Equipping biomedical students for science-society dialogue

Exploring competencies and training strategies

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ISBN: 978-94-6506-466-6
DOI: 10.33540/2555

Layout and printing: Ridderprint | www.ridderprint.nl

Equipping biomedical students for science-society dialogue

Exploring competencies and training strategies

Het toerusten van studenten biomedische wetenschappen voor de dialoog tussen wetenschap en samenleving

Een verkenning van competenties en trainingsstrategieën

(met een samenvatting in het Nederlands)

Proefschrift

ter verkrijging van de graad van doctor
aan de Universiteit Utrecht op gezag van de
rector magnificus, prof. dr. H.R.B.M. Kummeling,
ingevolge het besluit van het College voor Promoties
in het openbaar te verdedigen op

vrijdag 15 november des ochtends te 10:15 uur

door

Cathelijne Marije Reincke

geboren op 30 december 1977
te Lochem

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Voor Matis, voor Luutse

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CHAPTER 1

General Introduction

A forethought

The advancement of research and innovation in the field of biomedicine is accompanied with the emergence of increasingly complex socio-ethical questions. One clear example is the introduction of CRISPR-Cas9 as a molecular tool to edit DNA. In the annals of scientific recognition, the year 2020 witnessed the bestowal of the Nobel Prize in Chemistry upon key developers of CRISPR technology: Jennifer Doudna and Emmanuelle Charpentier. Preceding this recognition, CRISPR had gained global attention as an expedient and precise gene editing tool, with high potential to accelerate DNA research. However, in that same period, CRISPR had also found itself enmeshed in a burgeoning societal debate. Prospective applications, such as embryo genetic modification, evoked profound public apprehensions. Should humanity venture into the realm of germline engineering? Similar concerns pervaded the scientific community as well, prompting venerated figures within the community to advocate for stringent regulation of the use of CRISPR technology, as well as intensive societal dialogue to guide (future) decision making. In the Netherlands, this led to the instigation of a comprehensive nationwide public dialogue. Spanning diverse dialogue platforms dispersed across the country, participants encompassing members of the public, biomedical researchers, ethicists, patients, and pertinent stakeholders convened to deliberate upon the ethical ramifications and desirability quotient pertaining to human germline genetic modification as a potential application of CRISPR (Van Baalen et al., 2021).

The development of CRISPR is but one facet within a mosaic of transformative biomedical technologies that have emerged over the past three decades, each wielding far reaching implications for society. Noteworthy examples include mRNA technology showcased notably in the development of Covid-19 vaccines, neurotechnology, epitomized by brain implants facilitating the monitoring and modulation of cerebral activity, and bio-printing technology, instrumental in the fabrication of synthetic organs for human transplantation. From the mid-1980s onward, initiatives arose, mostly within the policy arena, to guide biomedical research and innovation along an ethically responsible trajectory. A well-known example is the ELSI framework that emerged in 1989 in the United States. This framework, denoting the ethical, legal, and social implications of emerging life sciences, was primarily developed to respond to socio-ethical questions arising from the Human Genome Project (Ryan & Blok, 2023). In 1994, a comparable framework, named ELSA, was introduced in Europe. Analogous to its American counterpart, ELSA strived to stimulate reflection on ethical, legal, and societal implications of scientific and technological advancements. Notably, this was achieved through the advocacy of stakeholder and public engagement, coupled with the proactive anticipation of socio-ethical issues (Zwart & Nelis, 2009). Subsequently, a cognate aspiration emerged with the advent of the responsible research and innovation (RRI) framework. RRI originated within the European Union circa 2010, as a research area striving to harmonize the nexus between policy and practice of research and innovation and the aspirations and exigencies of society (Stilgoe et al., 2013). An important aspect of RRI involves dialogue among diverse societal stakeholders, including scientists, policymakers, and the general populace (Von Schomberg, 2013). Although slightly different in focus or aim, all three frameworks have in common that they consider ongoing dialogue with society a prerequisite for the ethically sound governance of research and innovation processes. However, fostering productive science-society dialogue can be challenging. Misinformation, distrust, and (perceived) power differences all hinder establishing meaningful, inclusive conversations (Bijker, 2017; Iyengar and Massey, 2019). This dissertation endeavors to augment the quality and efficacy of science-society interactions, particularly by optimizing the communicative relationship between scientists and a non-scientific public. Subsequently, I will expound upon historical trends pertaining to the interplay between science and society, including changing communication dynamics, before delving into an examination of the evolution of science communication (training) in both theoretical underpinnings and practical applications.

Science and society: changing relations

The concept of societal engagement in scientific endeavors remains a relatively nascent development. Historically, until the latter part of the twentieth century, the realms of science and society existed as discrete entities, with minimal overlap. While scientific research received public funding, academic institutions, including universities, retained a significant degree of autonomy in shaping their research agendas. In return for this autonomy, they furnished society with knowledge dissemination and educational services (Gibbons, 1999). However, as the twenty-first century loomed, this paradigm began to undergo transformation, propelled primarily by the forces of globalization. Notably, the encroachment of industry into the domain of science increased greatly. Consequently, the longstanding primacy of advancing knowledge as the principal impetus driving the scientific enterprise gradually yielded ground to profit generation and wealth accumulation. Furthermore, the realm of social control over scientific endeavors has transcended its historical confines within the scientific community, now encompassing a broader array of stakeholders and the general populace (Krishna et al., 2014). This evolution has impacted the scientific community and its constituents in several ways. For instance, scientific issues are now much more formulated and discussed within the public domain, and scientists are often required to explain the societal relevance of research in grant applications. Furthermore, scientists are increasingly expected to actively involve society, either in the form of engagement (e.g., stimulating opinion-forming on science-related issues) or co-creation (e.g., involving citizens and communities in setting up the research agenda, research projects and/or data collection). Collectively, these developments underscore a discernible shift in the relationship between science and society over recent decades—from two discrete realms operating in isolation to a paradigm characterized by ongoing interaction and synergistic collaboration.

Public science communication

In the field of public science communication, the evolution of the science-society relationship is perceptible, particularly through the evolution of communication models. Science communication as a formal discipline emerged around 1980. At that point in time, public science communication was closely connected to the concept of scientific literacy. Primarily within the policy arena, there was widespread apprehension regarding the general populace's perceived inadequacy in understanding scientific concepts. Hence, given the purported positive correlation between scientific literacy and public endorsement of scientific endeavors, there was a prevailing sentiment to prioritize efforts toward "public education" initiatives (Stocklmayer, 2018). Research in science communication predominantly focus on optimizing the transmission of knowledge transfer from scientist to the public. However, starting from the 1990s, this educational approach to science communication, commonly referred to as the ‘deficit model’, came under intense scrutiny (Bucchi, 2008; Lewenstein, 2003). Concurrently, several events stemming from the scientific community evoke sustained public concern and debate, for instance, the BSE-epidemic and the introduction of genetically modified crops in Europe (Stocklmayer, 2018). Consequently, public trust in science is progressively compromised, prompting a growing realization that the deficit model is inadequate in assuaging concerns.

Calls for new ways to navigate science-society interactions intensified, predominantly advocating for the integration of dialogic elements—shifting from one-way to two-way communication. The dialogue model, and subsequently the participation model, emerge as contemporary alternatives to the perceived limitations of the outdated deficit model. Both models share a common emphasis on prioritizing public involvement over public education, with slight variation in how such involvement manifests in practice. Generally, the dialogue model entails the reciprocal exchange of perspectives wherein scientist and members of society engage in a collaborative process of knowledge exchange and mutual learning (Nerghes et al., 2022). Indeed, mechanisms such as public engagement, consultation, and deliberation serve as tangible manifestations of the dialogue model, facilitating the exchange of insights between scientists and society (Bucchi & Trench, 2021). Conversely, the participation model elevates the involvement of societal members to a more active role. For instance, through involving them in knowledge interpretation and/or co-construction (Bucchi & Trench, 2021). A good example of the latter is 'citizen science', which can take the form of citizens contributing to collecting scientific data. Both the dialogue model and the participation model emphasize the importance of integrating scientific knowledge with other perspectives and forms of knowledge, such as experiential knowledge, cultural knowledge, or knowledge based on values and beliefs. Implicit in this discourse is the recognition that solutions to pressing societal issues, such as climate change and global health threats, can only be sought in the collaborative endeavors between multiple stakeholders, including science and society at large.

Science communication training

Obviously, the evolving dynamics of the science-society relationship necessitate scientists to cultivate a novel set of competencies extending beyond the traditional ability to convey knowledge in a comprehensible manner, often requiring specialized training. As from the 21st century, scholars in the realm of science communication have conducted numerous studies aimed at informing the development of science communication training programs. These investigations span inquiries into the requisite skills and competencies for scientists, as well as considerations regarding the timing and methodologies of imparting such training (e.g., Baram-Tsabari & Lewenstein, 2017; Bray et al., 2012; Seethaler et al., 2019). Concurrently, there has been an immense increase in science communication training programs and courses worldwide. Nonetheless, despite this surge in training initiatives, widespread consensus on what constitutes 'effective' training remains elusive (Newman, 2020). Recently, there is growing recognition that science communication training should commence at an early stage, potentially integrating elements of training into undergraduate and graduate science curricula (Bankston & McDowell, 2018; Brownell et al., 2013; Kuehne et al., 2014; Nisbet & Scheufele, 2009). This thesis focusses on such early-stage training, specifically training as integrated in undergraduate biomedical sciences programs.

Science communication training in higher education

In recent decades, science communication training in the context of higher education, similar to science communication in general, has experienced substantial growth (Massarani et al., 2023). This involves the integration of both science communication modules or courses as part of science programs, as well as the establishment of dedicated science communication programs (e.g., a master in science communication). Last year, the Journal of Science Communication devoted a special issue to teaching science communication in higher education (Roche et al., 2023), underscoring the increasing scholarly focus on this area. Corresponding research centers mainly on the fundamental inquiries regarding science communication training: namely, what content should be included in such training and what methodologies are most effective for imparting this content.

Indeed, research examining the specific context of (under)graduate science curricula within the realm of science communication training remains relatively scarce. One relevant example is a study by Mercer-Mapstone & Kuchel (2017), which investigated key components for basic science communication training within Australian science bachelor's programs. This study culminated in the compilation of a comprehensive list of twelve core skills for effective communication, including the ability to identify the goal of communication and to stimulate audience engagement. Another significant contribution in this respect is the study by Baram-Tsabari and Lewenstein (2017), which delineates learning goals for science communication. Based on the six strands of learning formulated by Bell et al. (2009), the authors proposed six learning strands tailored specifically for learning science communication, each accompanied by strand-specific learning goals. Although the comprehensive framework is intended to capture science communication learning in totality, rather than specifying a particular course or curriculum, in a later study the same authors discussed the possibility of specifying different learning trajectories for different groups of learners (Lewenstein & Baram-Tsabari, 2022). They labeled learning goals as either generally relevant or only relevant for specific interactions or communicators. In addition, they differentiated between essential and advanced learning goals. Arguably, science communication training in the context of undergraduate science education could restrict to addressing (mainly) the essential and generally relevant learning goals. This way, science students learn to form a solid groundwork which, in a later stage, and depending on specific interests or career choice, could be extended with competencies contained in advanced learning goals, or those directed to specific types of interaction. A last notable contribution is a study by Wack et al. (2021), presenting a framework for science communication training in the context of undergraduate biology education. In their work, Wack and colleagues amalgamate the core skills identified in prior research (Mercer-Mapstone & Kuchel, 2017) with recent work on communication objectives pertinent to contemporary science communication (Besley et al., 2018). Although each of the foregoing studies has produced valuable insights, furthering the field, a golden standard for science communication training as incorporated into (under)graduate science programs is as yet not established.

Furthermore, there appears to be an overall gap in scholarly understanding concerning the methodologies employed for training in science communication. This can in part be attributed to underdeveloped evaluation practices. Although the importance of evaluating science communication training has gained increasing recognition over the past years (Barel-Ben David & Baram-Tsabari, 2020), also in the context of higher education (e.g., Vickery et al., 2023), there remains a scarcity of comprehensive studies in this domain. Moreover, existing studies often focus on aspects such as message clarity or presentation improvement (see for example Rodgers et al., 2018; Rubega et al., 2021). Studies addressing training that prepares for meaningful dialogue seem largely absent.

Therefore, the questions surrounding what content to teach and how to effectively teach science communication in the context of higher education, as well as in science communication training overall, remain largely unanswered. This critical gap persists across both domains, highlighting an urgent need for further research.

Research aims and questions

This thesis aims to provide insight into what constitutes effective science communication training for undergraduate biomedical students. Specifically, this training is directed at equipping biomedical students for meaningful dialogue with society about the socio-ethical implications of biomedical research and innovation. To achieve this objective, this thesis focuses on the role that biomedical scientists should assume in their interactions with society, the competencies this role requires, and how these competencies translate into training in the context of undergraduate biomedical education.

The **main question** that is addressed in this thesis is:

"What constitutes effective science communication training for equipping undergraduate biomedical students for meaningful dialogue with society about the socio-ethical implications of biomedical research and innovation?"

To answer this question, the following **sub-questions** have been formulated:

Sub-question 1
What constitutes a constructive role for biomedical scientists in dialogue with society focused on socio-ethical implications of biomedical research and innovation?

Sub-question 2
Which competencies[1] are involved in fulfilling this role properly, and to what extent do undergraduate biomedical students (already) have these competencies?

Sub-question 3
Based on these understandings, which competencies do biomedical students need to develop, and how can they be taught in training in the context of biomedical sciences education?

Methodology

To address the formulated research question, I followed a research approach based on educational design research (EDR). Generally, EDR is deployed to tackle complex challenges in educational practice while at the same time furthering educational theory (McKenny & Reeves, 2018). Possible solutions to such challenges are developed and tested in iterative cycles, with related findings leading to the refinement of theory as well as feeding back into new cycles of developing and testing. This constant synergy between theory and practice fosters the establishment of both robust theoretical implications and relevant practical innovations (McKenny & Reeves 2014; 2021).

Typically, EDR involves three stages that are navigated iteratively (Figure 1). In the *Analysis and Exploration* phase, the problem is defined, including context and relevant stakeholders. Through a combination of literature study and collaboration with stakeholders, for example, educational practitioners, different facets of the problem are elucidated and subjected to critical reflection.

In the *Design and Construction* phase, the objective is to delineate potential solutions to the problem at hand. This constitutes a progressive process wherein broad or nonspecific concepts slowly evolve into more developed plans and strategies.

In the *Evaluation and Reflection* phase, prototype interventions are rigorously tested for their efficacy in mitigating or resolving the problem at hand. Findings are used to refine theoretical understanding of both the problem and the intervention, which may lead to congruent adaptations in educational design.

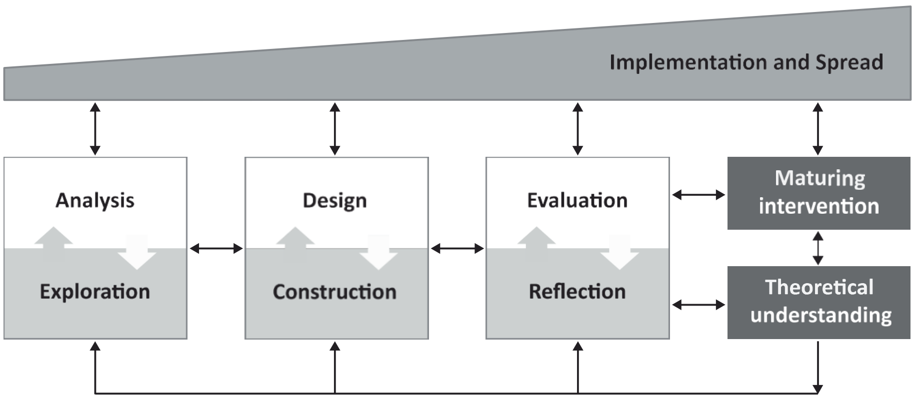

Figure 1: Generic model for conducting Educational Design Research (Reprinted with permission from McKenny & Reeves, 2018)

Dissertation outline

This thesis covers six chapters. Chapters 2-6 are divided over two parts; Chapter 7 constitutes the General Discussion.

Part 1: Biomedical scientists in dialogue with society: roles and competencies
In the first part, I delved into the competencies required by biomedical scientists to foster meaningful dialogue with society. This involved a conceptual analysis of contemporary science communication theory (Chapters 2 and 3), complemented by an empirical analysis of an example of contemporary science communication practice (Chapter 3). To illustrate the latter, I investigated the Dutch dialogue on human germline genetic modification (HGGM). This involved a text analysis of guiding principles for the design and execution of this dialogue and an observational

study covering three dialogue sessions that were organized in the context of this dialogue.

Part 2: Designing and testing science communication training for biomedical science students

In the second part, I used the results of Part 1 to identify focus areas for training and to develop and test a proto-type intervention. Firstly, I examined the extent to which students are capable of translating a set of generic instructions for engaging in dialogue into examples of concrete behaviors. This led to the formulation of two recommendations for designing training (Chapter 4). In the subsequent chapter, I delved deeper into the second recommendation. Here, I presented a framework developed to analyze students' writing products with the goal to examine how biomedical science education can influence students' views of the nature of science and, in extension, students' views of science communication (Chapter 5). Finally, in Chapter 6, I elaborated on the first recommendation by scrutinizing the efficacy of a training intervention designed to enhance students' active listening skills. This entailed providing students with an observation tool to facilitate the practice of active listening and analyzing their experience through interviews.

General Discussion

In the general discussion (Chapter 7), the findings of the individual chapters are combined and used to address the main question posed by this thesis. This is followed by a discussion and reflection on the implications for science communication training research and practice. I compared and contrasted science communication in the context of biomedical research and innovation with the context of science-related issues that could be considered more urgent, such as climate change and COVID-19. I conclude by underscoring the importance of active listening in enhancing the dialogic relationship between science and society.

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Part I

Biomedical scientists in dialogue with society: roles and competencies

CHAPTER 2

From deficit to dialogue in science communication
The dialogue communication model requires additional roles from scientists

An adapted version of this study is published as "Reincke, C. M., Bredenoord, A. L., & Van Mil, M. H. (2020). From deficit to dialogue in science communication. The dialogue communication model requires additional roles from scientists. *EMBO Reports,* 21(9), 1–4. doi: 10.15252/embr.202051278."

INTRODUCTION

As applications of gene editing in medicine, agriculture, and biotechnology become increasingly feasible, public interest and calls for public dialogue intensify. The UK Royal Society initiated the “Genetic Technologies Public Dialogue” in 2017 to explore the views of UK citizens on possible applications of gene editing. Last year, the Netherlands set off to organize multiple public dialogues on human genetic germline modification (HGGM) over one year. The overall goal of the Dutch dialogue is to stimulate societal opinion forming on the desirability of genetically modifying the human germline (van Baalen et al, 2019). Researchers from different disciplines— biomedicine, ethics, and reproductive medicine—will attend these sessions as experts along with other participants. Together, they will discuss and explore the broad societal implications of the science and potential clinical applications of HGGM. However, it raises the question whether these experts (here referred to as researchers with expertise on HGGM from within their specific discipline) know how to participate in public interactions such as these.

Indeed, several studies conducted both in Europe and the USA indicate that the majority of scientists still adhere to a so- called “deficit model” when interacting with non-scientist publics (Davies, 2008; Dudo & Besley, 2016). According to the model, scientists and other experts possess crucial knowledge that non-scientists lack, and the purpose of science communication is to “fill the knowledge gaps” in a largely one-way flow of information from expert to layperson. It also assumes that more scientific literacy or more knowledge induces a positive attitude with respect to science, for example, feelings of trust (Nis- bet & Scheufele, 2009). The deficit model has been heavily criticized, among other things for its implicit assumption that scientific expertise and worldview are dominant over other forms of knowledge (Jasanoff, 2011).

