	0.48 (medium)	Decreased
Research participant	2.45 ± 1.11	2	2.82 ± 1.34	2	0.041	0.34 (medium)	Decreased
Planetary perspective	3.84 ± 1.42	3	4.10 ± 1.47	4	0.08	0.33 (medium)	No significant change
Methodologist	3.71 ± 1.30	3	4.40 ± 1.61	4	0.004	0.48 (medium)	Decreased
Pharmaceutical company	4.63 ± 1.39	4	4.21 ± 1.38	4	0.05	0.34 (medium)	No significant change
Legal expert	4.89 ± 1.29	4	3.66 ± 1.65	3	<0.001	0.82 (large)	Increased

6.1.3. Missing Perspectives Before and After the Course

In addition to rating the relevance of the perspectives that were discussed in the thematic sessions, students were asked to list perspectives they felt were missing from the course. In the pre-test, 40 students provided 52 suggestions, whereas in the post-test, 21 students suggested a total of 30 perspectives. It should be noted that this question was optional. Although the pre-test was completed by 87 students and the post-test by 83 students, only 40 and 21 students, respectively, provided responses to this open-ended question. The mentioned perspectives are summarized in Table 4.

Table 4. Number of times perspectives were mentioned as missing, before and after the course.

	Pre-Test (40 Students, 52 Perspectives)	Post-Test (21 Students, 30 Perspectives)
Society	14	13
Patient family	8	
Animals/lab animals	5	1
Journalists/media	5	
Medical doctor	5	6
(Fellow)Researchers	4	1
Economic perspective	3	
Government	2	1
Other	Future/Historic, Legislation, Religious, Political, Other disciplines, Financial Advisor	Future/Historic, European, Teacher, Supplier, Research Journals, Corporate sector, University, Alternative viewpoints (“Wappie”)

Students mention both disciplinary perspectives, (e.g., economic perspective or medical doctor), and societal perspectives (e.g., the government, society, and the family of patients) as missing from the course. The lower number of missing perspectives reported after the course may suggest that students perceived fewer gaps in the perspectives addressed. However, this reduction should be interpreted with caution, given the optional nature of this open-ended question and the relatively limited number of student responses.

One possible explanation is that some perspectives students initially identified as missing in the pre-test were still discussed in the thematic sessions. For example, economic considerations and the role of government in the approval of medicines were discussed within the session focusing on the pharmaceutical company perspective, while the use of laboratory animals was addressed in the session on the planetary perspective. Although these perspectives were not the primary focus of the sessions, their inclusion may have contributed to students perceiving fewer missing perspectives.

Notably, the perspective of society as a whole remained the most frequently mentioned missing perspective in both the pre-test and post-test. Also, the student suggesting the 'Wappie' perspective (which is a generally pejorative Dutch name for individuals with an alternative science skeptic viewpoint) shows that to better align with student expectations in future iterations, diverse societal opinions could be the subject of discussion.

6.2. Effectiveness of Educational Design of Each Perspective-Focused Module

6.2.1. Perceived Effectiveness of Educational Intervention per Perspective

To examine a possible link between the perceived relevance of a perspective and the effectiveness of the educational intervention, students ranked each perspective according to how effective they found them in broadening their biomedical perspective. The Friedman test indicated a significant difference in effectiveness rankings across the six perspectives ($\chi^2(5) = 168.05$, $p < 0.001$). The Pairwise Wilcoxon signed-rank test indicated no significant differences between the mean ranks of the patient and the pharmaceutical company and between the planetary and methodologist perspectives. Students experienced the legal expert thematic sessions as the most effective, and the planetary perspective and the methodologist as the least effective (Table 5, Supplemental Table S4). Kendall's W = 0.405 ($p < 0.001$) indicated moderate agreement among students regarding these rankings. The ranking in effectiveness corresponds with the results above, indicating that the legal expert's perspective increased in perceived relevance, and the methodologist's and planetary's perspectives declined, indicating that there is a possible link between effectiveness of the educational design and the perceived relevance of the perspectives.