Public dialogues such as in the UK and the Netherlands are expected to become more common as a means to stimulate solid opinion forming based on a wide range of views. For these dialogues to be successful however, it is essential that experts step away from the deficit model. Here, we describe what constitutes a constructive expert role in public dialogues, and how an expert can fulfill this role. We start with a brief introduction on theoretical principles underlying the dialogue model of science communication. We then explore expert responsibilities with a real-life example: the Dutch dialogue on HGGM. We end with suggestions for good practice that are relevant for any field of science communication.

Principles of two-way science communication

Today, communication experts consider the deficit model to be obsolete (Nisbet & Scheufele, 2009; Dudo & Besley, 2016), and from the late 20th century on, more bi-directional forms of science communication have become popular. In the dialogue model, non-scientific forms of knowledge, such as cultural and experiential knowledge, are considered to have equal value as scientific knowledge since complex societal issues such as HGGM can impossibly be dealt with by using only scientific knowledge. Science may offer insights in possible risks and benefits of modifying the human germline, but not in the individual or social meaning assigned to these risks and benefits. For example, there may be differences in regard to how we value health and disease that are to some extend influenced by factors such as culture, (religious) beliefs, and personal experiences. Not so long ago, the introduction of cochlear implants to correct deafness in young children evoked strong reactions within the deaf community. In general, hear- ing people consider deafness as an impairment that has to be corrected if possible. The deaf community however, with its specific culture and social bonding, think of deaf children as perfectly healthy and see no reason to operate on them (Lane & Bahan, 1998). In the dialogue model, the deaf community would be particularly encouraged to share its perspective.

Science communication based on the dialogue model—also referred to as public engagement with science—foregrounds a two-way flow of information from expert to layperson and vice versa. A key feature is mutual learning (McCallie et al, 2009), which may be characterized as the process in which different views, values, experiences, and concerns are exposed with the intention to learn with and from each other. In sum, the dialogue model explicitly acknowledges different forms of knowledge, scientists and non-experts have equal status, and together they are expected to learn with and from each other.

The role of experts in the dialogue model

The target audience in the dialogue model can no longer be regarded as passive receivers of knowledge, and the overall purpose of delivering expert knowledge has changed. Besley et al (2018) propose a set of eight communication objectives for scientists engaging in bi-directional science communication, in which we clearly recognize the responsibilities of sharing input that is well received by others, and listening to and learning from the input of others. In addition, there seems to be a separate set of objectives related to fostering interpersonal appreciation, such as respect and trust. This is why we attribute a third responsibility for experts in the dialogue model: investing in relationships. This is in line with contributions of others pointing to the importance of relationship-building in interactions between (scientific) experts and non-experts (Nisbet & Scheufele, 2009).

In sum, we contend that experts in the dialogue model have three main responsibilities: sharing input that is well received by others; listening to and learning from the input of others; and investing in relation- ships with others. Notably, the third responsibility can be seen as the result of the first and second, but also as a catalyzer of both. In other words, relationships may be built in the process of sharing and listening and learning, but at the same time may foster sharing and listening and learning: this should become a self-enhancing process.

For the purpose of a dialogue, will it suffice to just instruct experts to take notice of these three responsibilities? We think not. For example, when considering sharing input; what specific knowledge is expected, and how is it best delivered? Or what should experts say or do to invest in relationships and with whom? In the remaining of this paper, we will further explicate each of the expert responsibilities and make corresponding recommendations. We use the Dutch dialogue on HGGM as a vehicle to identifying starting points for behavioral and/or attitudinal demands. It was instigated by the Dutch Government and is organized by a number of societal parties with relevant expertise (Box 1). Van Baalen and colleagues drafted ten "lessons" (five on content and five on process) to support design and execution of the dialogue (van Baalen et al, 2019).

Share knowledge

Experts in the Dutch dialogue are advised to not only discuss HGGM in terms of medical risks and benefits, but also in terms of personal and societal implications. Techno- moral vignettes based on future scenarios can be used to present information in a meaningful context (van Baalen et al, 2019). Experiences from the past demonstrate that it could be challenging for experts to discuss questions and concerns that they regard as outside their field of expertise (Radstake et al, 2009). However, it may be that this is exactly what publics expect from experts: to take responsibility for the topic in a broader sense, by including, for example, economic or political issues.

Box 1. The Dutch dialogue on HGGM; rational and goals. From van Baalen *et al.* (2019, pp. 14–15)

The Dutch dialogue on HGGM is to some extent a response to discussions on the tenability of the current Dutch Embryo Act. This act prohibits both the creation of human embryos for merely research purposes, and the development of a pregnancy with genetically modified embryos or germ cells. In the past few years, different scientific organizations and advisory boards (Dutch Health Council, Commission on Genetic Modification, and the Dutch Royal Academy for the Sciences) called for an extension of the Dutch Embryo Act to allow the creation of human embryos for merely research purposes, and for public debate on the development of a pregnancy with genetically modi- fied embryos or germ cells. In the 2017 Dutch Coalition Agreement it had been recorded that possible adjustments of the Dutch Embryo Act would require extensive public debate on the social and ethi- cal implications concerned. In 2018, the Health, Welfare and Sports minister explicated his wish to arrange for broad and inclusive societal discussion, in order to foster public opinion forming with which political decision making could be supported. The two-year project 'Public Dialogue on Human Genetic Germline Modification' was granted, with the overall goal to:
".. .facilitate and stimulate broad societal dialogue, a process of collective opinion forming. Therefore the broad public has to be reached, informed, and stimulated to discuss among each other the hopes, wishes and concerns with regards to genetically modifying germline DNA in embryos, as well as its broad societal implications."

In fact, such public dialogues are being held—at least partly—to prevent the break-down of a broad and constructive debate such as happened after the introduction of genetically modified crops in Europe. Instead, it should be the goal to anticipate such situations and to give HGGM a fair chance of being questioned not only for its potential risks, uncertainties, and concerns, but also to consider its potential benefits and formulate conditions for clinical use. In this regard, doubt and criticism is to be taken serious and deserves discussion. Experts, in turn, should not hide behind their expert knowledge, but also respond to questions and concerns that they regard as outside their field of expertise. Even better, they should bring up those questions and concerns themselves. To put it in the words of Jennifer Doudna, co-inventor of CRISPR- Cas9: "Scientists are equipped to not only advance ongoing scientific research but also guide the public conversation. Individuals and the scientific community alike have a responsibility and opportunity to help shape future research in an ethical manner" (Kearny & Doudna, 2020).

Listen and learn

Less than two years ago, the announcement by He Jiankui that he genetically modified the genome of two twin girls, provoked strong public reactions. Experts in the Dutch dialogue therefore have to be prepared for being confronted with sometimes extreme and highly diverse expressions of concern. In these instances, it is especially important to remain open and to listen. However, even more important is that experts are willing to open their frame of reference and engage in a mutual learning process that can yield meaningful accomplishments in terms of closing the gap between science and society.

There are previous examples of online dialogues, such as the one organized by a Dutch online magazine about parenting that discussed extending the common storage period of blood from standard neonatal screening beyond five years; it failed at least partly because experts had considered these encounters with the public as merely a diagnostic tool to get information on that publics' opinions, questions, and concerns (Radstake et al, 2009). Instead, they found themselves confronted with public appeals to critically reflect on their own attitudes with regard to—as they felt—"off-topic" issues brought up by the public (Radstake et al, 2009).

Clearly, in dialogue it cannot be decided beforehand, or by a specific group, what needs to be discussed. In this light, it is important for experts to realize that opening their frame of reference starts the minute others start to speak and that the responsibility to listen and learn can by no means be narrowed down to the expert perspective. However, when participants behave disrespectful toward experts, or pertinently refuse to assess their own views, the expert responsibility to listen and learn can no longer hold. Dialogue builds on mutual respect, and when one party consistently fails to show that respect, it is legitimate for the other to withdraw.

Although HGGM can evoke strong reactions, non-expert participants may feel hesitant to speak or may believe their contributions of little value (van Baalen et al, 2019). They may be afraid to ask witless questions or fear that their concerns will be put aside as irrational. Lastly, some may have strong convictions that their voices will not influence political decision- making at all. For all these reasons, experts should put serious effort in encouraging others to speak, for instance by emphasizing that expert knowledge is not the only valuable perspective or by stressing the importance of hearing many different voices; it may also help to pose thought-provoking questions. Moreover, listening in an open and non-judgmental way might be equally important. In doing so, experts can assist in creating a safe and comfortable environment, in which participants feel confident to express themselves.

Invest in relationships

In public dialogues, experts that express themselves in a highly scientific manner may create a sense of distance and may deter others from contributing (van Baalen et al, 2019). On the other hand, demonstrating expertise is believed to enhance feelings of trust (Besley et al, 2018). Therefore, experts are to constantly navigate between gaining trust by showing expertise while avoiding being too scientific. Relationships may strengthen when dialogue participants experience a mutual sense of equality.

For experts, it is not easy to be seen as an equal partner however. First, experts are at risk of being suspected to merely participate in the HGGM dialogue to obtain legitimacy for research or to acquire financial support. Second, experts may unknowingly give the impression that the science behind HGGM is absolute and certain, when in reality it is not. Third, apart from being blamed for hiding behind their wall of expertise, experts are at the same time easily accused of over- rating their specific expertise. Biologists in the Dutch dialogue on HGGM for example may have solid knowledge on the shortcomings of current gene-modifying techniques, but they can only speculate on how fast technical problems will be solved and hypothetical scenarios become reality. In order to be genuinely seen as equal partners in the dialogue, we advise experts to communicate in an open and transparent way on their interests, as well as on the uncertainties in and the limitations of their knowledge.

In the case of HGGM, different normative views are at stake. For example, applying HGGM will unquestionably change practices, norms, and values around pregnancy and reproduction, as well as perceptions of disease and disability (van Baalen et al, 2019). When experts behave in a way that might suggest they are not receptive to different normative views, for example, because they cannot display genuine interest in the beliefs and emotions of others, they are at risk of creating distance. Environmentalists might advocate that HGGM will negatively affect biodiversity and ecosystems.

Religious groups might claim that HGGM intervenes with the work of God. Patients with genetic conditions might struggle with feelings of rejection given the possibility to correct genetic mutations before birth, or they might fiercely advocate the introduction of HGGM to prevent transmitting the mutation to their children. All these (groups of) people either oppose HGGM or have strong feelings about it. Yet, since HGGM can be seen as the product of science, these emotions are easily projected onto the scientific community and its members, probably increasing already existing feelings of mistrust. At this point, displaying a willing- ness to listen and learn will not suffice. The best thing for experts then might be to convince their dialogue partners that they genuinely respect their beliefs and emotions with regard to HGGM, and that they truly care. In the end, it will be society at large— mostly by means of political decision- making—who decides on if and/or when HGGM will become available. Dialogue is not about reaching consensus, but about learning with and from each other. In that sense, public dialogues can be seen as opportunities to bring science closer to society; to improve relations; and to demonstrate that scientists do care.

CONCLUDING REMARKS

Since public dialogues are becoming more frequent and can be positively influenced by experts truly willing to learn instead of falling back into a deficit-like mode of communication, we believe it is important to clarify the responsibilities of expert scientists. Our paper proposes recommendations for scientists on the basis of matching science communication theory to the goal and design of the Dutch dialogue on HGGM. Although specifically formulated in relation to this particular dialogue, these recommendations can be valuable for the many public dialogues on HGGM and other topics that are currently initiated throughout the world, and any two-way science communication that aims to engage its participants in meaningful dialogue. As a next step, training aimed at equipping scientists with supportive skills should be developed. Ultimately, this would lead to higher quality dialogues, in which science-based societal questions have a better chance at being addressed in a socially robust way.

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CHAPTER 3

How to fulfill the expert role in public dialogue: The Dutch dialogue on human germline genetic modification as a case

An adapted version of this study is published as “Reincke, C. M., Bredenoord, A. L., van Baalen, S., & van Mil, M. H. (2022). How to fulfill the expert role in public dialogue: The Dutch dialogue on human germline genetic modification as a case. *Frontiers in Communication*, *7:985759*.”

ABSTRACT

Over the last decades science communication theory appears to have evolved at a much faster pace than science communication practice. Scientists seem willing to step into the public domain, but a genuine two-way interaction with the public is only rarely observed. We argue that part of this discrepancy between theory and practice may actually be caused by the lacking of a clear description of the modern expert role; the role a scientist should take in contemporary science communication. In this contribution we use an example of good practice—the Dutch dialogue on human germline genetic modification—to inform theory. We analyse guiding principles for the design and execution of this dialogue and observe expert behavior in three separate dialogue sessions. With the combined findings, we present a detailed description of the modern expert role in terms of three responsibilities, with for each responsibility three prompts for behavior. For the responsibility to share these are to select expert knowledge that is relevant to the goal; to present expert knowledge in a meaningful and accessible language; and to be cautious in sharing personal considerations. For the responsibility to listen and learn these are to consider interactions with members of the public as opportunities to learn; to be patient and supportive; and to assist in stimulating in-depth dialogue. For the responsibility to invest in relationships these are to assist in creating an ambiance of safety and relevance; to preserve trust; and to convey respect for every contribution and every point of view. Each behavioral prompt is further concretized with concomitant actions and practice examples as collected from observing experts in action. The implications for scientists engaging in contemporary science communication, as well as for science communication trainers, are discussed.

INTRODUCTION

Over the last few decades, public dialogues accompanying the introduction of new and emerging technologies have become increasingly common worldwide. In the Netherlands, a public dialogue on human genetic germline modification (HGGM) ran between October 2019 and December 2020. In multiple dialogue sessions members of the public and experts (here: researchers and health care professionals with expertise on HGGM from within their specific discipline) assembled to discuss the desirability of modifying the genetic code of human germline cells (DNA-dialoog, 2021). Former research indicates that fostering meaningful interactions between technology experts and representatives of the public can be challenging. Entrenched ideas about "roles and responsibilities" easily hinder establishing genuine two-way dialogue (Krabbenborg and Mulder, 2015). In addition, increased circulation of misinformation (e.g., false rumors or otherwise incorrect or misleading information) and (perceived) hierarchal differences may complicate feelings of trust (Bijker, 2017; Iyengar and Massey, 2019). We contend that public dialogues, and other expert-public interactions alike, can well benefit from gaining insight into what constitutes a constructive expert role in contemporary encounters between experts and the wider public.

The field of science communication has a clear history in studying communication between science experts and the public. Over time insights concerning the "why" and "how" of science communication changed; largely summarized in what is now often called the turn from deficit to dialogue (Smallman, 2016; Bucchi and Trench, 2017). As from the late twentieth century the dialogue communication model, typically associated with two-way interaction and mutual benefits, gradually discredited the one-way, science-centered approach linked to the deficit model. A major shift, which was accompanied by extensive scholarly discussion (see for example, Bucchi, 2008; Short, 2013; Bucchi and Trench, 2017). Some argued that the dialogue model would never be able to function without deficit-like elements—meaning that two- way interaction was always to be preceded with a one-way transmission of "required" (scientific) knowledge. Others were convinced the dialogue model would only be used as a cover to pursue in fact deficit goals—such as filling knowledge gaps. Regardless of the tenability of these assertions, it can be called striking that today's scientists—when interacting with non- scientist publics—keep displaying mostly deficit-like thinking (i.e., in which informing is key) (Davies, 2008; Hamlyn et al., 2015; Dudo and Besley, 2016; Jensen and Holliman, 2016; Metcalfe, 2019). Obviously, new insights in the field of science communication might not automatically filter through to the scientists responsible for its practice. Yet, this discrepancy between theory and practice may also suggest a failure of modern models such as the dialogue model to offer sufficient guidance on how to fulfill the expert role. While in the deficit model the expert role seems rather straightforward, that is "simply" delivering expert knowledge in an accessible way, the dialogue model lacks such clear directions.

Along with shifting accents in theoretic models, science communication scholarship has focused on (skill) training— either as part of (post-) graduate science curricula or as stand- alone courses or workshops. Questions have been posed as to what such training entails and how it might be improved (e.g., Bray et al., 2012; Besley et al., 2016; Yuan et al., 2017; Stevens et al., 2019). Moreover, efforts have been made to capture learning goals (Baram-Tsabari and Lewenstein, 2017) or identify key skills (Mercer-Mapstone and Kuchel, 2017) with which to guide existing and future training. What may complicate such efforts is the wide range of activities through which the act of science communication manifests. Different activities imply differences with regards to setting (e.g., science museums as opposed to public hearings), target audience (e.g., youth as opposed to patient groups) and so forth. Additional complexity, however, may be induced by lacking a well-defined description of the (modern) expert role. Without a clear-cut idea of what an expert should do or how (s)he should act, it is impossible to construct concerning educational strategies for training in science communication.

The Dutch dialogue on HGGM offers a welcome opportunity to investigate the modern expert role in a real-life situation. As we contend, particularly science-public interactions handling highly controversial topics with significant impact on humanity can well benefit from dialogue-oriented experts. This paper discusses how the Dutch dialogue as a concrete example of science communication practice can inform science communication theory (i.e., the modern expert role). In previous work, we called on researchers in the life sciences to rethink their role in public dialogue. We proposed three expert responsibilities that could help them to get a sharp view on this role (Reincke et al., 2020). Here, we use these responsibilities as a lens to focus analysis and interpretation of two data sources of the Dutch dialogue: (1) an advisory report containing guiding principles for design and execution of the dialogue, and (2) real-time observations of experts in action.

The structure of this paper is as follows. In our theoretical framework below, we situate each responsibility as one of three sub roles in theoretical work on the dialogue model and modern science communication in general, as well as scholarly literature on skills and training (Section Expert responsibilities in dialogue). We proceed by offering a brief introduction on rationale and set-up of the Dutch dialogue (Section The Dutch dialogue as an example of good practice). Next, we describe how we used this dialogue to study the modern expert role in practice (Section Methodology to study the Dutch dialogue). With the combined findings, we present a description of the expert role in terms of three expert responsibilities, concomitant behavioral prompts, and examples of concrete behavior as observed in practice (Section Results). We close off with a reflection on study limitations and discuss the implications of our findings (Section Discussion).

Expert responsibilities in dialogue

One of the key changes in moving from deficit to dialogue concerns the meaning of the act of science communication, for example as reflected in perceived goals and outcomes. In the "old" deficit model, the meaning of science communication seems absolute: it serves to educate a scientifically illiterate public, largely departing from the assumption that increased knowledge leads to an increase in trust (Stocklmayer, 2018). In the "new" dialogue model on the other hand, science communication seems to hold varying meanings, serving variable goals, wearing multiple faces. Regardless of function or form however, the dialogue model clearly transcends a mere transmission purpose of science communication. Scientific knowledge is no longer considered as reflecting absolute truth; rather is it used in combination with other forms of knowledge, including values and experiential expertise, to create shared understandings (McCallie et al., 2009). This is not to say that in the dialogue model scientific knowledge has been downgraded to "just another opinion", or that the integrity of the scientific method is questioned. It merely suggests that in modern science communication one can no longer speak of the expert. Especially in the case of complex science- based societal issues—being largely "conflicts over values and worldviews"—expertise is hold by many (McCallie et al., 2009). Science communication then, serves mainly to accommodate mutual learning [Lehr et al., 2007; American Association for the Advancement of Science (AAAS), 2016]. Consequently, today's scientists have to move beyond the informing role that requires them to share scientific knowledge, to extend it with a role that requires them to be receptive to the expertise of others.

Share tailored knowledge and insights

Informing in the dialogue model encompasses more than in the deficit model. In the deficit model scientists typically share knowledge that is crucial from a scientists' perspective. In the dialogue model, where scientists and members of the public are equal partners in conversation (both capable of bringing in valuable contributions), scientists need to take into account the needs and preferences of non-scientists. Moreover, they can be held accountable for adequate reception of shared knowledge. They should put effort in, amongst other things, using comprehensible language and connecting with prior knowledge and interests (see for example, Varner, 2014; Cooke et al., 2017). Research into skills and training confirms this shift toward a more audience-centered view on informing in modern science communication. For example, Mercer-Mapstone and Kuchel (2017) reported core competencies for scientists to effectively communicate with the public, amongst which they identified the ability to adjust language to and to align content, context and mode of communication with an audience. Bray et al. (2012) conducted a Delphi study amongst New Zealand experts of science communication, leading them to suggest training programs should focus on skills related to being able to connect with an audience, as well as to stimulate an audience to state their point of view. In sum, informing in the dialogue model is better defined as sharing tailored knowledge and insights (in short: share). According to our view, this knowledge and insights can be both professionally and personally based. As members of society and equal partners in conversation, scientists can be expected to share personal considerations, such as hopes and fears, as well.

Listen and learn

Being receptive to the expertise of others requires, first of all, a willingness to listen. Indeed, Yuan et al. (2019) reported both scientists and communication scholars consider listening to non-scientist publics an important communication objective for modern science communication. Furthermore, listening (e.g., to audience concerns) has been found to prevail as a learning goal in contemporary science communication training (Baram- Tsabari and Lewenstein, 2017). Yet, being receptive to the expertise of others seems to imply more than mere listening. The scarce scholarly literature in which the modern scientific expert role is explicitly discussed points to the importance for scientists to acknowledge other forms of expertise, such as the experiential knowledge that patients have (e.g., McCallie et al., 2009; Escobar, 2011; Zwart et al., 2017), and to be willing to learn from others (Illingworth, 2017; National Academies of Sciences, Engineering, and Medicine, 2017). We define being receptive therefore, as listening and learning.

Invest in relationships

Many goals associated with the dialogue model or modern science communication in general can be linked to either the sharing or the listening and learning role of scientific experts. Informing and stimulating debate on science-related issues with societal implications, seeking public input into science issues, or influencing the direction of scientific research and policy (Miller, 2001; Bucchi, 2008; McCallie et al., 2009; National Academies of Sciences, Engineering, and Medicine, 2017), to name just a few. Others however, do not seem to fit in either category. For example building trust, which is another frequently mentioned goal in regard to modern science communication [e.g., American Association for the Advancement of Science (AAAS), 2016; Hebets, 2018; Kappel and Holmen, 2019]. In the same vein, recent research within a North-American population of academics revealed eight communication objectives for scientists (Besley et al., 2018) of which only four seem to address the sharing and listening and learning roles. All other objectives reflect relational aspects, such as feelings of trust, equality and a sense of shared identity (Besley et al., 2018). This is why we define a third role for expert scientists in the dialogue model: invest in relationships. This can concern both the more pragmatically motivated, communicative relationships for the actual duration of the interaction, and—from a more ideological point of view—affective relationships that allow for structural cooperation on the long run—e.g., in collectively handling complex issues.

In accordance with the above given (sub) roles, in our theoretical framework we distinguish three responsibilities for expert scientists in modern science communication: share (1), listen and learn (2), and invest in relationships (3).

The Dutch dialogue as an example of good practice

Rationale and set-up

The Dutch dialogue on HGGM, which was funded by the Dutch Government, was initiated by a multidisciplinary consortium of 11 organizations with a range of expertise (hereafter: DNA-Dialogue). The project aimed to stimulate a nation-wide dialogue on the desirability of modifying heritable DNA in human embryos, i.e., a collective process of opinion forming (Van Baalen et al., 2019). Thereto, multiple dialogue sessions were organized in which various experts conversed with various publics, led by a conversation moderator. Of the 27 dialogue sessions in total, individual session ranged from intimate conversations with as little as three people to large-scale group conversations of as much as 210 participants. Some were set up to reach mixed audiences (i.e., the general public); others were directed to a specific audience (e.g., children and youth, women with a migration background). More information about the sessions, as well as an overview of the public perceptions as expressed by participants, can be found in Van Baalen et al. (2021).

Lessons for a public dialogue

In preparing the dialogue, an advisory report containing ten "lessons" to inform the design and execution of the dialogue was drafted by one of the parties of DNA-Dialogue; the Rathenau Instituut (Van Baalen et al., 2019). The Rathenau Instituut performs research and organizes societal debates on the impact of science, technology and innovation on society. The results of their work are, among other things, meant to inform political decision making on science, technology and innovation. As an institute, it was involved in organizing public dialogues on new and existing technologies that (can) have a major impact on society, e.g., nanotechnology (Hanssen et al., 2008), synthetic biology (Rerimassie and Stemerding, 2014) and nuclear waste (De Vries et al., 2015). The ten lessons for the Dutch dialogue on HGGM were based on years of experience, a review of the debate on HGGM in the Netherlands so far and a systematic analysis of the social and ethical issues concerning HGGM. Moreover, the formulated lessons were proven successful in pilot focus groups with diverse publics prior to the dialogue (Heugens et al., 2019).

METHODOLOGY TO STUDY THE DUTCH DIALOGUE

Analysis of the advisory report

For the purpose or our study, we considered the advisory report drafted by the Rathenau Instituut as a guide to setting up a dialogue in which expert scientists fulfill a modern expert role. We used our theoretical framework, i.e., the three expert responsibilities, as a lens to analyze the content of the ten "lessons".

The goal of our analysis was twofold:

1. to examine if and how the responsibilities could be recognized in the lessons
2. to consolidate each responsibility with concrete prompts for behavior

In step 1, we screened the full text of the ten lessons for elements that could be linked to either one of the responsibilities. In three separate rounds, one for each responsibility, we searched for either direct, expert-specific instructions, e.g., an advice to avoid using jargon, or (more) indirect instructions that could be discerned from guidance on other aspects of dialogue design and/or orchestration. All relevant passages were collected (see Table 1). In step 2, we used the selected passages to discern prompts for expert behavior (see Section Results).

Observations

Parallel to analyzing the lessons an observation scheme was developed for observing (invited) experts in the Dutch Dialogue. Thereto, theoretical insights as presented in Section Expert responsibilities in dialogue were complemented with results of a first, gross, analysis of the ten lessons. This resulted in a list of 16 items representing behavioral and attitudinal aspects, divided over the three responsibilities. Items linked to the responsibility to share included for example "puts knowledge in a relevant context" and "uses comprehensible language". For the responsibility to listen and learn they included for example "listens attentively" and "asks questions". Items linked to the responsibility to invest in relationships at last, included for example "is open and transparent" and "shows interest". Each item contained a short description of related (observable) behavior, as well as (possible) concrete examples. The goal of the observation was twofold:

1. to examine if and how the responsibilities could be recognized in experts in practice
2. to collect concrete practice examples for each responsibility

Observations were done in real-time, without making use of video and/or audio recordings afterwards (only one session was recorded in audio). Data are therefore per definition incomplete and must be read as a qualitative exploration of expert behavior. The observation scheme served as a means to focus attention on specific behavior (consistent with the 16 items) during the observations, and as a coding scheme to categorize and analyze the data afterwards. In total, three dialogue sessions were observed by making use of the observation scheme. Sessions 1 and 2 took place at the yearly recurring Housekeeping and 9 Months (pregnancy) Fair in the country's capital Amsterdam. Both sessions were attended by a moderator and two experts: a biomedical geneticist (hereafter E1), also last author on this paper, and a medical psychologist (hereafter E2). Public attendants, 11 for session 1 and 10 for session 2, had either signed up for the dialogue in advance, thereby earning a free ticket for the fair, or were recruited by the organizers (DNA- Dialogue) on the spot. Session 3 was organized by Veritas-forum, a foundation with a Christian base that organizes gatherings for students and lecturers of higher education about life's big questions, in consultation of DNA-dialogue. The session was attended by 75 public participants (mostly students), a moderator and two experts: an ethicist (hereafter E3) and a biomedical ethicist (hereafter E4).

Table 1: Lessons for a public dialogue. Selected and reprinted from *Discussing the modification of heritable DNA in embryos - Lessons for a public dialogue* (p. 86-92), by S. van Baalen, J. Gouman, P. Verhoef, 2019, Rathenau Instituut

1	The questions of ‘whether’ and ‘how’ are interlinked – the dialogue should, therefore, not be limited to one or the other
	• ‘Scientists and opinion makers regularly suggest that the discussion about the modification of the DNA of embryos … should not be concerned with the question of ‘whether we wish to use it’, but only the question of ‘how we are going to use it’. … that question cannot be answered without thinking about the purposes for which it will be used and the conditions under which it will be used.’
2	Include the question of what is at stake in the dialogue
	• ‘To expand the dialogue on human germline genome editing as widely as possible, it is important not to establish any prior constraints.’ • ‘The challenge is to expose this [implicit normative assertions about what is or is not at stake] and to conduct a dialogue about whether, and if so why, such concerns (…) are relevant in the case of germline genome editing. In other words, any subject that participants in the dialogue regard as relevant must be acknowledged and explored in the dialogue.’
3	Clearly explain what is needed to make use of human germline genome editing (the research trajectory and basic conditions for the use of the technology in practice).
	• ‘…it must be clear to the participants what will be needed before genome-editing technologies can be used to modify heritable DNA of embryos (and hence of future persons).’ • ‘…there is still considerable uncertainty about the opportunities for and risks of clinical application [of HGGM].’ • ‘How great the theoretical benefits of modifying heritable DNA will actually be in practice is, ... still uncertain; the same applies to who could profit from those benefits’
4	Discuss the broader implications of the targeted editing of the human genome for the individual, society, and humanity
	• ‘The dialogue must, …, not only be about genome-editing technologies (such as CRISPR-Cas9) themselves (the purposes they can be used for, their medical benefits and their risks). Their impact on the practices and the social context in which they are applied must also be discussed.’

	• '….there must be a discussion of how the practice of reproductive medicine and the norms and values surrounding pregnancy and reproduction will change. The same applies to attitudes towards sickness and disabilities.'
5	Turn it around: think about the society of the future – what its core values should be and what role modification of heritable DNA in humans could play in that respect
	• 'Reflection on broad social consequences of germline genome editing also raises questions about the type of society we pursue and what key values should be protected in it.'
6	Organise a dialogue not only between groups of stakeholders and interested parties, but also amongst themselves
	• 'Scientists, patients with a serious heritable disorder and prospective parents do not form a homogeneous group and their attitudes towards germline genome editing will differ. It is, therefore, important for these groups to converse not only with each other, but also amongst themselves.'
7	Actively seek ways of reaching and informing less accessible groups and engaging them in the dialogue
	• 'It is not necessary for everyone to have an active voice in a dialogue, but the largest possible number of groups should be represented.'
8	A dialogue is not a platform for exchanging fixed views
	• 'There are various interests involved in this dialogue, such as the desire of many scientists to create embryos specifically for research …' • '… the crucial objective of the dialogue is to promote a joint process of opinion formation.' …. 'It must be clear in advance to the participants that they do not necessarily need to have made up their minds, that there is room to express doubts and reservations and to explore the issues together.'
9	Involve and instruct appropriate experts and people with practical experience
	• '… we stressed the importance of providing all of the participants with sufficient information about the broad potential consequences [of HGGM] for individuals, society and humanity to take part in the debate.' • 'They [specialists and practical experts] must use language that is intelligible to everyone in attendance.' • 'The presence of patients with a serious heritable disorder or 'learned' scientists might lead to …. or to people being too reticent to engage in the discussion.'
10	Think carefully about the themes, the material, the terminology and the subject matter that will be discussed during the sessions
	• 'Present the material in a context that fits with the personal environment of the participants. This could be done using the techno-moral vignettes … based on the scenarios … .' • '… there should always be room for members of the audience to express their concerns and ask questions.'

Data of each session consisted of quotes and short situational descriptions as noted by two separate researchers. The collated data were used to draft a detailed observatory report for each session. In step 1, agreement was sought between observers on coding each observatory report according to the 16 items of the observatory scheme. During this coding process, we experienced some difficulties with applying codes. For example, we noticed some items had overlap with others, which made it difficult to code consistently. Furthermore, although all items were accompanied by short descriptions of target behavior, including examples, sometimes it appeared difficult to decide whether a given behavior could be classified as such. In the meantime, the definitive analysis of the lessons had resulted in the formulation of nine prompts for behavior (see also Section Results), that in fact covered all 16 items, but in a more considered and coherent configuration. This is why we decided to follow up with a second step of analysis of the observatory reports. In this step 2, we analyzed each observatory report on the base of the nine formulated behavioral prompts (three per responsibility) (see Section Results).

Ethical approval

The medical ethical review board of the UMC Utrecht concluded that this study falls outside the scope of the Dutch laws that regulate medical research with humans and therefore did not require review.

RESULTS

Table 2 presents the collated results from the lessons and the three observed dialogue sessions. For each responsibility, three behavioral prompts were discerned from the lessons. For each prompt, at least one example was observed in practice. The most illustrative examples are displayed in Table 2. In the remaining of this section, we will expand on our results. For every behavioral prompt, we start by explaining how we discerned it from the lessons. Next, we describe observational data that we found applicable to this prompt.

Responsibility to share (1)

Select expert knowledge that is relevant to the goal

Lessons

Firstly, we recognized the responsibility to share in lessons 3 and 4. In lesson 3, Van Baalen et al. recommend experts in the Dutch dialogue to clarify the (scientific and technical) steps that still need to be taken to progress toward practical use of HGGM as well as to stress the uncertainties in the opportunities and threats of its applications. In lesson 4, they advise to focus on more than medical risks and benefits of HGGM, and to include in the discussion possible personal and societal implications. Informing people on these different aspects of HGGM is believed to support people in shaping their opinion in a solid way, which is the goal of the Dutch dialogue. Expert scientists thus, are to select out of their full body of knowledge those bits that are relevant to the dialogue goal. As it may differ between (groups of) people what knowledge is indeed relevant (e.g., due to differences in prior knowledge, ideas and experiences), expert scientists may benefit from studying dialogue partners' backgrounds in advance. During the dialogue session, they could invite dialogue partners to explore what knowledge they consider relevant to the goal.

Observations

For sessions 1 and 2, several observations were noted that can be linked to sharing knowledge relevant to the goal. Examples include a reflection on the opportunities and risks of HGGM (e.g., medical but also broader such as related to social equality) and a reflection on the (im)possibilities of standard procedures as an alternative to HGGM (1.1.1 in Table 2). For session 3, only more general remarks were made that reflected poor execution of this prompt. For example, it was noted that both experts started off with an introduction on the subject matter that contained many (irrelevant) specialist details.

Present expert knowledge in a meaningful context and accessible language

Lessons

Secondly, we recognized the responsibility to share in lessons 9 and 10 that advise experts to use plain, accessible language (9), and to help participants recognize the relevance of shared scientific knowledge by presenting it in a meaningful context (10). Again, what counts as a meaningful context and accessible language, differs between (groups of) people. We advise expert scientists therefore—in addition to studying dialogue partners' backgrounds—to make a serious effort to connect to their ideas and experiences, as well as important values. A specific example of putting knowledge in a meaningful context is a so-called techno-moral scenario (as also suggested in lesson 10). Techno- moral scenarios have been shown to stimulate reflection on the moral impacts of emerging technologies, by providing possible personal and societal effects in a meaningful context (Boenink et al., 2010).

Observations

For all sessions, positive examples of putting knowledge in a relevant context were noted. For instance, E2 shared a practice case where HGGM could have been life changing. In this case a couple of prospective parents had undergone standard procedures to prevent passing on a genetic predisposition for a given condition to their offspring. When this failed, HGGM could in theory have offered them additional possibilities to fulfill their child wish after all. Furthermore, E4 explained the term inviolability by putting it in the context of a hospital on fire, forcing one to choose between the lives of a child and a box full of embryos; who would you save? (1.2.2 in Table 2). For session 3, a few examples of non-accessible language were noted (e.g., "plural reasoning"), for sessions 1 and 2 none.

Be cautious in sharing personal considerations, including viewpoints

Lessons

In the lessons presented by Van Baalen et al. it remains unclear whether experts in the Dutch dialogue should share merely professionally based knowledge and insights or that they can also share personal considerations such as hopes, concerns and viewpoints with regards to HGGM. In our view, excluding expert scientists from (actively) participating in the opinion- forming process may create distance, which is not considered positive. For example, this may foster an idea that scientists are not, in the same way as their dialogue partners are, members of society. In the same vein, we do not expect expert scientists to adopt a neutral position or to feign neutrality when in fact they hold a particular stance. Especially the latter might undermine an expert's credibility (Davies, 2022), which in turn can complicate feelings of trust (see also Preserve trust). On the other hand, expert scientists sharing personal considerations may unwillingly influence non-expert participants. Experts in the Dutch dialogue are invited because of their (perceived) expertise concerning (aspects of) HGGM. This could well imply that an expert's contribution deserves superiority over that of the average participant not invited as expert. In light of all, we recommend expert scientists, foremost, to be cautious in sharing personal considerations. For example, when expressing a (personal) position or viewpoint, they should refrain from acting authoritative and/or persuasive toward others. Moreover, we encourage them to be transparent about the reasoning behind their position or point of view, e.g., to which extent it is based on epistemic knowledge, and which additional factors, knowledge or values play a role.

Observations

Several examples were noted of sharing personal considerations. In sessions 1 and 2, personal considerations included mainly concerns and reflections. For example, at some point E1 indicated to be somewhat nervous that allowing HGGM would lead to societal pressure to use it, e.g., to reduce healthcare expenses. Another example is when E2 reflected back at the practice case above, recalling that it was in this situation that she had asked herself for the first time: what if HGGM could have been applied? (1.3.3 in Table 2). For both sessions, no remarks were made of experts being authoritative or persuasive in sharing personal considerations. In session 3, personal considerations included mainly viewpoints. It was noted that, in stating their point of view, sometimes the experts tended to be somewhat directive. For example, E4 answered the question in the "hospital on fire" case scenario (who would you save?) by firmly stating: "the child of course". On the other hand, at several instances both E3 and E4 concluded with indicating that they were very interested to hear the other experts' point of view.