Table 5. Mean rankings and standard deviations of perceived effectiveness of educational design of each perspective after the course (n = 83). Rankings were compared using the Friedman test, with pairwise differences assessed through the Wilcoxon signed-rank test. Lower mean rank values indicate higher perceived effectiveness.

Perspective	Mean Rank ± SD	Effectiveness Rank
Legal expert	1.72 ± 1.09	1
Patient	2.73 ± 1.40 a	2
Pharmaceutical company	3.17 ± 1.40 a	2
Research participant	3.89 ± 1.41	3
Planetary perspective	4.73 ± 1.30 b	4
Methodologist	4.75 ± 1.33 b	4

Rankings for a and b were not significantly different ($p > 0.05$), resulting in shared final ranks.

Our findings indicate that participating in the thematic sessions influenced students' perceptions regarding the relevance they attributed to a set of six perspectives for broadening their biomedical perspective, to some extent. Moreover, the ranking of perceived effectiveness of the thematic sessions aligns with relevance shifts. To illustrate, students rated the legal expert thematic session as the most effective session to broaden their biomedical perspective, and this corresponds with a significant rise in how relevant they rate the legal expert's perspective. Moreover, they rated the methodologist on a shared last position for effectiveness, and this was reflected in a decrease in perceived relevance from position 3 to a shared 4th position. This suggests that the thematic sessions may have shaped students' perception of relevance. However, this may have to be corrected for original perceived relevance; for instance, after the course, the legal expert was rated as the most effective thematic session but not as the most relevant perspective. The patient's perspective remained the most relevant perspective, but the corresponding thematic session not as most effective. Apparently (and not surprisingly), there is also a limit to how educational interventions can influence perceived relevance. In the remainder of this manuscript, we'll discuss how educational design features influenced students' relevance perceptions.

6.2.2. Mentioned Design Elements That Contributed to Effectiveness

To examine which elements of the educational design influenced the ratings students gave to the perspectives for broadening their biomedical outlook, we asked students which educational elements in the thematic sessions they found most effective. A total of 78 students responded to this question, identifying 140 design elements. For each perspective, we categorized the mentioned elements as either person-related (who was present in the session), content-related (what was discussed during the session), or process-related (how the session was structured, e.g., teaching methods). The results are presented in Table 6.

Table 6. Number of design elements mentioned by students for each perspective, categorized by type (Who, What and How). The first number in each cell indicates how often a design element was mentioned. The number in parentheses represents how many students mentioned an element in this category.

		Design Elements Regarding:		
Perspective	**Number of Design Elements Mentioned (Number of Students)**	**Who**	**What**	**How**
Legal expert	78 (45)	7 (7)	21 (21)	50 (33)
Patient	45 (22)	15 (15)	13 (13)	17 (15)
Pharmaceutical company	11 (6)	3 (3)	3 (3)	5 (4)
Research participant	4 (4)	0	2 (2)	2 (2)
Planetary perspective	0	0	0	0
Methodologist	2 (1)	1 (1)	1 (1)	0
Total	140 (78)	26 (26)	40 (40)	74 (54)

In their responses, students most frequently described design elements related to the 'how' of the sessions, with many mentioning multiple elements regarding the session structure and teaching methods. In contrast, elements related to 'who' was present during the session were discussed the least, which is understandable, as there is only one possible 'who' element per session. However, there were still notable difference between perspectives. For the patient perspective, the presence of patients was the most frequently mentioned design element. 15 out of 22 students (68%) identified the presence of patients

as a factor contributing to the effectiveness of the session. In contrast, for the legal expert's perspective, only 7 out of 45 students (16%) mentioned the presence of the legal expert. For the legal expert's perspective, 'how' elements were most commonly discussed, with 33 out of 45 students (73%) mentioning at least one aspect of how the session was structured.

To further examine the difference between design elements, we analyzed which specific design elements were mentioned for the two perspectives that had the most responses (the legal expert's perspective and the patient perspective). An additional reason for further examining these perspectives was that they represent both a disciplinary (legal expert) perspective and a societal (patient) perspective. The specific design elements students mentioned are listed in Table 7.

Table 7. Categorization of the specific design elements students discussed for the patient and the legal expert perspective.