Responsibility to listen and learn (2)

Consider interactions with members of the public as opportunities to learn

Lessons

Firstly, we recognized the responsibility to listen and learn in lessons 1 and 2 that highlight the importance of keeping a maximal open dialogue, and lesson 8, stating that dialogue does by no means stand for exchanging already fixed opinions. This calls upon expert scientists, as well as all other participants, to enter a dialogue with an open mind and a willingness to listen. To stimulate openness, we recommend expert scientists to consider interactions with members of the public as opportunities to learn. They should make an effort to understand different forms of knowledge and varying perspectives, and encourage others to say more. For example by asking

Table 2: *Behavioral prompts and examples of concrete behavior per responsibility*

Behavioral prompts		
		Responsibility to
1.1	Select expert knowledge that is relevant to the goal	- Prepare for a session by studying dialogue partners' backgrounds - Invite dialogue partners to explore what knowledge *they consider* relevant to the goal
1.2	Present expert knowledge in a meaningful context and accessible language	- Connect to the values, ideas and experiences of dialogue partners - Use techno-moral scenario's to sketch the moral impact of technologies
1.3	Be cautious in sharing personal considerations, including viewpoints	- Refrain from acting authoritative and persuasive towards others - Be transparent about the reasoning behind a (personal) position or point of view
		Responsibility to
2.1	Consider interactions with members of the public as opportunities to learn	- Make an effort to understand different forms of knowledge and varying perspectives - Encourage others to say more, e.g., by asking (further) questions
2.2	Be patient and supportive	- Allow for moments of silence and convey non-verbal involvement - Actively invite others to contribute
2.3	Assist in stimulating in-depth dialogue	- Introduce different perspectives and viewpoints - Help identify and explore borderline cases
		Responsibility to
3.1	Assist in creating an ambiance of safety and relevance	- Be modest and refrain from dominating the conversation - Emphasize that complex issues such as HGGM can only be addressed by combining many forms of knowledge, including values and emotions
3.2	Preserve trust	- Balance between showing expertise and being transparent (e.g., about interests) and honest (e.g., about uncertainties in knowledge) - Refrain from using expertise to persuade and/or to compensate for gaps and uncertainties in knowledge
3.3	Convey respect for every contribution and every point of view	- Display genuine curiosity and ask open questions - Check back at understanding

Concrete example situations	
Share (1)	
1.1.1	E1 reflects on the (im)possibilities of standard procedures (embryo selection) as an alternative to HGGM
1.2.2	E4 explains inviolability: Imagine a hospital on fire, forcing you to choose between the lives of a child and a box full of embryos; who would you save?
1.3.3	E2 shares a practice case in which she had asked herself for the first time: what if HGGM could have been applied? She continues with indicating that she is very anxious to hear others' thoughts on this case.
Listen and learn (2)	
2.1.1	E1 elaborates on a participant stating to see no problem in 'making' children more intelligent, asking her whether she can think of an application of HGGM that she would say: "this is not ok anymore?"
2.2.2	E3 and E4 show to have full attention for a public attendant sharing his thought about living with autism, by looking in his direction and frequent nodding
2.3.3	E1 stimulates public attendants to approach HGGM from a financial point of view: "What if we consider HGGM as a means to reduce healthcare expenses?"
Invest in relationships (3)	
3.1.1	E2 regularly passes the moderator's invitation to speak to others, therewith consciously re-directing attention from her to public attendants
3.2.2	E1 indicates that there are still many uncertainties with regards to the safety of HGGM
3.3.3	E1 demonstrates genuine curiosity toward a public attendant showing some resentment by questioning: "could we ask where this resentment comes from?"

3

(further) questions, or by trying to reveal values underlying spoken words. It may also help to consider in advance what it is they would want to learn (while at the same time accepting that this may not match with what others wish to share and/or want them to learn).

Observations

Several observational notes were made that can be linked to this prompt. In a direct way this concerned asking (further) questions, which was mainly observed in sessions 1 and 2. For example, at some point a public attendant reacted at the question posed by the moderator which conditions participants would rate as "serious enough" to use HGGM for, indicating that she believes perceptions about the severity of a condition are very personal. E1 elaborated on that asking her: "would it be best to leave the choice whether or not to use HGGM all up to prospective parents?" Another example is that E1 elaborated on a participant stating to see no problem in "making" children more intelligent, asking her whether she can think of an application of HGGM that she would say: "this is not ok anymore?" (2.1.1 in Table 2). In a more indirect way this concerned a mix of varying behavior. For example, one time E4 warned the moderator when a participant requested for the microphone, which the former had not noticed. Another example is that both E1 and E4 indicated at some point in the dialogue that they do not have a clear opinion on HGGM yet, and that therefore they are happy to participate in this dialogue.

Be patient and supportive

Lessons

Secondly, we recognized the responsibility to listen and learn in lesson 10, stating that there should be sufficient time and opportunity for questions and concerns coming from the public. It may well be that, in comparison to other participants, expert scientists are already well versed in the topic at hand. They might have reflected on the subject more often, or they have encountered many different perspectives already. In order to ensure every participant has the chance to actively participate in the dialogue process, it seems important for expert scientists to realize that others may need time. Time to interpret incoming information, time to construct a response, and time to find words to express this response. We recommend expert scientists therefore to be patient and supportive. They should allow for moments of silence, and confirm their partners in dialogue with non-verbal involvement. It may also help to actively invite others to contribute.

Observations

In all sessions, observations were noted that indicated patience and supportiveness. Mostly by displaying non-verbal involvement and inviting others to contribute. An example of the former is that E3 and E4 demonstrated full attention for a public attendant sharing his thought about living with autism. Especially when this participant indicated that he would have been happy using HGGM if it could have meant for him to live a (more) normal life, E3 and E4 looked in his direction and nodded frequently (2.2.2 in Table 2). Examples of the latter include E2, in asking the group of public attendants how they view the possibility of using HGGM for the couple in the practice case above, and E1, in posing the hypothetical question how public attendants would think of making their offspring a bit more intelligent and attractive.

Assist in stimulating in-depth dialogue

Lessons

In a more implicit way we recognized the responsibility to listen and learn in the recommendation to include different societal groups in the dialogue process (lessons 7 and 9), to have these different groups also converse amongst themselves (lesson 6) and to discuss HGGM from a broader societal point of view (lessons 4, 5 and 9). Robust opinion-forming, based on a wide range of perspectives and many different viewpoints, does not only require knowing or hearing them. It also needs bringing all these perspectives and viewpoints together, followed by deep reflection and careful balancing of benefits and harms. However, some groups in society are more difficult to reach than others. Furthermore, bringing many different groups together at the same time can be challenging in terms of organization. It is therefore that we advise those expert scientists that have encountered many different perspectives and viewpoints already (see also prompt Be patient and supportive), to bring in some of these perspectives and viewpoints themselves. In this way they could assist in stimulating in-depth dialogue [note: by thinking in terms of societal groups, it is important to keep in mind that individual members may in fact hold very different views (see also lesson 6)]. In the same vein, it may help to invite participants to collectively identify and explore borderline cases.

Observations

In sessions 1 and 2, a few examples were noted that can be interpreted as stimulating in-depth dialogue. For instance, at some point a public attendant shared her negative experience with (professional) healthcare for her disabled daughter ("it's dramatic"). In reaction to that, E1 stimulated further reflection on healthcare quality and the role of HGGM by inviting public attendants to approach HGGM from a financial point of view: "What if we consider HGGM as a means to reduce healthcare expenses?" (i.e., with HGGM certain diseases could in theory be eliminated) (2.3.3 in Table 2). Another example is that E1, at some point, suggested that it might be interesting to imagine if and how HGGM can affect our definitions of health and disease, and/or how we view fellow citizens that choose not to use HGGM. For session 3, no observational notes were made that indicated this prompt.

Responsibility to invest in relationships (3)

Assist in creating an ambiance of safety and relevance

Lessons

Firstly, we recognized the responsibility to invest in relationships in lesson 9 that alerts expert scientists to refrain from assuming the role of "learned" scientist, since this may discourage others to contribute to the conversation. Especially when discussing highly complicated matter such as HGGM, participants may—apart from needing time—feel little confident to express themselves. Moreover, they may believe their involvement in the dialogue is mainly tokenistic and/or struggle with hierarchal differences. In order to overcome these hindering beliefs, expert scientists can be recommended to assist in creating a safe ambiance such that all participants feel confident to contribute, as well as a shared sense of relevance. In relation to the former, expert scientists can be advised to remain modest and to refrain from dominating others and/or the conversation. In regard to the latter, it could help to emphasize that complex issues such as HGGM can only be addressed by combining many forms of knowledge, including values and emotions.

Observations

For sessions 1 and 2, several notes have been made of E2 trying to re-direct attention from her to public attendants that could be interpreted as being modest or refraining from dominating the conversation. For example, more than once she passed an invitation of the moderator to share her point of view on to others (3.1.1 in Table 2). With regards to session 3, observational notes indicate that the conversation was in fact very much dominated by the experts. The moderator gave them constant opportunity to speak, whereas public participants were only rarely invited to contribute. Secondly, observations were noted that indicated creating relevance. An example is when at some point after several public attendants had shared their thoughts, E2 reacted upon that stating how their contributions clearly illustrated that HGGM actually concerns everyone. Another example is when E1—in reaction to the moderator's question how he views Dutch law, i.e., its current restrictions for research in his disciplinary field—indicated that this is exactly why this dialogue is so important. "After all, why would I desire investigating a technique that society does not deem preferable?"

Preserve trust

Lessons

Secondly, we recognized the responsibility to invest in relationships in lesson 8, stating that in the dialogue around HGGM different interests are at stake. For example, scientists might have the ambition to further knowledge on early- stage embryo development for which generating embryos in a laboratory specifically for research purposes should be permitted (note: currently Dutch law prohibits this). Obviously, when discussing the desirability of applying a technique that has the potential to shape future life in an impactful way for all, any (perceived) conflict of interest may complicate feelings of trust. To preserve trust, we recommend expert scientists at all times to be transparent about interests. In the same vein, we advise them to be honest about limitations and uncertainties in knowledge, as well as about the positions they hold (see also Be cautious in sharing personal considerations, including viewpoints). Both transparency about interests and honesty about limitations and uncertainties have been shown to stimulate public trust in science (Johnson and Slovic, 1995; National Academies of Sciences, Engineering, and Medicine, 2016). However, another factor that has been linked to trust is expertise (Hendriks et al., 2016a). And showing expertise can feel conflicting with being transparent and honest, especially being honest about uncertainties and limitations in knowledge. Thereto, we advise expert scientists to carefully balance between showing expertise and being transparent and honest. Above all, they should refrain from using expertise to persuade and/or to compensate for uncertainties and gaps in knowledge. In fact, actively communicating flaws or uncertainties in research results, has been shown to positively influence perceptions of integrity—and therewith trust (Jensen, 2008; Hendriks et al., 2016b).

Observations

Several examples were noted that can be linked to preserving trust, mainly in the form of being transparent and/or honest. For instance, somewhere in the beginning E1 stated that there are still many uncertainties with regards to the safety of HGGM (3.2.2 in Table 2). Somewhat later, he indicated that we cannot get round the fact that the first human to use HGGM on [with granted permission] will be part of an experiment that should be closely monitored, as we are simply not sure how it will turn out. There were no observational notes that indicated using expertise to persuade and/or to compensate for uncertainties and gaps in knowledge.

Convey respect for every contribution and every point of view

Lessons

Thirdly, we recognized the responsibility to invest in relationships in lessons 4 and 5 that point to dialogue as a collective exploration of the normative views at stake. Notably, any participant in dialogue can be held accountable for respectfully handling normative views that conflict with his or her own. However, particularly in the case of expert scientists, not respecting the views of dialogue partners might strengthen feelings of inequality. We advise expert scientists therefore to actively show that they respect every contribution and every point of view. For example by displaying genuine curiosity, and by asking open—instead of closed—questions. It may also help to repeatedly check whether the words of others are understood as they were meant.

Observations

A few notes were made that can be linked to showing respect. For example, one time E2 reacted on two opposing views as expressed by public attendants, by stating how much she welcomed both their points of view (the perspective of a prospective parent against that of an unborn child). Another example may reflect genuine curiosity. When at some point, a public attendant seemed to show some resentment, E1 reacted with: “could we ask where this resentment comes from?” (3.3.3 in Table 2). A last example is that both E1 and E2 tried to reassure one of the public attendants who expressed her amaze and concern: “Am I really the only one in favor of HGGM?” by stating she is certainly not, and that in any case it is important that she expresses her opinion.

DISCUSSION

In this paper we investigated the scientific expert role in a real-life case: the Dutch dialogue on HGGM. We started with examining an advisory report for the design and execution of this dialogue. We analyzed if and how we could recognize three expert responsibilities that are contained in the expert role, in the "lessons" presented in the report. We used our findings to concretize each responsibility with concomitant behavioral prompts. Next, we analyzed if and how we could recognize these behavioral prompts in practice by observing expert behavior in three separate dialogue sessions. With the results, we were able to consolidate each behavioral prompt with at least one example of concrete expert behavior. Before reflecting on the implications of our results, we will discuss the most important study limitations.

Study limitations

One key limitation is that we studied the expert role within a specific context. Our findings therefore, apply primarily to this context and cannot automatically be extrapolated to other contexts. Different contexts, e.g., with regards to (geographical) location, or topic of dialogue, might require differences e.g., as to how behavioral prompts are operationalized into actual behavior. For example, different cultures may have different norms or habits about demonstrating non-verbal involvement. Moreover, factors that determine trust in experts may differ between populations and/or vary depending on the topic. Mihelj et al. (2022) examined trust in experts in times of COVID-19 within a relatively understudied population (inhabitants of four east European countries characterized with generally low levels of trust in science). They found additional factors (positively) related to trust in experts, i.e., perceptions of an expert's political independency and whether one knew an expert personally. Different contexts may also pose differences as to how individual responsibilities are interlinked and/or how they work best together. For example, in case of polarized issues such as childhood vaccination or climate change, scientists can be confronted with fierce opposition or deeply grounded distrust. This may place significant interest on the responsibility to invest in relationships, in expense of others. Future research should be directed at extending our findings with results from multiple different contexts.

Secondly, the number of dialogue sessions (n = 3) and expert scientists (n = 4) of which we collected observational data is fairly low. This might have resulted in a biased and/or incomplete view of experts in action. In fact, in hindsight, we must conclude that sessions 1 and 2 were indeed examples of good practice (i.e., dialogues in which experts fulfill a modern expert role). In session 3 however, experts seemed to have a more traditional role. To illustrate, in session 1, public attendants and experts were seated interchangeably in a circle- like configuration, the moderator was able to walk around. No strict agenda was followed and public attendants and experts were more or less free to contribute as they wished. In session 3 on the other hand, the experts were seated on an elevated stage. The moderator walked around on the stage and public attendants were seated in rows in front of and facing the stage. The session started with two (long) lectures, 15–20 min each, provided by the two experts. The remaining of the session was built around five statements that were formulated to stimulate discussion (e.g., “Applying HGGM for non-medical purposes is ethically responsible”). With every new statement that was brought in, both experts and public attendants could react by showing emoticon cards that expressed different emotions (e.g., sad, happy, hesitant). However, most of the time only the experts were asked to explain the emoticon card of their choice in words. Public attendants were only rarely invited to react verbally. Overall, session 3 turned out not to be a convincing example of good practice. We recommend future research to test and/or extend our results with data from a range of experts, different set-ups of dialogue sessions, and various numbers of participants.

Conclusions and implications

On the base of our findings, we present a description of the scientific expert role in terms of three responsibilities, with for each responsibility three behavioral prompts and three concomitant practice examples. Even though the latter are specific for the context of our case study, in a more generic way these examples are meant to offer both expert scientists and professionals in the field of training important insight in how to convert behavioral prompts into actual behavior. It is our hope that, by offering a first (detailed) description of the expert role in modern science communication, we infuse scholarly discussion and stimulate further research on the topic. We invite scholars in the field of science communication and related disciplines to use our description for further scrutinization and/or refinement. Educational research could be directed at developing educational strategies for training associated target behavior. In this respect, it seems important to note that our description is meant to inform the expert role in a context of science communication where mutual learning between scientists and members of society is key. We investigated this expert role by studying an example of such a context: the Dutch (public) dialogue on HGGM. However, this does not mean that we claim our description applies to all sorts of (science-based) public dialogue or public dialogue in general. There are fine examples of public dialogues that do not aim for (direct) mutual learning between experts and public participants, where experts are not actively participating in the dialogue, but only have a limited role of introducing a topic and/or sharing important background information (see for example Reedy et al., 2020; Blacksher et al., 2021).

Although, in general, all three responsibilities within our description of the expert role seem equally important and are likely to act upon each other, we are inclined to think that the responsibility to listen and learn serves as the best starting point to improve expert performance with relatively little investment. As we mentioned in the introduction of this paper, despite ages of evolution in science communication theory, experts seem to have remained "stuck" in deficit-like thinking that keeps them mostly in a speaking position. Yet, despite a growth in training programs and considerable interest of scientists to participate in it, the majority of science communication training still focuses mainly on speaking behavior, such as message clarity and storytelling (Dudo et al., 2021). Although these are very important competences for a scientist interacting with the wider public, such a focus on speaking does not particularly invite scientists to transcend the informing role in favor of other roles. If we aim for scientists to engage in genuine two-way dialogue, science communication training should at least take both arms of the communication process equally serious: speaking and listening. In fact, being a complex skill, listening can be challenging to do well. For example, "active listening", a specific form of listening often associated with good listening, involves specialist communication behavior such as paraphrasing another's contribution, conveying non-verbal involvement and asking questions that encourage elaboration (Weger et al., 2010). Moreover, to listen with full attention requires one to overcome common habits such as responding in reflex or rushing into judgment (Escobar, 2011). It is therefore that, in closing of this paper, we plead for renewed training aimed at making scientists aware of the many pitfalls associated with listening, while at the same time providing them with the necessary tools and practice to develop positive listening behavior. As we contend, such focused training has the potential to bring theory and practice of science communication closer together and therewith makes it possible to use science, technology and innovation in a responsible way for mankind.

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Part II

Designing and testing science communication training for biomedical students

CHAPTER 4

Identifying focus areas for science communication training in the context of undergraduate science education

An adapted version of this study is accepted for publication in *International Journal of Science Education, Part B: Communication and Public Engagement* as "Reincke, C. M., Pieterman-Bos, A., & van Mil, M. H. (2024). Identifying focus areas for science communication training in the context of undergraduate science education".

ABSTRACT

In this paper we present recommendations for integrating science communication training into undergraduate science curricula. Science communication training is increasingly acknowledged as an important element of science education. It is essential to introduce this training early in academic development, ideally at the undergraduate level. The current study was aimed at identifying specific focus areas for such training within an undergraduate biomedical sciences program. To this end, we tasked undergraduate biomedical science students with translating general instructions for engaging in science-society interactions into specific descriptions of concrete communicative behavior. Following thematic analysis of 121 student responses, we identified two primary focus areas, resulting in two recommendations. Firstly, training should concentrate on helping students to operationalize complex communicative concepts, such as respect and listening, into concrete communicative behavior. In this regard, a special emphasis should be placed on aspects of nonverbal communication. Secondly, science communication training should prioritize fostering informed views of the nature of science, while connecting to building knowledge and understanding of models of science communication. This approach could enhance students' receptivity to important aspects of the dialogue model, such as the acceptance of diverse forms of knowledge and the recognition of scientists and non-scientists as equal participants in dialogue. For both recommendations, we contemplate potential educational interventions and/or pedagogical approaches.

1. INTRODUCTION

In recent years, scientists have faced increasing media interest and public scrutiny, particularly in biomedicine, a field driving new technologies with significant socio-ethical implications. Examples include bio-printing, stem cell research, and DNA sequencing. Some technologies have prompted nation-wide public dialogues (e.g., Van Baalen et al., 2021), requiring biomedical scientists, alongside members of society, to engage in public conversations about their applications. As biomedical advancement continues, scientists can expect continuous calls for some form of interaction with the public. To ensure these interactions foster productive science-society relations, science students, especially biomedical science students, should receive comprehensive communication training, alongside their scientific education.

Indeed, universities worldwide are increasingly inclined to provide science communication training at various academic stages. Correspondingly, a growing body of research into science communication focuses on integrating such training into undergraduate, graduate, and postgraduate science programs (e.g., Bray, 2012, Mercer-Mapstone & Kuchel, 2017; Wack et al., 2021; Willoughby et al., 2024). Central questions involve what to train (or teach) and how, but also whom to train when. Noteworthy in this respect is the work of Baram-Tsabari and Lewenstein (Baram-Tsabari & Lewenstein, 2017; Lewenstein & Baram-Tsabari, 2022). Informed by studies on informal science learning (Bell et al., 2009), they proposed a framework for learning science communication covering a range of learning objectives divided over six different learning strands (i.e., 'Affective', 'Content knowledge', 'Methods', 'Reflection', 'Participation', and 'Identity'). In specifying separate learning trajectories for different groups of learners, they labeled each learning objective according to relevance (e.g., generally relevant, or only relevant for specific interactions or communicators) and stage of learning (i.e., essential, or advanced). Hence, the Baram-Tsabari & Lewenstein framework could offer useful guidance to developing science communication training in the context of (under)graduate science education. Arguably, this training should focus on the essential, and generally relevant learning objectives, ensuring that students learn the basics of science communication, which can serve as a solid groundwork for their future endeavors. However, translating learning objectives into tailored learning activities requires further investigation into learning mechanisms and existing competencies of (under)graduate science students.

With the current study, we aimed to gain insight in the specific training needs of undergraduate biomedical science students, particularly those related to preparing for meaningful dialogue with society. Specifically, and as elaborated in Section 2, we sought to determine which types of communicative behaviors students find most challenging to actualize in science-society interactions. To achieve this, we examined students' ability to translate a set of generic instructions for engaging in dialogues with a general audience, into concrete behavior within a specific communication context. This investigation was conducted among first-year students enrolled in the undergraduate biomedical sciences program at Utrecht University.

2. THEORETICAL BACKGROUND

2.1 Importance of identifying concrete behavior

Science communication scholars widely acknowledge the importance of goal setting in designing and engaging in science communication efforts. Inspired by strategic communication scholarship, Besley et al. (2018) underscored the distinction between communication goals and objectives. While goals encompass overarching aims, objectives provide specific guidance on what to do to achieve those goals. For scientists involved in public communication, distinguishing between goals and objectives can be challenging, hindering the alignment of goals with appropriate objectives. Consequently, many scientists tend to focus on a limited set of objectives they know or feel capable of pursuing, such as informing and inspiring (Besley et al., 2018; Metcalfe, 2019; Waltz et al., 2024).

Communication objectives can be further translated into concrete communicative behavior, a critical aspect in effective science communication. Our research starts from the premise that this transition poses a substantial challenge for scientists, pivotal in their communication learning process. Translating communication objectives into behavioral actions helps form clear mental models, aiding in training and execution of the actual behavior (Ericsson, 2020). Investigating scientists' ability to determine such concrete behavior for various objectives can aid in identifying training needs. For example, it reveals challenging behaviors or overlooked ones.

2.2 Overt and specific communicative behavior

In this study, communication was viewed as a form of skilled performance, a commonly adopted perspective amongst communication scholars. Accordingly, communication encompasses a set of integrated, learned, or trained behaviors. Generally, these behaviors are goal-directed and situation-specific (Hargie, 2019a).

Communicative behavior can be covert or overt. Covert behavior includes cognitive activities, emotions, and physiological processes that are not visible outwardly, e.g., thoughts, attitudes, feelings, and heart rate. Conversely, overt behavior, involves observable and measurable actions, e.g., movements or activities. Applied to the context of interpersonal communication, overt communicative behavior is what one can hear you say or see you do (Sundel & Sundel, 2017). This includes verbal and nonverbal communication. Nonverbal communicative behavior comprises body language, such as body contact, postures, and movements, and paralinguistic features like tone and speed of speech (Hargie, 2019b).

In our study, we focus on overt communicative behavior (verbal and nonverbal), as interpersonal communication relies on interactants reacting to each other's overt behavior. This behavior can be defined more or less specifically, with specific formulations providing detailed descriptions, facilitating accurate observation. For instance, "involving others in the conversation" is less specific and observable than "asking others to share their thoughts". The ability to formulate specific behavior is crucial for effective training. Detailed descriptions aid in forming accurate mental representations and receiving valuable feedback.

Hence forth, when the word "concrete" is used (e.g., concrete communicative behavior, making behavior concrete), it means the degree of observability, particularly whether it involves overt behavior and how precisely it is described.

3. STUDY CONTEXT

This study occurred during a 10-week (half-time) mandatory course in the undergraduate biomedical curriculum at Utrecht University. Throughout this course, students reflect on the field of biomedical sciences from different disciplinary angles (e.g., philosophy of science, ethics, theory of law), and different perspectives (e.g., patient, public). In the "Public perspective" segment, students delved into the theory and practice of public science communication, including public dialogue. The dialogue model of science communication is contrasted with the deficit model, favoring the former for fostering societal dialogue. Students must apply these insights to a real-life case of public dialogue aimed at stimulating public opinion on the desirability of xenotransplantation (i.e., transplantation of animal organs into humans). They're prompted to reflect on the involvement of scientific experts in this dialogue.

4. STUDY DESIGN

This study is within a broader research project focused on designing and testing learning activities and pedagogical approaches for science communication training in biomedical sciences. The goal is to create effective training for future biomedical scientists to engage in meaningful dialogue with society. The project adopted theoretical and methodological principles from educational design research (EDR). An essential aspect of EDR is integrating educational theory with enhancing educational practice (McKenny & Reeves, 2018). EDR typically encompasses three stages: 'analysis and exploration', 'design and construction', and 'evaluation and reflection' (McKenny & Reeves, 2014). This study was part of the analysis and exploration phase. The primary objectives of this phase were to define and elucidate the current science communication knowledge and skills of undergraduate biomedical students, including identifying gaps compared to desired competencies, and to develop initial educational design proposals to bridge these disparities.

4.1 Study approach

To explore challenging communicative behaviors in science-society interactions, we analyzed student reflections on the involvement of scientific experts in the xenotransplantation case study. Students recorded their thoughts online after reading the case description and instructions to devise covert communicative behaviors linked to expert responsibilities and concomitant behavioral prompts outlined by Reincke et al. (2022). Students were tasked with assuming the role of an expert engaged in a dialogue session with twenty public attendees, addressing each prompt listed in Table 1.

4.2 Participants and data collection

All students attending the Public Perspective segment completed the online assignment and were requested consent for research use of their responses. Out of 127 students, 121 agreed to participate. All participants (identified as P1-P121) were first-year undergraduate biomedical science students aged 18 to 21 at Utrecht University.

4.3 Data analysis

We employed Braun & Clarke's reflexive thematic analysis (RTA) framework (Braun & Clarke, 2019; 2021) and NVivo 12 Pro for analyzing student responses. Initially, responses were categorized by the three responsibilities. The first author extensively reviewed each response to grasp the formulated communicative behaviors and their observability.

Table 1: Student assignment public dialogue on xenotransplantation

What would participants to the dialogue see you do or hear you say that could tell them that you:

Responsibility	*Prompts for behavior*
Share	1) Share (only) knowledge that is relevant to the dialogue goal 2) Present knowledge in a meaningful context and accessible language 3) Are careful in sharing personal considerations, e.g., (personal) positions
Listen & Learn	1) Consider this dialogue as an opportunity to learn 2) Act patient and supportive 3) Assist in stimulating deep conversations
Invest in relation-ships	1) Assist in creating an ambiance where others dare and wish to speak 2) Are committed to preserve or enhance trust 3) Respect all participants and every contribution

Subsequently, each response was meticulously examined to identify words, phrases, or sentences representing various communicative behaviors, labeled with descriptive code names. Coding was conducted organically and inductively, drawing on the first author's theoretical and practical expertise. Codes were occasionally merged, discarded, or renamed to create a comprehensive and distinct set of communicative behaviors. While most codes were semantic (explicit in transcripts), a few latent codes (implicit meaning) were also generated. Upon completing all responses, codes and associated transcripts were analyzed to create in-code categories. For instance, we categorized transcripts containing just the literal code name (e.g., "demonstrate patience") separately from those where the behavior was further specified (e.g., "demonstrate patience by hearing one out"). This method was reviewed in regular meetings between the first and second authors. The authors deliberated on whether to categorize responses based on individual prompts for each responsibility (see Table 1). While fewer than 10% of students had clearly separated their answers, a decision was made to categorize the remaining 90%. However, during initial coding, it was observed that many answers could apply to multiple prompts. For the research and result communication, we found it more informative to identify concrete behaviors without interpreting them based on specific prompts.

In the second phase, codes and assembled transcripts were analyzed per responsibility to uncover patterns of meaning. This entailed two key aspects: assessing the observability and relevance of each communicative behavior according to Reincke et al.'s (2022) framework, and examining how codes related to each other. Through this process, five shared meaning patterns relevant to our research question were identified. After validation by the second author, these patterns were discussed with the third author. Subsequently, two themes (referred to as focus areas) were formulated to encapsulate our key insights for enhancing science communication education and training.

5. RESULTS

As mentioned in Section 4, five patterns were identified relevant to our research. The first two were merged into focus area 1, while the third to fifth were grouped into focus area 2. Below, we will explain both focus areas in more detail, outlining their construction from the data and their application in science communication training.

Focus area 1: Aid students in translating intricate communicative acts, like respect and listening, into concrete verbal and nonverbal behaviors.

This focus area stems from our combined insights regarding students' ability to make complex communicative acts concrete (A), and the proportion of nonverbal to verbal behaviors in their responses (B).

Complex, multicomponent communicative acts remain relatively abstract (A)

In the second phase of our thematic analysis, we observed distinct variations in the tangibility of coded communicative behaviors, particularly in responses related to the responsibilities to listen and learn, and invest in relationships. While students adeptly identified relevant behaviors, they sometimes struggled to operationalize them. Examples of where students successfully concretized behavior, beginning with 'asking questions,' are presented below. Asking questions was a frequently mentioned relevant behavior in both responsibilities which we also considered relatively concrete. Many respondents also specified the purpose of their questioning. For example, to hear others' perspectives- including opinions (e.g., *"They will see me ask questions to all [participants], how they think of donor animals"* [P16]), to enhance comprehension (e.g., "*Maybe I'd ask questions that would further explain some people's point of view, therewith making it more understandable and useful for me"* [P61]), or to deepen conversations (e.g., *"Asking questions so that [..] you can dig deeper than only the surface of someone's point of view"* [P58]). Additional examples of relevant, commonly mentioned communicative behaviors (cited by at least ten respondents) that we view as relatively concrete include "avoiding interruption/hearing one out," "responding to inquiries," and "(verbally) showing appreciation" (e.g., for participation in the discussion, for sharing opinions). Instances where students didn't consistently make behavior concrete are illustrated below.

Two examples we find particularly illustrative are "respecting" and "listening." These are relevant, frequently mentioned behaviors (across both responsibilities) that we consider less concrete. While it's relatively straightforward to observe someone asking questions and tally each instance, it's more challenging to pinpoint every occasion where someone demonstrates respect or engages in listening. As mentioned in Section 2, two factors influencing the accuracy of observational processes, and used to measure concreteness, are 1) the extent to which observed behavior involves covert, next to overt actions, and 2) how precisely the behavior is articulated. "Respecting" and "listening" score low on both factors. Listening involves cognitive processes like selecting and attending to information, which are not externally visible. Similarly, respecting a conversation partner encompasses attitudinal aspects that are private unless self-reported by the individual observed. Additionally, both respecting and listening are complex skills requiring further breakdown into various observable behaviors for meaningful observation. How students utilized "respecting" (referred to as "respect") and "listening" in their responses, is examined below, considering how these insights could inform training for each skill separately.

Respect

Analyzing students' responses, we found that roughly half mentioned "respect" at least once, whether as a verb (e.g., *"respect anyone's contribution"* [P6]), a noun *(e.g., "by showing respect"* [P4], *"treat everyone with respect"* [P14]), or an adjective *(e.g., "by respectfully treating viewpoints"* [P38]). However, only about one-fifth operationalized respect into more concrete behavior. This included actions like refraining from judging or rejecting others' ideas or viewpoints (e.g., *"to respect anyone's opinion, by not arguing against them, but only adding your point of view"* [P93]), acknowledging difference (e.g., *"making clear that there is still controversy over [xenotransplantation], and that that is respected. To understand that people have different opinions and beliefs"* [P49]), and confirming others (e.g., *"not bringing others down, but respecting their opinion, and offering them a chance to explain how they view it"* [P47]). Importantly, while all these behaviors are relevant in dialogue, we considered only the last (i.e., confirming others) as directly related to a key aspect of respect. We'll explain this shortly.

Responses were also sought for expressions that implicitly conveyed the concept of respect without using the terms "respect(ing)" or "respectful." We did this because students had been actively asked to operationalize respect into concrete behavior in responding to prompt 3 within the responsibility to invest in relationships (i.e., respect all participants and every contribution). However, we only coded one expression in this regard: *"To state that you take [people's] viewpoints and insights into account in further research"* [P28].

From the above, it can be inferred that students either view "respect" as a behavior that can be accurately observed, or they find it challenging to translate "respect" into tangible behavior (or a combination of both). Given that only a minority succeeded in operationalizing respect, the latter conclusion appears partially true. While significant, this finding isn't surprising. Communication scholars have long highlighted the difficulty of defining respect. There's little consensus on whether respect should be approached as an attitude, behavior, or emotion (Hedinger, 2000), and its explanation varies depending on the communication context (Beach et al., 2007; Langdon, 2007).

Respect in the context of dialogue

In the context of dialogue, Escobar (2011) defined respect as "active engagement with the views and feelings of others." He suggested communicative actions related to respect, such as approaching conversation partners with genuine curiosity and critically reflecting on stereotype thinking. Comparing Escobar's definition to students' operationalizations of respect, we observed that only confirming others (specifically, offering them a chance to explain) aligns well. Other behaviors that could fit this framework include asking open questions and checking at understanding (Reincke et al., 2022). While asking questions was frequently mentioned by students, few specified them as "open," and there was no indication they connected asking questions to the concept of respect.

Escobar also emphasized openness as crucial in dialogue, defined as embracing multiple perspectives, diverse communication styles, the potential for error, and the capacity for change (Escobar, 2011). While respect involves active effort to enhance understanding, openness implies a passive acceptance of diversity and the potential for learning from others. Upon reevaluation of students' operationalizations of respect, the first two (not rejecting viewpoints and accepting differences) appear aligned with the concept of openness. Interestingly, we identified multiple expressions of openness in students' responses, roughly categorized into two groups. The first category comprised expressions asserting that every opinion is valid, and there is no absolute right or wrong (e.g., *"Trying to demonstrate that to me it is okay, whatever your viewpoint or input may be. All opinions are welcome"* [P108]). The second involved statements or explanations that opinions were not to be judged or disapproved of (e.g., *"When people state an opinion that I disagree of I can give that back, but I do stress that they are in their full right to think different than me"* [P27]). These categories overlapped significantly with expressions coded as respect, containing the word "respect(ful)" and an operationalization. Additionally, we found responses explicitly mentioning "openness" (or its variations). In some cases without further operationalization (e.g., *"it is important to be open to all kind of different viewpoints"* [P43]), in other cases with (e.g., *"I would open up to the opinions of [other participants]. I would ask how they view the issue and learn from it, and [I would] listen to a different perspective. This may well influence my own point of view"* [P99]).

One observation is that students tended to articulate concrete behaviors more readily for openness than for respect. Often, they did so inadvertently (without explicitly linking to openness) or while operationalizing respect. This suggests that openness may be more concrete for students than respect. This insight could be valuable for training, as students could be encouraged to recognize that what they commonly identify as respect is essentially openness. Additionally, both openness and respect embody similar concepts, with openness being more passive and respect more active. Thus, understanding openness could provide a gateway to comprehending respect in dialogue contexts and recognizing associated tangible behaviors. For instance, students could realize that by augmenting openness with active behaviors, such as asking (open) questions with the intent to learn, openness could evolve into respect.

Listening

For listening, we observed a similar pattern to respect, although slightly less pronounced. Roughly half of all respondents mentioned listening at least once. Among these, about half didn't offer further explanation or specification. For instance: *"I would listen to what participants have to say"* [P103]. This also encompassed instances where students mentioned 'good listening' or 'careful listening' (e.g., *"I would carefully listen to what people have want to ask or contribute"* [P69]). Still, approximately half of the students who mentioned listening had provided further explanation or specification. However, in most cases this was only minimal, such as *"listening without judgement" (e.g., to give others the chance to respond to him or her. Then, to listen to it without prejudice"* [P10]), *"listening with patience" (e.g., "keep listening patiently"* [P40]), and *"listen with interest" (e.g., "to listen with interest to the people speaking"* [P18]). Only a small group (less than 10) had operationalized listening into (examples of) concrete behavior in a clear manner. Two illustrative examples are listed below.

> *"Demonstrating to listen, for example through body language: nodding in agreement, letting them hear verbally to be listening" [P24]*

> *"To show that you are truly listening, you can, as a start of your own contribution, shortly summarize what someone else said" [P81]*

From the above, it can be inferred that, similar to respect, students either viewed listening as a behavior that can be accurately observed, or they found it challenging to translate listening into tangible behavior (or both). Compared to respect, students more frequently attempted to provide further explanation or specification for listening. However, we only identified a few relevant concrete behaviors.

Listening in the context of dialogue

In comparison to respect, listening has been extensively researched by communication scholars. Various definitions, taxonomies, and forms of listening have been proposed over time. Additionally, efforts to define "good listening" often equate it with active listening, particularly within dialogue contexts (e.g., Holmesland et al., 2014). Key components of active listening include conveying (nonverbal) engagement, paraphrasing a speaker's message, and asking questions (Weger et al., 2014). Various questionnaires and observation scales assess active listening competency, such as the active listening scale (ALOS), which categorizes listening behaviors into nonverbal, verbal, and general categories (Fassaert et al., 2007). Concrete behaviors on the ALOS include facing, paraphrasing, and asking exploratory questions. Apart from asking questions (albeit without the criterion of being 'open'), few mentioned these behaviors, and many didn't link them to listening.

This insight is crucial for science communication training. Students could benefit from support in translating listening into tangible behaviors, potentially utilizing listening scales like the ALOS.

Nonverbal communication is often overlooked (B)

As outlined in Section 3, students were prompted for each responsibility to consider what public attendants to the dialogue would perceive in their verbal and nonverbal behavior. However, a significant underrepresentation of nonverbal communication in students' responses across all responsibilities was observed. This included limited diversity in suggested nonverbal behaviors and a low frequency of their mention. Particularly for the responsibility to share, nonverbal communication primarily involved paralinguistic features (i.e., how one says something), mentioned only by a few students. Examples included tone of voice (e.g., *"Speaking on a human tone"* [P10], *"I speak to participants enthusiastically"* [P4]) and speaking pace (e.g., *"talking slowly"* [P85]). However, students often remained unspecific in their formulation (i.e., what is enthusiastic?). Nonverbal characteristics beyond paralinguistics (i.e., body language) were identified predominantly in the responsibilities to listen and learn and invest in relationships. Examples included taking notes ("*I take notes*" [P38]), facing and eye-contact (e.g., *"I would face people when they are speaking"* [P2]), nodding (e.g., *"nodding when someone says something good"* [P63]), open body posture (e.g., *"By taking on an open attitude, physically, you give people more of an idea to be open to questions and critique"* [P94]), and positioning (e.g., *"Taking seat with the rest of the public instead of standing on a stage"* [P92]). None of these behaviors was mentioned by more than 10 students, and collectively involved fewer than twenty students.