	Design Element Data	**Patient Perspective**	**Legal Expert Perspective**
		Times Mentioned	**Times Mentioned**
Who	Perspective Owner	14	6
	Enthusiastic Speaker	0	1
What	Personal Stories	8	0
	Interesting Content	2	11
	Imposing Content	1	0
	Unique Content	1	2
	Multiple Perspectives Discussed	1	0
	Specific Content Discussed	0	4
	Content was related to Biomedicine	0	1
How	Interactive Education	16	8
	Constructive Alignment	1	6
	Instructional Clarity	0	18
	No Discussions	0	1
	Use of Clear Examples	0	6
	Small Group Size	0	2
	Alternating between Information and making Assignments	0	9

In the case of the patient perspective, students frequently cited the presence of patients and direct interaction with them as the key design elements contributing to the session's effectiveness. In contrast, for the legal expert perspective, the presence of a perspective owner appeared to be less critical. Instead, students highlighted the teaching competencies of the legal expert as a major factor in their learning experience. Elements categorized under 'instructional clarity' included the use of well-structured information, a clear presentation style, and an appropriate session pace. Notably, none of these instructional clarity elements were mentioned in relation to the patient perspective. This difference may be attributed to varying student expectations: students may not hold individuals with a non-academic (patient) perspective to the same teaching standards as those with an academic (legal expert) perspective. Another possible explanation is that students perceived the relevance of the patient perspective as more self-evident compared to the legal expert perspective. This aligns with findings from the pre-test relevance rankings (Table 2), where the patient perspective was rated as highly relevant, whereas the legal expert perspective was perceived

as relatively less important. As a result, the mere presence of a patient may have been enough to engage students, while the legal expert perspective required additional support through engaging content, strong teaching skills, and a well-structured session format to capture students' interest. In addition, interactive learning was valued; students valued interaction with the perspective owner in both the patient and legal expert thematic sessions. Specifically in the legal expert session students valued the opportunity to apply their newly acquired knowledge in assignments in the legal expert thematic session.

7. Conclusions and Discussion

Interdisciplinary and transdisciplinary (ITD) collaboration is essential for addressing complex socio-scientific issues, as such issues require the integration and critical appraisal of knowledge from both disciplinary and societal perspectives. From an educational perspective, this positions critical thinking (CT), the ability to evaluate evidence, reflect on assumptions, and engage with alternative viewpoints, as a core competency for future biomedical scientists. Drawing on the theory of boundary crossing, this study examined how educational designs that emphasize identification (becoming aware of one's own and others' perspectives) and reflection (reconsidering one's assumptions in light of alternative viewpoints) can support this form of critical engagement in higher education. As the present study focuses on an early-stage undergraduate course, the form of critical engagement examined does not presuppose a fully developed disciplinary identity. Rather, engaging students early in identifying and reflecting on their emerging disciplinary perspectives may help prevent the uncritical acceptance of disciplinary dogmas and foster openness to alternative perspectives later in the curriculum.

The findings of this study support the idea that introducing students to multiple perspectives in an educational setting can influence how they assess the relevance of these perspectives. While students consistently prioritized the patient perspective both before and after the course, participation led to shifts in relevance rankings, most notably an increased appreciation of the legal expert perspective. Interpreted through a critical thinking lens, these shifts suggest that targeted educational interventions can prompt students to reconsider initial assumptions and to more critically appraise perspectives they may previously have undervalued. Additionally, students' perceptions of effectiveness aligned with the relevance shifts, indicating that well-designed educational experiences can enhance students' appreciation of diverse perspectives.

The lower perceived effectiveness of the planetary and methodologist perspectives warrants further reflection. One plausible interpretation is that these perspectives may have been perceived as less novel or less distinct from students' existing frames of reference. Sustainability-related issues are increasingly prominent in education and public discourse, which may have reduced the extent to which the planetary perspective introduced new ways of thinking. Similarly, the methodologist perspective is more closely aligned with students' emerging biomedical disciplinary perspective, potentially resulting in fewer perceived perspective shifts.