One may infer that students either undervalued nonverbal communication or lacked familiarity with its forms and meanings. This has implications for science communication training. Nonverbal communication is pivotal in interpersonal communication (Gordon & Druckman, 2018), both independently and in conjunction with verbal communication. Verbal messages can gain reinforcement when paired with appropriate nonverbal cues. For instance, demonstrating interest may involve asking a question while making eye contact or leaning forward. Conversely, misalignment or absence of nonverbal cues can lead to confusion or misunderstanding between conversational partners. Science communication training should underscore the significance of nonverbal communication in science-society dialogues and assist trainees in recognizing and employing diverse nonverbal behaviors. The Nonverbal Immediacy Scale (NIS) illustrates how engagement can be translated into nonverbal behavior (Richmond et al., 2003). It encompasses elements like maintaining eye contact, nodding in agreement, and leaning forward. The NIS could fulfill a similar role in facilitating the recognition and practice of nonverbal behaviors as the ALOS does for listening behaviors. Importantly, trainees should comprehend that nonverbal communication, like communication overall, can be interpreted variably based on contextual factors such as culture or interaction setting. For example, reliability estimates for the NIS have been shown to vary between different countries (Özmen, 2011).

In summary, we recommend to assist students in translating intricate communicative concepts, like respect and listening, into tangible communicative actions. This may entail promoting a deeper understanding of communicative acts, emphasizing nonverbal communication's significance, and providing established operationalizations of complex behaviors via observation tools or rating scales.

Focus area 2: Prioritize fostering informed views of the nature of science, and connect to building knowledge and understanding of models of science communication

This focus area stems from our analysis of students' responses concerning sharing personal considerations (C), perspectives on science communication (D), and understandings of the nature of science (E).

Student responses point to a hesitance to share personal considerations (C)

During our analysis of students' responses within the responsibility to share, we observed a discrepancy in how many students had approached prompts 1 and 2 (respectively: *share (only) expert knowledge that is relevant to the goal of the dialogue* and *present knowledge in a meaningful context and accessible language*) and to prompt 3 (*be cautious when sharing personal considerations*). For prompts 1 and 2, these students adhered to the instructions by outlining tangible behaviors (e.g., avoiding scientific jargon, emphasizing the impact of xenotransplantation rather than its technical aspects). However, for prompt 3, their responses predominantly focused on contemplating the value or appropriateness of sharing personal considerations. Many of these students appeared to believe that sharing personal considerations was of secondary importance, or even something to avoid. For example:

> *"I would present myself in a way that my own opinion does not come forward, and that [I am] only there to inform those people". [P65]*

> *"Speak as much as possible objectively about the topic and leave out your opinion". [P80]*

We will elaborate on this observation further below.

Student responses sometimes conflict with the dialogue model (D)

In analyzing student responses across all responsibilities, we observed expressions reflecting a traditional view of science communication. These expressions conflicted with the dialogue model emphasized in the assignment preparation, as indicated in Section 3, which underscores two-way knowledge exchange, equal value of knowledge, and equality in status and power between scientists and non-scientists. These aspects are vital for science-society interactions aiming to shape public opinion, as in the dialogue on xenotransplantation. Therefore, the presence of student responses conveying ideas conflicting with the dialogue model is notable. We found many of these expressions especially conflicting with the second and third aspects mentioned earlier. Further elaboration on each follows.

Scientific knowledge is more valuable than other forms of knowledge

Firstly, some students expressed the notion that scientific knowledge holds greater value than other forms of knowledge. For instance, P82 suggested that public contributions should be viewed through a scientific lens:

> "*Many people you converse with will have little knowledge in this area (that's why they aren't an expert), so then it is good when you explain their contribution from a scientific point of view".*

Similarly, P115 suggested that people's arguments should be countered by science, to foster knowledge dissemination:

> "*When they state an argument for or against, and you know a refutation to it, then share it, in order to transmit as much knowledge as possible".*

Somewhat related, P35 and P109 expressed themselves in a manner that could imply they perceived scientific knowledge as inherently opinion-forming, rather than acknowledging the role of interpretation based on personal values and beliefs.

> *"When someone tells anything that you disagree of, to still listen, and to accept, since they don't have the knowledge you have". [P35]*

> *"Be understanding and try to comprehend the arguments of those with another point of view. Remind yourself that these people don't have a background in this disciplinary field". [P109]*

Others interpreted the prompt to assist in deepening the conversation (prompt 3 in the responsibility to listen and learn) in terms of sharing more scientific knowledge:

> *"Offering deepening can be done through recommendations for the research projects, sites, and suchlike". [P37]*

> *"Provide extra information in case of uncertainty about something, or in case of a question how something works". [P40]*

While supplementing scientific knowledge could facilitate deeper discussions about science and society, it does not inherently deepen them. Science communication guided by the dialogue model prioritizes interpreting knowledge, primarily by integrating diverse perspectives and forms of knowledge to foster mutual learning. Consequently, deepening could entail balancing diverse viewpoints or uncovering the values that underpin differing perspectives.

Another clear example in which we recognized the idea that scientific knowledge is more valuable than other forms of knowledge, is that some students had used specific terms to describe scientific knowledge, such as 'factual' and 'objective'. Examples include the responses of P22, P38, and P90 below:

> *"In case it is an objective fact, I can say something like: several studies show…". [P22]*

> *"I present factual knowledge that is certain". [P38]*

> *"Transmitting factual knowledge, and in case of requests for an opinion, that you can't say much about it". [P90]*

A last example is students believing they were expected to deliver a lecture or presentation as experts, as seen in the response of P5:

> *"I would state in advance […] that during the presentation [people] can break in if something is unclear"* [P5]

Scientists are 'better' than non-scientists

Secondly, several students conveyed the idea that scientists are 'better' than non-scientists. For instance, R9 anticipated that others may make logic errors or say incorrect things:

> *"Do not interrupt, not even when something foolish comes out. Explain patiently when something is incorrect, and he/she makes a possible logic error within a consideration"* [P9].

Similarly, P14 expected public attendants to stall because of incomplete knowledge:

> *"Providing extra information when at some point in the conversation they stall because they have insufficient knowledge" [P14].*

Somewhat related, P32, P118, and P120 expected public attendants to ask foolish questions:

> *"You're not snippy in answering, from your perspective, simple questions" [P32]*
>
> *"In case of superficial questions: deepening the subject through asking questions" [P118]*
>
> *"Being open to questions from the public (even when you think that you have been very clear, and that it concerns a rather simple question; relate to the thoughts of the public" [P120]*

Additionally, some students perceived lacking scientific knowledge as a rationale for disagreements. For example P78 stated that:

> *"When people share their opinion/view on the subject, ask questions yourself and show that you are open to these ideas, by not refusing to accept the ideas that don't match with your knowledge" [P78]*

Others seemed to be convinced that experts (should) ask questions for which the answer is already known, therewith suggesting some sort of a teacher role:

> *"Asking questions that make them think. Also, not helping too much, so that they participate actively themselves" [P14]*
>
> *"You ask the public questions in a way that they can think themselves. You do not spell it all out just to show that you know" [P32]*

Relatedly, some believe that public participants may not always provide valuable contributions, and, more critically, that experts determine the value of these contributions. Examples include statements made by P63 and P79:

> *"When you hear something good, or what you agree of, nodding to demonstrate that this person says something good" [P63]*
>
> *"Sometimes indicating that someone has a good insight. So, for example, saying thank you, or telling them how good of an insight that is" [P79]*

Finally, many students believed that scientists alone determine which scientific knowledge is relevant for shaping opinions. This suggests either that students believed scientists can discern relevant scientific knowledge for different individuals or that they are best suited for this task. For instance, one group of students listed the topics that should be explained (e.g., *"I explain the principle of using animal donor organs and how the [human] body reacts to this, and I explain how these organs are grown in animals"* [P27]. Others mentioned that when sharing pieces of knowledge, they would explicitly state that this was relevant (e.g., "*explicitly stating that the knowledge I share is relevant to the dialogue*" [P24], *"For example by indicating that what we discuss today is important. So, that you actively state that everything you share is important"* [P79]). Yet, others remained vague or merely reiterated the prompt (e.g., *"not sharing irrelevant knowledge or mentioning other irrelevant facts" [P89]).* Note that these reactions may partly stem from how the first prompt within the responsibility to share was framed ("share only knowledge that is relevant to the goal of dialogue"). However, students could have recognized that opinion formation is highly individualized, with significant differences in what people deem relevant knowledge. The prompt doesn't ask them to define what constitutes relevant knowledge but rather to ensure they share only what is relevant. Consequently, students could have included communicative behaviors aimed at understanding which scientific knowledge others consider important.

To summarize, in students' responses we observed expressions and response patterns suggesting that some students hold ideas about scientists and scientific knowledge incongruent with the dialogue model of science communication. This discrepancy may impede their ability to engage in genuine dialogue with society about developments in their field, both presently and in the future.

Student responses sometimes conflict with informed views of the nature of science (E)

In analyzing student responses, we observed not only perspectives on science communication but also on the nature of science (NOS). Some expressions suggested students may have uninformed views of NOS, overlapping with traditional ideas about science communication and hesitation to share personal thoughts. The idea that scientific knowledge constitutes a set of irrefutable facts conflicts with acknowledging the tentative, inferential, and theory-laden nature of scientific knowledge, and the social and cultural embeddedness of science. The consensus framework for NOS education propagates these views, including the recognition of scientific knowledge as empirical, creative, and socially negotiated. It also rejects the notion of a singular "Scientific Method" and highlights distinctions between scientific theories and laws (Abd-El-Khalick et al., 2008; 2023).

Students' beliefs that correct scientific knowledge automatically dictates widely accepted opinions, and that scientific experts dictate which knowledge is relevant for forming opinions, or whose contributions valuable, also conflict with some consensus views. It is important to recognize that individuals vary in background, life experience, and religious beliefs, all influencing how they interpret and utilize knowledge for opinion formation. For instance, people may differ in their assessment of risks and benefits, prioritizing different aspects or interpreting them differently. Moreover, individuals may vary in their assessment of when risks and benefits are adequately supported by data.

Lastly, the notion that personal considerations are secondary or should be avoided conflicts with consensus views as well. This implies a separation between scientists' personal attributes and the knowledge they share, disregarding the inherent influence of personal factors on knowledge interpretation and relevance assessment. Recognizing this, students, acting as scientific experts, can appreciate the value of sharing personal considerations. This practice aids other participants in interpreting scientific knowledge and encourages reflection on its significance, fostering shared responsibility and mutual equity, which in turn enhances dialogue. However, scientists must exercise discretion due to their privileged position in dialogues, such as having more speaking opportunities or greater clarity in expressing their views, potentially overshadowing public participants.

In summary, students' expressions reflecting a traditional view of science communication, conflicting with the dialogue model, often align with uninformed views of NOS, indicating a potential correlation. This suggests that in our student population, uninformed NOS perspectives may underlie traditional science communication views. Therefore, we recommend prioritizing fostering informed views of the nature of science, while connecting to building knowledge and understanding of models of science communication. Informed NOS views could make students more receptive to key tenets of the dialogue model of science communication, such as acknowledging the validity of non-scientific knowledge and viewing non-scientists as equal counterparts to scientists. Moreover, informed NOS views may facilitate reflection on the implications of sharing personal considerations, empowering students to make thoughtful choices in communication.

6. CONCLUSION AND DISCUSSION

Science communication training is increasingly integrated into academic curricula. In this study, our objective was to pinpoint focus areas for developing science communication training within an undergraduate biomedical sciences program. Our emphasis was on enhancing students' capacity to articulate specific communicative behaviors for engaging in public dialogue. This skill is crucial for establishing precise behavioral expectations and enhancing feedback effectiveness. Two key areas were identified, resulting in two training recommendations.

Firstly, our analysis revealed that students encounter challenges in rendering complex communicative acts, such as respecting and listening, into tangible behaviors. They either fail to operationalize them or outline behaviors that inadequately align with the concepts. Even when relevant behaviors are mentioned, they often aren't linked to respecting or listening. Relatedly, we found that students tend to accentuate verbal behaviors, implying difficulties in formulating nonverbal communicative behaviors or comprehending their significance. Based on the combined findings, we formulated our first training recommendation to aid students in translating intricate communicative concepts, like respect and listening, into tangible communicative actions, including highlighting the importance of nonverbal communication. Respect and listening are generally recognized as important competencies for contemporary science communication. Both are included as (elements of) learning goals in the Baram-Tsabari & Lewenstein framework for learning science communication (Baram-Tsabari & Lewenstein, 2017; Lewenstein & Baram-Tsabari, 2022). Within the broader objective to connect with an audience, we find “Shows respect for an audience (and avoids showing disrespect)” and “Listening to audience needs and goals”. Additionally, listening competency manifests through the learning objective “Demonstrates that scientists want to listen to audience concerns”. Notably, while the respect objective is categorized as essential, both listening objectives are labeled as advanced. In the specific context of training for public dialogue, we would advocate for including listening, similar to respect, as an essential learning objective. Moreover, especially in the context of training integrated in undergraduate science programs, when addressing these learning objectives, we advise to emphasize fostering conceptual understanding of both competencies. For example, by helping trainees to differentiate between respect and openness and utilizing observation tools and rating scales like the ALOS and the NVS.

Secondly, our analysis pointed to an overall hesitance to share personal considerations, such as viewpoints or positions. Additionally, it revealed notions regarding the value of knowledge and the authority of expert scientists, conflicting with the dialogue model of science communication. Furthermore, our analysis indicated ideas about the nature of science suggesting uninformed NOS views, aligning with traditional notions of science communication. Based on the combined findings, we formulated our second training recommendation to prioritize fostering informed NOS views, while connecting to building knowledge and understanding of models of science communication. Developing more informed views of NOS could foster trainees' receptivity to diverse perspectives, and therewith enhance their ability to engage in genuine dialogue with a range of publics. Obviously, learning to enact specific behaviors associated with, for example, demonstrating willingness to understand is distinct from genuinely feeling this willingness. As long as students perceive scientific knowledge as more valuable than non-scientific knowledge or view non-scientists as ignorant, fostering genuine openness to mutual learning may prove challenging. However, as students develop more nuanced views of NOS, for example, recognizing scientific knowledge's tentativeness and subjectivity, they may truly appreciate the value of engaging with diverse perspectives. Baram-Tsabari & Lewenstein list several learning objectives related to NOS understanding, of which some are labeled as essential (e.g., “Understands science as a human endeavor”) and some as advanced (e.g., “Is aware of the limitations of scientific approaches to understanding the natural world”). Our findings confirm the relevance of these learning objectives in science communication training, particularly in the context of (under)graduate science education (and certainly when focused on public dialogue). Science students, as opposed to professional scientists, are still learning about the nature, origin, and limits of science and scientific knowledge. Furthermore, research indicates that learning scientific inquiry, which is at the heart of science education, does not automatically lead to more informed views of NOS, in fact, sometimes students’ NOS views become less informed (Abd-El-Khalick & Lederman, 2023). Therefore, NOS scholars have been advocating to combine learning scientific inquiry with instructional interventions that involve explicit reflection on NOS. Recently, Pieterman-Bos et al. (2023, Preprint) pointed to the role of scientific discourse in developing understandings of NOS. As they indicate: “there might be implicit notions relating to NOS (e.g., scientific observations are objective) underlying scientific discourse (e.g., omitting first-person sentences) that uninformed readers (e.g., students) might translate to uninformed views of NOS (e.g., science starts with neutral observation).” They propose an analysis framework for characterizing implicit notions relating to NOS in biomedical scientific discourse, and highlight its potential for stimulating explicit reflection on NOS in educational settings. Here, we advocate the same framework to be used in the context of science communication training, allowing both fields to mutually reinforce one another. For example, an adapted version of the framework could be used to characterize implicit notions relating to NOS in scientists' communicative behavior in interaction with society. In this way, students could combine developing informed NOS views with fostering comprehension of the dialogue model, and therewith enhance their ability to engage in meaningful dialogue with society.

In moving forward, we will have to explore how our training recommendations translate into effective interventions. How can we best assist students in operationalizing complex communicative acts? What constitutes effective NOS teaching in the context of science communication training for undergraduates? Hence, interventions should be studied for efficacy and tailored to various communication contexts and student cohorts. While our recommendations are broadly applicable to undergraduate science curricula, nuances may exist across different programs. Given the ongoing advancement of biomedicine, with its attendant ethical and social implications, it's vital to continue preparing biomedical students for meaningful engagement with diverse audiences. This entails instilling an understanding of the mutual learning process between science and society and equipping students with the skills to foster equitable dialogue.

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CHAPTER 5

Understanding epistemological tenets underlying scientific language use: A multifaceted analysis framework

An adapted version of this study is published as “Pieterman-Bos, A., Reincke, C., van de Schoot, R., & van Mil, M.H.. (2024). Understanding Epistemological Notions Underlying Sceintific Language Use: A Multifaceted Analysis Framework. *Frontiers in Education, 9*:1452111.

ABSTRACT

Helping university students develop productive views of what characterizes good scientific research and scientific knowledge is an important objective of science education. However, many studies show that students' views of the nature of science (NOS) do not become more informed or even become less informed after learning activities that engage students in scientific practice. This could mean that the way we teach students to conduct scientific research might unintentionally strengthen or bring about uninformed views of NOS. In this article, we argue that scientific discourse (how language is used in science) might play a role in this relation between learning scientific inquiry and uninformed views of NOS. We argue that there could be implicit notions relating to NOS underlying scientific discourse that uninformed readers might translate to uninformed views of NOS. We call these implicit notions underlying scientific language use "epistemological tenets." In this article, we further define this construct of epistemological tenets, contrast it with explicit views of NOS and other related constructs, explain how we think epistemological tenets might affect explicit views of NOS, and present a framework we developed to characterize them in scientific language use. It is a descriptive and interpretative analysis framework which combines, optimizes, and extends several text analysis methods, discourse analysis, and reflexive thematic analysis. We provide a guide to use the framework and discuss quality criteria. We finish by advocating the framework for educational researchers interested in developing instructional interventions during which learning about science is combined with explicit reflection on NOS. Identifying epistemological tenets in scientific language use could provide starting points for these activities by making explicit the translation from NOS understanding to scientific practice and vice versa.

INTRODUCTION

Helping university students develop productive views of what characterizes good scientific research and scientific knowledge is an important objective of science education. Many studies have been conducted to understand how students at different school levels view the nature, origin and limits of knowledge and the process of knowing (Abd-El-Khalick & Lederman, 2023). Theories about knowledge are known as epistemologies. Science education and research attending to epistemology often focuses on students' views about a specific subset of characteristics of the nature of scientific knowledge and knowing. This subset of views is defined by science educators and they are often called views of the nature of science (NOS) (e.g., Lederman, 1992). Most studies of students' NOS views focus on what students say their views of NOS are when this is explicitly discussed in class or for the purpose of educational research (Deng et al., 2011). Deng et al. (2011) call these views "professed views of the nature of science." Science educators aim to change students' uninformed views of NOS to informed views. To that end, there are three common types of NOS instructional interventions: explicit-reflective interventions where NOS is explicitly addressed in class, implicit interventions where NOS is implicitly taught through student participation in science, and a combination of participation in science and explicit reflection on NOS (Abd-El-Khalick & Lederman, 2023). Most studies using an implicit approach show that students' NOS views do not become more informed or even become less informed after mere experience with scientific practice, either through inquiry or exposition (Abd-El-Khalick & Lederman, 2023). This could mean that the way we teach students to conduct scientific research could unintentionally bring about or strengthen uninformed views of NOS. In this article, we argue that scientific discourse (how language is used in science) might play a role in this relation between learning scientific inquiry and uninformed views of NOS. For example, writing objectively about scientific observations (e.g., omitting first-person sentences), could give students the wrong impression that science starts with neutral observations, independent of the perspectives of the researcher doing these observations. In other words, there might be implicit notions relating to NOS (e.g., scientific observations are objective) underlying scientific discourse (e.g., omitting first-person sentences) that uninformed readers (e.g., students) might translate to uninformed views of NOS (e.g., science starts with neutral observation). While more informed readers (e.g., professional scientists) do not register these implicit notions relating to NOS or do not translate these to uninformed views. We call these implicit notions underlying scientific language use "epistemological tenets." In this article, we further define this construct of epistemological tenets, contrast it with explicit views of NOS and other related constructs, explain how we think epistemological tenets might affect explicit views of NOS, and present a framework we developed to characterize them in scientific language use. We built on several previously published text analysis methods with similar but smaller purposes. We combined, optimized, and extended this work to construct a more comprehensive analysis framework: the epistemological tenets analysis framework.

In addition, we emphasize the need for explicit reflection on NOS when teaching (about) scientific language use, since there is strong evidence that instructional interventions focused on learning about science or learning to do science need to be combined with explicit reflection on NOS for them to result in more informed views of NOS (Abd-El-Khalick & Lederman, 2023). We argue that identifying epistemological tenets in scientific language use could provide starting points for learning activities in which we explicitly reflect with students on these epistemological tenets and how they relate to views of NOS and, more broadly, epistemology.

The main aim of this article is to define our newly introduced concept of epistemological tenets and to present an analysis framework to characterize them in scientific language use. First, we outline the theoretical background and development of the framework. Then, we present the framework as a six-phase process to guide epistemological tenets analysis and discuss quality criteria. Lastly, we discuss the value and applicability of the framework.

THEORETICAL BACKGROUND

Before we introduce the analysis framework, we provide some theoretical background for using the framework. We start by summarizing existing text analysis approaches. Next, we introduce and define the concept of epistemological tenets. Then, we argue how they are related to explicit views of NOS and epistemology and describe how views of NOS are defined in literature. Lastly, we describe three theoretical and philosophical underpinnings of the analysis framework.

Review of existing text analysis approaches

The epistemological tenets analysis framework is based on various existing text analysis approaches. Roughly, we can discern three ways to analyze academic texts that could provide insights into underlying epistemological tenets: analyzing the structure, quality, and language of an argument. These approaches describe different aspects of how writers create arguments for scientific claims. We have combined them into the first building block of the epistemological tenets analysis framework (descriptive text analysis). The other building blocks are discourse analysis (Gee, 2014) and reflexive thematic analysis (Braun & Clarke, 2006, 2021b), discussed in Section 2.4. First, we summarize what aspects of the structure, quality, or language of an argument have been studied by others.

Structure of arguments

Concerning the structure of arguments, some influential research lines started with the work of Toulmin (1958) on argument structure and the work of Latour and Woolgar (1986) on the construction of scientific facts. Since Toulmin's structure is not directly applicable to more complex arguments, Science education researchers have extended the structure to academic arguments (Jiménez-Aleixandre & Federico-Agraso, 2009; Kelly et al., 1998, 2007; Kelly & Chen, 1999; Kelly & Takao, 2002; Takao & Kelly, 2003). They studied both the structure and quality of arguments. Concerning the structure, they assessed the coordination of evidence across epistemic levels by reconstructing the argument structure based on its argument components: data inscription, evidence, justification, and claim (see Table 1 for an explanation of these argument components). These reconstructions of argument structures are subsequently used to further assess the quality of arguments.

Quality of arguments

To assess the quality of the arguments, previous studies evaluated the pertinence (relevance) of the evidence (Jiménez-Aleixandre & Federico-Agraso, 2009), the sufficiency of the evidence (Jiménez-Aleixandre & Federico-Agraso, 2009; Kelly et al., 2007; Sandoval & Millwood, 2005), the level of rhetorical reference to data inscriptions (Sandoval & Millwood, 2005), and the type of justifications used for claims (Sandoval & Millwood, 2007). Kelly et al. (2007) assessed sufficiency of the evidence and coordination across epistemic levels. This assessment covers different aspects, each on a scale from 0 (non-existent) to 4 (excellent). These aspects include the following: solvable and clearly stated thesis or question; multiplicity and plausibility of lines of reasoning; potential sufficiency of data; inclusion, identification, and description of appropriate data representations and their use to support an explanation; relevancy and clear identification of the relevancy of the data used; validity of inferences; convergence of lines of reasoning to a conclusion; and overall support of the thesis. Jiménez-Aleixandre and Federico-Agraso (2009) assessed pertinence, sufficiency of evidence, and coordination across epistemic levels. They did not distinguish different aspects but assessed all three as a single measure and as either adequate or not.

Table 1 Argument aspects assessed in existing text analysis approaches.

Argument aspect	Code	Description
Argument components (Jiménez-Aleixandre & Federico-Agraso, 2009)	Data inscription	The tables and figures of the article. For ease of reading, we refer to data inscriptions as "table," "figure," or "tables and figures."
	Evidence	Sentences about the experimental results supporting the claims.
	Justification	Establishes the connection between a data inscription or evidence sentence and a claim (the equivalent of Toulmin's warrant). Justifications can be direct, being a simple justification in support of a claim, or subsequent, being both the endpoint for one argument (i.e., a claim) and a connection between evidence and claim in a second argument (i.e., a justification).
	Claim	The thesis the authors are seeking to demonstrate.
Coordination of the evidence across epistemic levels (Jiménez-Aleixandre & Federico-Agraso, 2009)	Sufficient/ insufficient	Epistemic level relates to the degree of abstractness of knowledge claims, from grounded, low inference claims to progressively more general, theoretical claims. Argument structure succeeds from data inscription to evidence (sentence), to first level claim, to second level claim.
Pertinence of the evidence (Jiménez-Aleixandre & Federico-Agraso, 2009)	Pertinent/ not pertinent	Is the evidence presented relevant for the claim?
Level of rhetorical reference to data inscriptions (Sandoval & Millwood, 2005)	Inclusion	A figure or table is included in the explanation without reference to the inscription in the text.
	Pointer	A non-descriptive reference to a figure or table (e.g., "See graph 1").
	Description	A summary or other description of the figure or table with no suggestion of its relation to a claim.

	Assertion	A sentence about a figure or table in which the figure or table is asserted to show or prove a claim, without an explanation as to how it does so.
	Interpretation	A sentence that explicitly relates specific features of an inscription to a claim.
Type of warrant used for a claim (Sandoval & Millwood, 2007)	Authority	Instances where a student explicitly states a source of authority or lack thereof (e.g., teacher, class, book).
	Causal	Warrants that refer to reasons based on a theoretical concept, or explanation of a theoretical concept.
	Empirical	Reasons citing some kind of empirical evidence or lack thereof (e.g., literature reference, data).
	Factual	Repeating of the original claim by using the exact same words, paraphrasing, or rephrasing.
Statement types (Latour & Woolgar, 1986)	Type 5	Statements corresponding to a taken-for-granted fact.
	Type 4	Statements explicitly addressing a “fact” as such.
	Type 3	Statements about other statements, using modalities and references.
	Type 2	Statements that contain modalities which draw attention to the circumstances of the evidence affecting the level of generality of the statement.
	Type 1	Statements that are conjectures or speculations.
Modality (Hyland, 1998; Plappert, 2019)	Hedge	Words used to decrease the certainty of a statement.
	Booster	Words used to increase the certainty of a statement.
	Implicature	Words used to speculate at the level of speaker meaning (what a writer implicates) while at the sentential level (what a writer writes) the statement has a higher level of certainty. Example: “Gene X is associated with disease Y.” At the level of speaker meaning, it suggests that Y *might* be caused by A.

5

The arguments assessed by Sandoval and Millwood (2005) were of a slightly different type. They assessed a student assignment where high school students were asked to explain specific evolution-related questions through exploration of provided data. They assessed some aspects of argument quality based on criteria that depend on the strong delineation of the assignment, which are not applicable for the current study. However, Sandoval and Millwood do specify an aspect of quality of arguments that is relevant for the current study, the "level of rhetorical reference to data inscriptions."

Through their analysis of the use of data inscriptions (i.e., figures and tables) in student explanations, they identified five levels of rhetorical use: inclusion, pointer, description, assertion, and interpretation (see Table 1).

In another study, Sandoval and Millwood (2007) characterized what type of warrants students provided for their scientific claims. They identified four types of warrants in interviews with students about their conceptions of the best way to convince someone of something in science: authority, causal, empirical, and factual (see Table 1). Sandoval and Millwood describe that they have compared student responses with their actual use of warrants in the essays, although they do not go into detail on how they did so. Nevertheless, these categories might also be recognizable in scientific language use.

Language of arguments

The last aspect of argumentation that could provide insight in the epistemological tenets underlying scientific writing is the language used. The language used to communicate scientific claims can signal their perceived epistemic status (i.e., the degree of certainty awarded to knowledge claims). Three studies that are of importance for the current study are those of Latour and Woolgar (1986), Hyland (1998), and Plappert (2019). These studies are centered around the language of varying strengths of knowledge claims and based on philosophical and sociological studies of Bruno Latour, Thomas Kuhn, George Lakoff, and Paul Grice.

Kuhn (1970) already exemplifies that knowledge is not just conveyed but *constituted* by the use of language. Latour and Woolgar (1986), in addition, argue that the certainty of knowledge claims can be recognized in their linguistic structures, although there is no simple relationship between these structures and the level of certainty they express. Latour studied the extent to which some statements appeared more fact-like than others. He recognized five statement types that express different levels of certainty of a "fact" (see Table 1). However, the form of a statement does not always directly correspond with its recognized level of certainty. For example, the inclusion of a reference might, on the one hand, detract from the certainty of a statement because it denotes the involvement of human agency in its production. On the other hand, it might lend weight to a statement that might otherwise be considered unsupported (Latour & Woolgar, 1986).

The role of certainty in academic texts has also been researched by linguists. A very influential line of research investigates the role of modal words and expressions that express an author's attitude towards what they are saying (e.g., could, may, possibility, clear, etc.). An often-used model to describe the use of linguistic devices to nuance claims in academic texts is that of hedging (Hyland, 1998; Lakoff, 1973). According to Lakoff, who coined the term, hedges are "words whose job is to make things fuzzier or less fuzzy" (Lakoff, 1973, p. 471). Hyland (1998) built on this work to describe their role in the negotiation of academic knowledge. Hedges are a way "to balance objective information, subjective evaluation and interpersonal negotiation, and this can be a powerful persuasive factor in gaining acceptance for claims" (Hyland, 1998, p. 354). In general, hedges indicate either a lack of commitment to the truth value of a statement or a desire not to express that commitment unequivocally (Hyland, 2005). Hyland (2005) discusses three functions of hedges: to specify the actual state of uncertainty of a claim, to protect the writer against consequences of overstatements, and to appeal to the capability of readers to evaluate provisional statements. However, it is good to note that there is also an observed difference in the use of hedges between first and second language users. Second language students used a more limited range of hedges, offered stronger commitments, and showed greater difficulty with conveying a precise degree of certainty (Hyland & Milton, 1997).

Another relevant remark on the use of the model of hedging for assessing the conveyance of certainty of claims is made by Plappert (2019). He points out that the model overlooks the use of implicit meaning to convey (lack of) certainty. Plappert argues that the most typical type of claim made in the *Nature Genetics* articles he analyzed is a type four claim, without modalities (e.g., mutations in the gene encoding X *cause* disorder Y). He identifies only very few hedges, some of which do not even seem to convey uncertainty of the claim. However, he does identify multiple instances of implied causative relationships. In some instances, authors use a specific verb that signals possible causation (e.g., "associate"). Thereby, they seem to prefer unhedged claims that do not involve a speculation at the sentential level, but at the level of speaker meaning. With this observation, Plappert explicitly draws on Grice's theory of implicature (Grice, 1989). In short, this theory describes that there is a difference between what a speaker "says" (sentential level) and what they "implicate" (level of speaker meaning) (Grice, 1989). Plappert draws on Grice's conversational maxims to explain how scientists use implicature to make type one, two, or three statements at the level of speaker meaning, while making type four statements at the sentential level.

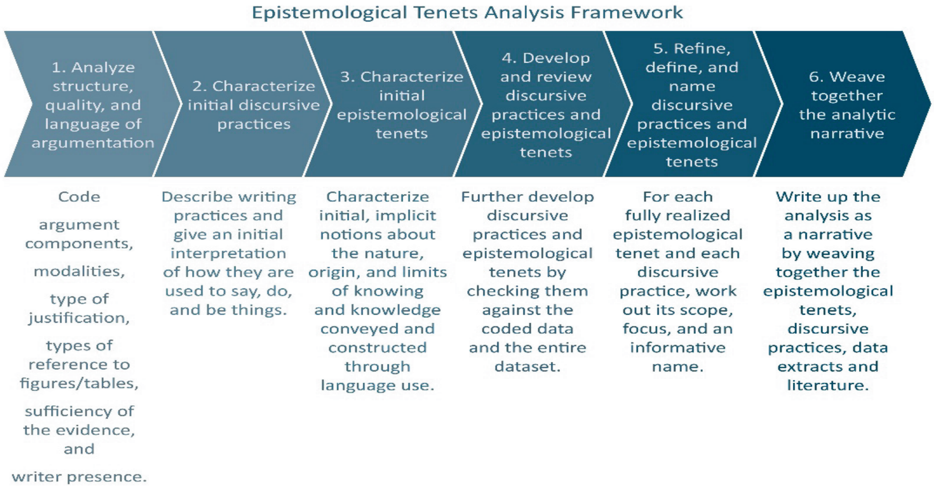
To summarize, these approaches focus on the structure, quality, and language of scientific arguments. They result in descriptions of writing practices without relating them to underlying epistemological tenets that might be conveyed and constructed through them. In our framework, we combine and optimize these approaches from different fields to form phase 1 of epistemological tenets analysis. By adding five other phases, we proceed the analysis from descriptions of writing practices (argumentation analysis) to interpretations of what these practices can tell us about the epistemological tenets they might convey and construct. However, before we explain these phases of the framework in detail, we first explain the concept of epistemological tenets, relate it to views of NOS and epistemology, and point the reader's attention to some theoretical and philosophical underpinnings of the epistemological tenets analysis framework.

Introducing epistemological tenets underlying scientific language use and their relation with views of NOS

With our approach to analyzing students' scientific writing, we introduce a new concept in science educational research; epistemological tenets underlying scientific language use. Epistemological tenets, as we define them, are notions about the nature, origin and limits of knowing and knowledge conveyed and constructed through language use. To explain this definition, we explicate its parts and contrast it with the following related concepts: epistemology, views of NOS, and epistemological beliefs. An overview of the different concepts we discuss in this article and how they are related to the epistemological tenets analysis framework can be found in Figure 1 and Table 2.

One aspect of the definition to explicate is "about the nature, origin and limits of knowing and knowledge"; the "epistemological" part of epistemological tenets. A person's epistemology is their theory of knowledge; what counts as knowledge and how it comes about. Throughout history, various philosophers have formulated such theories. These theories differ in scope. Some have formulated ideas about how we can justify our beliefs in general (what we will call broad scope), some specifically write about how knowledge comes about in academic research contexts (medium scope), and others only describe how knowledge comes about in science (small scope). The broad scope encompasses all of a person's views about the nature of knowledge and the process of knowing in general and can include ideas about how they as a person determine whether their personal belief is justified (e.g., whether to trust authority or science textbooks as a reliable source). The medium and small scope only consider how we decide which beliefs are justified in academia. There is a difference between these two in which disciplines of academic research they include. A science specific epistemology (small scope) usually includes natural sciences and sometimes also social sciences. A general epistemology of academic research (medium scope) pertains to sciences and humanities, thus also includes disciplines in the humanities and interpretivist approaches to social sciences (Sundholm, 2014). This difference is especially relevant in our own research context since Dutch students learn about sciences and humanities as one concept, encompassing all academic research, with the word "wetenschap," also known from German as "Wissenschaft." In addition, students at Dutch universities are all trained to be academic researchers, "wetenschappers," since there are separate institutions for the applied sciences. So, Dutch universities are decidedly different from, for example, colleges or universities in the United States of America. We introduce the concept of epistemological tenets, here, to apply it in research into language use in academic research (the medium scope of epistemology) or scientific research (small scope). The context of our own research is science (small scope), since the students we study and teach are students in the biomedical sciences.

Figure 2 Relationships between concepts in the epistemological tenets analysis framework



In the second part of the concept, “tenets,” we chose to point toward the implicit and often incoherent nature of our construct of epistemological tenets. They are latently present in writing or speech, and they are not necessarily part of a coherent epistemology. The difference with “ideas” or “views” about aspects of scientific knowing and knowledge is that epistemological tenets in a text do not necessarily correspond with the writer’s explicit beliefs about these aspects. Epistemological tenets are conveyed and constructed through a certain way of writing (writing practices, Table 2). Why a writer has chosen this specific way of writing is probably the result of a combination of factors. These can include the writer’s explicit ideas about NOS and epistemology, but, for example, also the epistemological assumptions, history, and rules and conventions of their field of research and the instructions of co-authors or teachers (Figure 1). With our discourse analytic approach, we take this context into account in our interpretation of writing practices (resulting in discursive practices, Table 2). However, this remains the interpretation of the researcher doing the analysis. With this analysis we cannot make inferences about the writer’s intentions or views. Therefore, we have explicitly included the following aspect in the definition of epistemological tenets: “conveyed and constructed through language use.”

It is also good to note the difference between epistemology and views of NOS. Not only is there a difference between their scope (knowledge in general or specifically scientific knowledge), there is also a difference in topics discussed. NOS is a construct created by science education researchers and educators with the specific purpose of identifying what, mainly K-12, students should know about the nature of scientific knowledge and knowing (Abd-El-Khalick & Lederman, 2023). The resulting frameworks are not epistemologies since they purposefully remain silent on certain aspects of epistemology (especially non-resolved controversies) and they are generally simplified, for pragmatic and didactic reasons. Reasons include time spent on NOS teaching and learning, and students’ interests and readiness for learning (McComas, 2020). So, the construct of NOS addresses a specific set of aspects of epistemology, focusing on generally agreed-upon conclusions in a for students accessible manner. It is also good to note that it is still debated in the science education community which topics and views should be included in NOS teaching and learning (see section 2.3). These debates also regard the question of whether or not to address non-resolved controversies in epistemology (Abd-El-Khalick & Lederman, 2023). Nonetheless, our concept of epistemological tenets can relate to both epistemology and NOS, since it involves any notion relating to the nature, origin, and limits of knowledge and knowing.

Table 1 Explanation of concepts

Concept	Explanation
Epistemological tenets	Notions about the nature, origin and limits of knowing and knowledge conveyed and constructed through language use. They do not necessarily equate with the writer's or speaker's explicit views about knowledge and knowing.
Epistemology	A theory of knowledge; a theory about the nature, origin, and limits of knowing and knowledge.
Views of NOS	Views of the nature of science, detailing what a person believes about (the epistemological underpinnings of) scientific knowing, as a set of activities, and scientific knowledge, as a result of those activities (Lederman, 2007). Most often used for explicit, professed views. Most commonly describes only a specific subset of characteristics of science, called the consensus view of NOS (Abd-El-Khalick & Lederman, 2023).
Epistemological beliefs	A person's personal beliefs about knowledge and knowing (Hofer & Pintrich, 1997).
Epistemic	Relating to knowledge. "Epistemic level" relates to the degree of abstractness of knowledge claims, from grounded, low inference claims to progressively more general, theoretical claims (Kelly et al., 2007). "Epistemic status" relates to the degree of certainty awarded to knowledge claims.
Writing practice	A communicative act or a description thereof. Communicative acts can be words, phrases, sentences, text structure, argumentative moves, the act of combining any of those in a specific way (e.g., using two words interchangeably), and the inclusion of certain information or the omission of it.
Discursive practice	Description and interpretation of a communicative act in its context. It describes the communicative act itself and the interpretation of the researcher about the meaning of this act in its context.
Discourse	Language in use. It concerns how language is used to create meaning, for example, how it is used to say, do, and be things. Discourse analysis is the analysis of language in use, studying connections among and across sentences and studying how context gives meaning to language use and how language use gives significance to context (Gee, 2014).