Students' qualitative responses highlighted the role of different educational design elements in shaping their learning experiences. The presence of patients was the most frequently cited factor contributing to effectiveness, whereas for the legal expert perspective, students placed greater emphasis on strong teaching skills and structured content delivery. This suggests that students may hold different expectations depending on whether a perspective is disciplinary (e.g., legal expert) or societal (e.g., patient). Regardless of the perspective of the thematic session, students valued opportunities to interact with the perspective owner and to apply their newly acquired knowledge. These interactive elements might be essential for supporting the learning mechanisms of identification and reflection.

They could be further harnessed by introducing assignments where students are actively asked to define differences between what they have learned about the new perspective and their own personal and disciplinary perspective (i.e., an identification process).

7.1. Study Limitations

A central limitation of our findings is that students were asked to reflect on educational design elements only for the perspective they ranked as most effective. As a result, students primarily identified design elements contributing to the effectiveness of the patient and legal expert perspectives. Consequently, the data do not allow for a systematic comparison of instructional design across all thematic sessions, which limits our ability to compare the differences in effectiveness between disciplinary and societal perspectives thoroughly. Differences in perceived effectiveness can therefore not be directly attributed to differences in session design. Interpretations regarding variation in effectiveness should thus be regarded as tentative and point to directions for future research and course design.

In addition, the patient perspective was already ranked highly in the pre-test, indicating that students may have entered the course with a pre-existing bias about which perspectives they considered important. This initial positioning may have constrained the extent to which educational interventions could further influence students' relevance judgments for this perspective.

Furthermore, while this study examined short-term changes in students' perceptions of relevance, interpreted as indicators of developing critical engagement with multiple perspectives, it remains unclear how these changes translate into a sustained appreciation of multiperspectivity or into longer-term development of critical thinking capacities.

A further limitation is that critical thinking was assessed indirectly through students' relevance judgments rather than through direct performance-based measures. Future research could address this by combining perception-based indicators with validated critical thinking assessments, such as the Halpern Critical Thinking Assessment (Halpern, 2012, de Bie et al., 2015), alongside context-specific assessments such as the open-ended questions or the argumentative writing tasks.

Finally, the present study did not assess whether exposure to diverse disciplinary and societal perspectives contributed to the broader competencies and attitudes required for interdisciplinary and transdisciplinary collaboration in students' subsequent educational trajectories or professional practice. Longitudinal research is therefore needed to examine how preparatory ITD education supports the durable development of critical thinking competencies in addressing complex socio-scientific challenges.

7.2. Implications for Practice

The results of this study indicate that teaching methods and session structure play a crucial role in students' perception of effectiveness in increasing their appreciation of diverse perspectives. Future course designs could explore more structured approaches to integrating perspectives, to create a more balanced and engaging experience across all perspectives.

Additionally, the societal perspective remained one of the most frequently mentioned missing elements in both the pre-test and post-test. This suggests that future iterations of the course should further integrate discussions on broader societal viewpoints. In addition to incorporating more diverse societal viewpoints, a potential improvement to the course could be the inclusion of sociology or political science as disciplinary perspectives. These fields could introduce students to methods for analyzing and researching societal opinions, helping them better understand how public perceptions influence biomedical innovation and policy. Such an addition would further enrich their ITD learning experience

by deepening their engagement with the social dimensions of science. Finally, the course development team valued the presence of perspective owners during the education session. Therefore, the perspectives discussed were perspectives that allowed for direct interaction. However, some perspectives can only be hypothesized or explored theoretically (e.g., future offspring in case of genetic germline modification). The inclusion of hypothetical perspectives and discussion about their relevance for discussing SSIs might be a valuable addition to the described course.

In conclusion, this study shows that educational interventions can influence how students perceive the relevance of diverse perspectives in addressing SSIs. By incorporating the boundary-crossing mechanisms of identification and reflection as learning approaches to support critical thinking development, the course encouraged students to engage with both disciplinary and societal viewpoints. Our findings offer practical insights for designing early-stage undergraduate education that fosters critical thinking and better prepares students to navigate complex, real-world challenges.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/educsci16020348/s1, Data S1: Pre-test and post-test assignment; Table S1: Pairwise comparisons of pre-test relevance rankings; Table S2: Pairwise comparisons of post-test relevance rankings; Table S3: Differences in Relevance Rankings; Table S4: Pairwise comparisons of effectiveness ranking.

Author Contributions: Conceptualization, E.M.G., A.P.-B., C.M.R. and M.H.W.V.M.; methodology, E.M.G. and C.M.R.; validation, E.M.G. and A.P.-B.; formal analysis, E.M.G., A.P.-B., C.M.R.; data curation, E.M.G.; writing—original draft preparation, C.M.R., E.M.G.; writing—review and editing, E.M.G., A.P.-B., M.H.W.V.M.; visualization, E.M.G.; supervision, M.H.W.V.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The research reported in this article involves healthy human participants and does not utilize any invasive techniques, substance administration or psychological manipulations. Therefore, compliant with Dutch law, this study only required, and received, approval from the Netherlands Association for Medical Education (NVMO) Ethical Review Board (no. 2024.3.5). Furthermore, this research was conducted according to the principles expressed in the Declaration of Helsinki, and written informed consent from each participant was obtained.

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

Data Availability Statement: The dataset supporting the conclusions of this study is not publicly available because participants did not provide explicit consent for their data to be used beyond the scope of the original research project. Researchers interested in accessing the data for academic purposes may contact the corresponding author to discuss potential options, subject to ethical and institutional considerations.

Acknowledgments: During the preparation of this manuscript, the authors used a large language model (LLM), specifically OpenAI's ChatGPT version 4.o, to support the writing and revision process, as well as to assist in translating the Dutch assignment and student responses into English. The LLM was employed solely for purposes of linguistic refinement and improving the clarity of selected passages. All conceptual development, academic argumentation, data interpretation, and final editorial decisions were made exclusively by the authors. The authors have reviewed and edited the output and take full responsibility for the content of this publication.

Conflicts of Interest: No potential conflict of interest was reported by the authors.

Abbreviations

The following abbreviations are used in this manuscript:

CT	Critical Thinking
ITD	Inter- and Transdisciplinary
SSIs	Socio-Scientific Issues
SD	Standard Deviation

References

Abd-El-Khalick, F., Summers, R., Brunner, J. L., Belarmino, J., & Myers, J. (2024). Development of VAScoR: A rubric to qualify and score responses to the views of nature of science (VNOS) questionnaire. *Journal of Research in Science Teaching*, *61*(7), 1641–1688. [CrossRef]

Abd-El-Khalick, F., Waters, M., & Le, A. P. (2008). Representations of nature of science in high School chemistry textbooks over the past four decades. *Journal of Research in Science Teaching*, *45*(7), 835–855. [CrossRef]

Agustian, H. Y. (2023). The critical role of understanding epistemic practices in science teaching using wicked problems. *Science and Education*, *34*(1), 485–510. [CrossRef]

Akkerman, S. F., & Bakker, A. (2011). Boundary crossing and boundary objects. *Review of Educational Research*, *81*(2), 132–169. [CrossRef]

Alvargonzález, D. (2011). Multidisciplinarity, interdisciplinarity, transdisciplinarity, and the sciences. *International Studies in the Philosophy of Science*, *25*(4), 387–403. [CrossRef]

Augsburg, T. (2014). Becoming transdisciplinary: The emergence of the transdisciplinary individual. *World Futures*, *70*(3–4), 233–247. [CrossRef]

Beauchamp, T. L., & Childress, J. F. (2001). *Principles of biomedical ethics*. Oxford University Press.

Boix-Mansilla, V. (2017). Interdisciplinary learning: A cognitive-epistemological foundation. In *The Oxford Handbook of Interdisciplinarity* (2nd ed.). Oxford University Press. [CrossRef]

Boland, R. J., & Tenkasi, R. V. (1995). Perspective making and perspective taking in communities of knowing. *Organization Science*, *6*(4), 350–372. [CrossRef]

Boon, M., & Van Baalen, S. (2019). Epistemology for interdisciplinary research—Shifting philosophical paradigms of science. *European Journal for Philosophy of Science*, *9*(1), 16. [CrossRef]

Boon, M., van Baalen, S., & Groenier, M. (2019). Interdisciplinary expertise in medical practice: Challenges of using and producing knowledge in complex problem-solving. *Medical Teacher*, *41*(6), 668–677. [CrossRef]

Creswell, J. W. (2021). *A concise introduction to mixed methods research*. SAGE Publications.

Daneshpour, H., & Kwegyir-Afful, E. (2022). Analysing transdisciplinary education: A scoping review. *Science and Education*, *31*(4), 1047–1074. [CrossRef]

Davies, M. (2015). A model of critical thinking in higher education. In *Higher education: Handbook of theory and research* (pp. 41–92). Springer International Publishing. [CrossRef]

de Bie, H., Wilhelm, P., & van der Meij, H. (2015). The Halpern Critical Thinking Assessment: Toward a Dutch appraisal of critical thinking. *Thinking Skills and Creativity*, *17*, 33–44. [CrossRef]

DeZure, D. (2017). Interdisciplinary pedagogies in higher education. In R. Frodeman (Ed.), *The Oxford handbook of interdisciplinarity* (2nd ed.). Oxford University Press. [CrossRef]

Dudo, A., & Besley, J. C. (2016). Scientists' prioritization of communication objectives for public engagement. *PLoS ONE*, *11*(2), e0148867. [CrossRef]

Ennis, R. (2011). Critical thinking: A streamlined conception. In *The Palgrave handbook of critical thinking in higher education* (Vol. 26). Palgrave Macmillan US.

Facione, P. A. (1990). *Critical thinking: A statement of expert consensus for purposes of educational assessment and instruction. Research findings and recommendations*. ERIC.

Fisher, K. (2003). Demystifying critical reflection: Defining criteria for assessment. *Higher Education Research and Development*, *22*(3), 313–325. [CrossRef]

Fortuin, K. P. J., Gulikers, J. T. M., Post Uiterweer, N. C., Oonk, C., & Tho, C. W. S. (2024). Developing a boundary crossing learning trajectory: Supporting engineering students to collaborate and co-create across disciplinary, cultural and professional practices. *European Journal of Engineering Education*, *49*(2), 212–235. [CrossRef]

Gerrits, E. M., Assen, L. S., Noordegraaf-Eelens, L., Bredenoord, A. L., & van Mil, M. H. W. (2023). Moral imagination as an instrument for ethics education for biomedical researchers. *International Journal of Ethics Education*, *8*(2), 275–289. [CrossRef]

Gerrits, E. M., Bredenoord, A. L., & van Mil, M. H. W. (2022). Educating for responsible research practice in biomedical sciences: Towards learning goals. *Science and Education*, *31*(4), 977–996. [CrossRef]

Giri, A. K. (2002). The calling of a creative transdisciplinarity. *Futures*, *34*, 103–115. [CrossRef]

Godemann, J. (2008). Knowledge integration: A key challenge for transdisciplinary cooperation. *Environmental Education Research*, *14*(6), 625–641. [CrossRef]

Guimarães, M. H., Pohl, C., Bina, O., & Varanda, M. (2019). Who is doing inter- and transdisciplinary research, and why? An empirical study of motivations, attitudes, skills, and behaviours. *Futures*, *112*, 102441. [CrossRef]

Gulikers, J., Khaled, A., Visscher, K., & Visscher-Voerman, I. (2025). Transdisciplinary learning environments that stimulate co-creation and co-learning between students and external partners: An empirical exploration. *Humanities and Social Sciences Communications*, *12*(1), 1768. [CrossRef]

Halpern, D. F. (2012). *Halpern critical thinking assessment: Test manual*. Schuhfried GmbH.

Horn, A., Scheffelaar, A., Urias, E., & Zweekhorst, M. B. M. (2023). Training students for complex sustainability issues: A literature review on the design of inter- and transdisciplinary higher education. *International Journal of Sustainability in Higher Education*, *24*(1), 1–27. [CrossRef]

Horn, A., Visser, M. W., Pittens, C. A. C. M., Urias, E., Zweekhorst, M. B. M., & van Dijk, G. M. (2024). Transdisciplinary learning trajectories: Developing action and attitude in interplay. *Humanities and Social Sciences Communications*, *11*(1), 149. [CrossRef]

Johnson, M. (1993). *Moral imagination*. University of Chicago Press.

Johnson, M. R., Dugan, J. P., & Soria, K. M. (2017). "Try to see it my way": What influences social perspective taking among college students? *Journal of College Student Development*, *58*(7), 1035–1054. [CrossRef]

Kahn, S., & Zeidler, D. L. (2019). A conceptual analysis of perspective taking in support of socioscientific reasoning. *Science and Education*, *28*(6), 605–638. [CrossRef]

Klein, J. T. (1996). *Crossing boundaries: Knowledge, disciplinarities, and interdisciplinarities*. University of Virginia Press.

Newell, W. H. (2013). The state of the field: Interdisciplinary theory. *Issues in Interdisciplinary Studies*, *31*, 22–43.

Nussbaum, M. C. (2003). *Upheavals of thought: The intelligence of emotions*. Cambridge University Press.

Oonk, C., Gulikers, J., den Brok, P., & Mulder, M. (2022). Stimulating boundary crossing learning in a multi-stakeholder learning environment for sustainable development. *International* Journal of Sustainability in Higher Education, *23*(8), 21–40. [CrossRef]

Parker, C. (2016). Pedagogical tools for peacebuilding education: Engaging and empathizing with diverse perspectives in multicultural elementary classrooms. *Theory and Research in Social Education*, *44*(1), 104–140. [CrossRef]

Pieterman-Bos, A., & van Mil, M. H. W. (2023). Integration of philosophy of science in biomedical data science education to foster better scientific practice. *Science and Education*, *32*(6), 1709–1738. [CrossRef]

Reincke, C. M., Bredenoord, A. L., & van Mil, M. H. (2020). From deficit to dialogue in science communication. *EMBO Reports*, *21*(9), EMBR202051278. [CrossRef]

Reincke, C. M., Pieterman-Bos, A., & van Mil, M. H. W. (2024). Identifying focus areas for science communication training in the context of undergraduate science education. *International Journal of Science Education, Part B: Communication and Public Engagement*, *14*(4), 450–464. [CrossRef]

Repko, A. F., & Szostak, R. (2020). *Interdisciplinary research: Process and theory* (4th ed.). Sage.

Spelt, E. J. H., Biemans, H. J. A., Tobi, H., Luning, P. A., & Mulder, M. (2009). Teaching and learning in interdisciplinary higher education: A systematic review. *Educational Psychology Review*, *21*(4), 365–378. [CrossRef]

Szostak, R. (2024). *Handbook of interdisciplinary teaching and administration*. Edward Elgar Publishing Limited.

Tripp, B., & Shortlidge, E. E. (2019). A framework to guide undergraduate education in interdisciplinary science. *CBE Life Sciences Education*, *18*(2), es3. [CrossRef]

van Baalen, S., & Boon, M. (2024). Understanding disciplinary perspectives: A framework to develop skills for interdisciplinary research collaborations of medical experts and engineers. *BMC Medical Education*, *24*(1), 1000. [CrossRef]

Vereijken, M. W. C., Akkerman, S. F., te Pas, S. F., van der Tuin, I., & Kluijtmans, M. (2023). 'Undisciplining' higher education without losing disciplines: Furthering transformative potential for students. *Higher Education Research and Development*, *42*(7), 1762–1775. [CrossRef]

Vogel, O., & Hunecke, M. (2024). Fostering knowledge integration through individual competencies: The impacts of perspective taking, reflexivity, analogical reasoning and tolerance of ambiguity and uncertainty. *Instructional Science*, *52*(2), 227–248. [CrossRef]

Waite, S., & Davis, B. (2006). Collaboration as a catalyst for critical thinking in undergraduate research. *Journal of Further and Higher Education*, *30*(4), 405–419. [CrossRef]

Wansink, B. G. J., Timmer, J., & Bronkhorst, L. H. (2023). Navigating multiple perspectives in discussing controversial topics: Boundary crossing in the classroom. *Education Sciences*, *13*(9), 938. [CrossRef]

Zwart, H., & Nelis, A. (2009). What is ELSA genomics?: Science & society series on convergence research. *EMBO Reports*, *10*(6), 540–544. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.