A last concept related to epistemology to contrast epistemological tenets and views of NOS with involves what is often called "epistemological beliefs." Epistemological beliefs are seen as a student's personal beliefs about the nature of knowledge and the process of knowing (Hofer & Pintrich, 1997). This often relates to their own knowledge, how they determine whether their own beliefs are justified (and thus can be seen as knowledge), and to their own learning, how a person learns and what their ability for learning is (Schommer, 1990). The concept of epistemological beliefs is mostly used within the field of educational psychology and has to do with students' cognitive development (King & Kitchener, 1994; D. Kuhn, 1999; Perry, 1968; Schommer, 1990). Views of NOS, on the other hand, describe (the epistemological underpinnings of) characteristics of scientific knowing, as a set of activities, and of scientific knowledge, as a result of those activities (Lederman, 2007). So, again, there is a difference in scope. Epistemological beliefs is a construct that uses epistemology in its broadest scope (beliefs about knowledge and knowing in general), while NOS is a construct that uses epistemology in the smallest scope (beliefs about scientific knowledge and knowing). Common elements in the construct of epistemological beliefs are beliefs about the certainty of knowledge (from fixed to more fluid), the simplicity of knowledge (from discrete, concrete and knowable to relative, contingent and contextual), the source of knowledge (from handed down by authority to derived from reason), and the justification of knowing (from right-or-wrong to a continuum of less or more justified beliefs) (Hofer & Pintrich, 1997). However, as Hofer and Pintrich (1997) concluded, there is no generally accepted definition of the construct of epistemological beliefs, and different authors include different additional elements in the construct. So, with some authors, there might be some overlap between epistemological beliefs and views of NOS. The epistemological tenets analysis framework is mostly focused on beliefs about knowledge in academic research (medium scope epistemology) or beliefs about knowledge in science (small scope epistemology), although it might also be applicable to define implicit notions in language use about personal knowledge, knowing, and learning (broad scope epistemology).

Although we contrast implicit tenets and explicit views, we argue that there might be a relation between the epistemological tenets underlying a writer's language use and their explicit ideas about epistemology. We believe, this relationship could have two directions. On the one hand, explicit ideas could engender epistemological tenets in language use. In other words, what a writer thinks about how knowledge comes about can affect how they write about knowledge. On the other hand, epistemological tenets in language use could affect explicit ideas. So, how a writer writes or what they read can affect what they think about how knowledge comes about. It is important to note that to assess these relationships, one needs to characterize both the epistemological tenets in a written product or reading exercise (with the epistemological tenets analysis framework) and the explicit views of the writer or reader, e.g., with a VNOS instrument (Abd-El-Khalick et al., 2023; Lederman et al., 2002), and explicitly study their relationship. We emphasize that the epistemological tenets analysis framework is to be used only for that first part, characterizing epistemological tenets in a written product or reading exercise. For research methods used to characterize a person's explicit NOS views, we refer the reader to the many works in science education literature addressing this. In the next section, we provide a short review of this literature.

A short review of views of NOS in science education literature

To study students' explicit NOS views, science education researchers have explicated characteristics of scientific knowledge and knowing which they believe are important for students to understand and act upon. The most commonly used framework for NOS education is the consensus framework (Abd-El-Khalick & Lederman, 2023). Science educators have formulated and substantiated the following list of consensus views, which forms the basis for NOS teaching and learning: scientific knowledge is empirical, inferential, creative, theory-driven, tentative, and socially negotiated. In addition, it includes the view that the existence of a single "Scientific Method" is a myth, that science is socially and culturally embedded, and that there is a difference between scientific theories and scientific laws (Abd-El-Khalick et al., 2008). However, it is good to note that this list of consensus views should not be treated as an exclusive, nor exhaustive list (Lederman, 2007). As we show with our use of the epistemological tenets analysis framework, there are additional aspects of science and scientific knowledge about which people or texts can convey different views or tenets (e.g., about the role of statistical outcome measures in scientific knowledge production).

It is also good to note that there are other approaches to NOS education and research, besides the consensus approach (Abd-El-Khalick & Lederman, 2023). These include the Reconceptualized family resemblance approach to NOS (RFN) (Cheung & Erduran, 2023; Erduran & Dagher, 2014; Kaya & Erduran, 2016), an approach focusing on questions rather than tenets (Clough, 2007, 2020), and the features of science approach (Matthews, 2012). Of these, the RFN approach is most used and referred to (Abd-El-Khalick & Lederman, 2023). The key components of the RFN include the aims and values of science, methods and methodological rules, scientific knowledge, scientific practices as well as the social-institutional dimensions of science including the scientific ethos, professional activities, social certification and dissemination, social power structures, political power structures, financial systems, and social organizations and interactions (Erduran & Dagher, 2014).

Furthermore, it is important to realize that the list of consensus views is merely a short summary of more nuanced views of NOS and that these denote aspects that might not be apparent to our reader. We, therefore, refer the reader to other NOS work for an explication of these views (Abd-El-Khalick, 2012; Abd-El-Khalick & Lederman, 2023; Lederman et al., 2002). The presented key components of the RFN require more extensive explication as well. Such an explication can, for example, be found in the work of Erduran, Dagher and McDonald (2019). For the current article it is good to note that the epistemological tenets framework is theoretically flexible with respect to the approach to NOS. We believe it can be used with both a consensus view approach and an RFN approach to NOS.

Theoretical and philosophical underpinnings

Although the epistemological tenets framework is theoretically flexible with respect to the user's approach to NOS, there are three theoretical assumptions underlying the framework that are essential to its use. First, we see language as constructing things in the world (e.g., Gee, 2014). Language is used to inform each other, but it is also used to do things and to be things (Gee, 2014). When one writes "The data were analyzed with SPSS," they are informing the reader about the program used for analysis. However, by writing it from the perspective of the data, the writer is also engaging in the practice of writing objectively about scientific procedures. In addition, because of their way of writing, the reader can identify the writer as an academic researcher. So, language is used to say, do, and be things. Therefore, it does not merely express things that already exist, it also creates things such as practices (writing objectively) and identities (researcher). In addition, language use does not only construct *ideas*, but it also constructs significance, practices, identities, relationships, politics (the distribution of social goods), connections, and sign systems and knowledge (Gee, 2014). This way of thinking about the constructive acts of language[1] is also important for using the epistemological tenets analysis

[1] We chose to call Gee's (2014) "building tasks" in our text "constructive acts of language," because of the parallel with the constructivist paradigm underlying this framework and because "task" implies agency on the part of language, while it is people who construct things *with* language.

framework. Through discourse analysis one characterizes what communicative acts in their data might convey to and construct in the world. These descriptions and interpretations of writing practices are called discursive practices (Table 2). Through these constructive acts of language, the way we and others speak and write can affect our views of a topic. That is not to say that it always will but it is good to be aware that it might change our views. This is especially relevant in the context of science education.

Second, and closely related, we see meaning as socially constructed (e.g., Latour & Woolgar, 1986). To provide meaningful characterizations of language use, we should use a critical approach in analyzing a writer's texts. A writer's language use cannot be characterized in isolation. We need to consider the discourses they are part of, and the ideas they might have about "proper" language use in scientific texts. In addition, other people than the writer can affect the final text, for example, informal and formal peer reviewers. Therefore, context is important in our analysis of language use. Furthermore, for students, we need to consider the fact that they are not just reporting scientific research but by doing so they are *learning* how to adequately report research as well. So, students not only might express the views they hold in the way they write about science, the way they write about science could also build their views. For example, when we teach students to write objectively, they could develop the view that a scientist's identity is unimportant and does not affect their science (relating to the theory-driven, creative, socially negotiated, and socially and culturally embedded NOS).

Third, in using the epistemological tenets analysis framework, we see the subjectivity of the researcher using the framework as vital to qualitative analysis. A researcher's interpretations of epistemological tenets underlying scientific language use are guided by the researcher's beliefs and feelings about the world, and their experience in it. In qualitative approaches, the researcher is the instrument for analysis (Nowell et al., 2017). We can only make sense of epistemological tenets underlying scientific language use by being a person with epistemological and NOS views ourselves. Therefore, the epistemological tenets analysis framework is not a step-by-step method that one follows to objectively characterize epistemological tenets in scientific language use. The researcher is the instrument of analysis, and the framework is a tool to guide the researcher in systematic interpretation of a dataset to construct knowledge about the epistemological tenets conveyed and constructed by the text. For any research instrument, it is important to examine how it works, what its underlying assumptions are, what its limitations are, and with which paradigms it does and does not fit. Since, here, the researcher is the instrument, careful and continuous self-examination, or reflexivity (Braun & Clarke, 2022), is key to using the epistemological tenets analysis framework. Although the analysis framework is not a step-by-step method, we did implement the six phases of reflexive thematic analysis in the framework. Structuring qualitative data analysis by these phases can help a researcher in systematically and robustly exploring, interpreting, and reporting their data and analysis (Braun & Clarke, 2006, 2021b). We elaborate on the use of researcher subjectivities as an analytical resource and the importance of continuous reflexivity in Section 4.2 of this article.

Because of these three theoretical assumptions, we see epistemological tenets as situated notions that are brought about through discourse rather than as individual properties held by individuals. In other words, with this analysis framework, we focus on epistemological tenets in writing products instead of NOS views held by a person (Table 2 and Figure 1). However, we do argue that student views can indeed be *formed by* their language use, actions, and behaviors, and that their views are context dependent (in contrast with language, actions, and behaviors as mere expressions of already formed conceptions).

In addition, it is good to realize that students generally do not have a coherent epistemology, nor do most scientists. So, when they behave in a certain way, that way may fit with a certain epistemology, but it does not mean that the student subscribes to that epistemology when you ask them about it or that they will always act according to that epistemology. Therefore, this analysis tells us something about a student's actions and how these actions can convey and construct notions relating to epistemology. This might be related to their explicit views of how knowledge comes about in science but does not necessarily have to be the case. Let alone that these epistemological tenets fit with a coherent system of beliefs relating to epistemology or NOS.

Summary: the building blocks for the epistemological tenets analysis framework

The epistemological tenets analysis framework is based on descriptive text analysis approaches of the structure, quality and language of arguments (discussed in Section 2.1), and two interpretative analysis approaches, which are discourse analysis (Gee, 2014) and reflexive thematic analysis (Braun & Clarke, 2006, 2021b). Together, these approaches are combined to characterize epistemological tenets underlying scientific language use. This results in two types of analytic outputs. First, an overview of *what* epistemological tenets are conveyed and constructed in the text.

Second, an overview of discursive practices, detailing *how* language use conveys and constructs epistemological tenets. The researcher using the epistemological tenets analysis framework characterizes what writing practices might say about the writer's ideas, presuppositions, identity, what they think is significant, how they treat the reader, and the ways of knowing they privilege (i.e., formulating discursive practices). From these discursive practices the researcher can characterize what epistemological tenets might be conveyed or constructed through them. These interpretative steps take epistemological tenets analysis a step further than previously published argument analysis studies in educational research (Section 2.1).

DEVELOPMENT OF THE FRAMEWORK

Context of study

To develop the epistemological tenets analysis framework, we have chosen to use student bachelor theses because these are culminating assessments which are used to assess students' knowledge and skills regarding scientific research and scientific writing. They are examples of how we have taught students to write and they regularly have a strong resemblance to the scientific articles they have read throughout their studies. Therefore, they can provide a rich source for educators to reflect on the epistemological tenets implicitly conveyed and constructed at university and on how these tenets might affect students' views of NOS and views relating to epistemology. We have chosen to use theses of biomedical students because this is our own disciplinary expertise.

A total of nine theses were used for the development of the analysis framework. Five of these were written in 2017/2018 and 2018/2019 (archived theses) and four in 2021/2022 (newly obtained theses). Theses were written during an internship at the end of a 3-year bachelor program Biomedical sciences at Utrecht University in The Netherlands. They were accredited with 15 European Credits upon completion. Students worked in the lab for approximately 2 weeks and for 8 weeks they performed a literature study and wrote their thesis (minimum of 30-35 pages). These theses contain a literature study (minimum of 25 pages) and a separate research report in the form of a science journal article. In 2017/2018, 2018/2019, and 2021/2022, 106, 138 and 96 students, respectively entered the course. Students were approximately 20-23 years old and had some course-based laboratory experience, but most had not participated in authentic research before. Most of the students followed only biomedical sciences or biology courses. Approximately 97% of the students continue with a Biomedical Research Master after their Bachelor program. Of those students, approximately 50% remain in research after their master's. So, biomedical sciences bachelor programs in the Netherlands are highly research oriented.

We started out with the archived theses, which we processed on the same lawful basis as that which allowed the collection of the personal data; processing is necessary for warranting the quality of the educational program by Utrecht University. For selection of archived theses for stages 1 and 2 of the development of the analysis framework (Section 3.2), we used random sampling. For obtaining new theses for stage 3 of the development, the students provided informed consent, and we used purposive maximal variation sampling. Ethical approval for acquiring and processing these data was granted by the Ethics Committee of the Faculty of Social and Behavioural Sciences of Utrecht University. We refer to our preregistrations (Pieterman-Bos, van Mil, & van de Schoot, 2021, 2022) for details about the sampling and case selection strategy.

How we developed the analysis framework

Here we provide a summary of how we developed the framework and describe where we deviated from the preregistrations.[2] A more elaborate description and justification of the development of the framework can be found in the supplemental files.

In stage 0, before data collection, we combined previously published argument aspects (e.g., "level of rhetorical reference to a data inscription") and corresponding codes (e.g., "pointer") as they were described (see Table 1) to develop an alpha version of our framework (version 0.1).

In stage 1, we developed and refined the framework based on the archived theses. During this stage we labeled data extracts with codes from the alpha version of the framework. This version consisted of only the first building block (descriptive text analysis). During this phase, we added a new aspect to this building block called "writer presence." Within the argument aspect "argument components" we have

[2] It is good to note that where we mention "discursive practice" in the preregistration for the analysis framework, we refer to data extracts that define and construct a code (e.g., "See figure 1" as an example of the code "pointer"). However, later during development we realized that discursive practices are better conceptualized as descriptions and interpretations of communicative acts in data extracts. We, here, call mere descriptions "writing practices" to make this distinction.

added Toulmin's (1958) "qualifier" as a code. To the argument aspect "level of rhetorical reference to data inscriptions," we added the code "introduction." Within the argument aspect "type of warrant used for a claim" we changed the code "causal" to "reasoning," because we found it better fitting with the description of the code. For the aspect "coordination of the evidence across epistemic levels" we created specific subcodes for the specific reasons for insufficient coordination (e.g., "partially or unexplained evidence"). Lastly, we refined the definitions of argument aspects This resulted in version 0.4 of the framework.

In stage 2, we used the five previously used archived theses to develop the interpretative phases of the framework. We used the findings of our analysis of the structure, quality, and language of arguments (building block 1, descriptive text analysis) to start analyzing epistemological tenets. By doing this interpretative analysis, we developed the interpretative phases of the framework. To that end, we used the second and third building blocks; discourse analysis and reflexive thematic analysis. We used the constructive acts of language as a lens to guide discourse analysis, by looking how writing practices were used to construct significance, practices, identities, relationships, social goods, connections, and sign systems and ways of knowing (see Section 2.4). We used the general discourse questions formulated by Gee (2014) as a starting point. We formulated questions for each of the argument aspects (e.g., relating to "type of warrant" or to "modality") and questions that were not related to these aspects (e.g., general question relating to the practice of reporting scientific research). We formulated these discourse questions based on the first and fifth thesis. Then, we evaluated their usability and validity with the other three theses, which we had previously used for the first phase of the framework (coding argument aspects). This did not result in changes or additions to the framework. In addition, using the first and fifth thesis again, we evaluated which argument aspects (phase 1 of the framework) were relevant for characterizing epistemological tenets and removed non-relevant aspects. We removed "pertinence of the evidence," and "statement types" because they had become redundant. Next, we formalized the interpretative phases (phase 2-6) of the analysis in the framework. We based these phases on the third building block, reflexive thematic analysis (Braun & Clarke, 2006, 2021b) and adapted them to fit the purpose of epistemological tenets analysis. We elaborate on the similarities and differences in Section 4. This resulted in the beta version of our framework (version 1.0b). Lastly, we tested this version of the framework again on the other three theses. This did not result in additional revisions to the framework. Therefore, we decided to proceed to stage 3 of development: evaluating the framework based on new theses.

For stage 3, we used the four newly obtained theses (Section 3.1). Using the framework (1.0b) for these theses did not lead to major changes to the framework. The only changes we made, were to merge some codes under the aspect of "writer presence," and to add some examples to a few codes. Since there were no significant changes, we decided to present this version of the framework as the first release (version 1.0). We will explain this version of the framework in detail in the next section.

THE EPISTEMOLOGICAL TENETS ANALYSIS FRAMEWORK

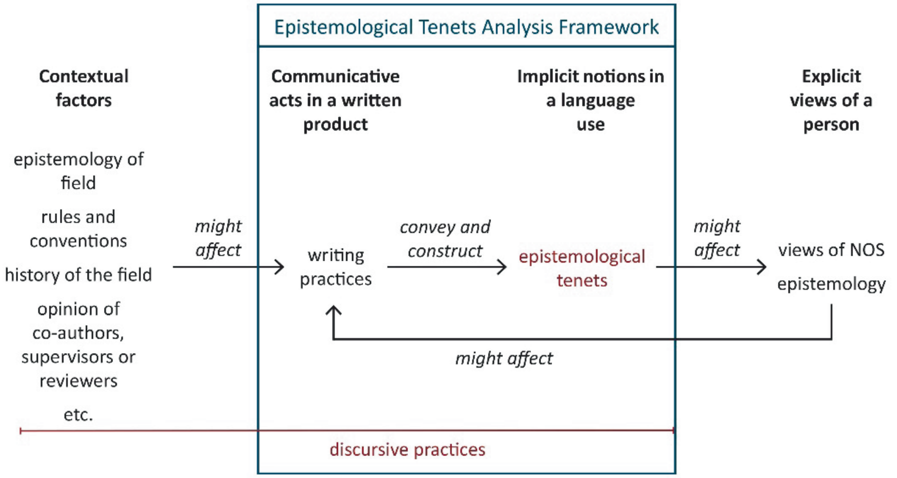
A six-phase process to guide epistemological tenets analysis

The epistemological tenets analysis framework describes a process that guides the researcher using the framework in analysis of written scientific texts with the aim of characterizing discursive practices and the epistemological tenets constructed by these discursive practices. The six phases of the process are similar to the six phases of reflexive thematic analysis (Braun & Clarke, 2006, 2021b). At the same time, they are different in content since they are focused on characterizing epistemological tenets rather than the more general concept of "themes." In addition, the framework builds on descriptive text analysis and discourse analysis approaches and thereby it puts stronger focus on the writing practices from which the epistemological tenets are constructed.

We present the framework as an instruction guide for researchers who might engage in epistemological tenets analysis in the future. We provide a guide through the six phases and offer examples to demonstrate how a researcher can use the framework for analysis of a scientific text. In the current article, the examples have a merely illustrative purpose. So, we recognize that the interpretations presented here are not fully justified by the current text. The substantive analysis will be published elsewhere.

The different phases of the framework are summarized in Figure 2. It is important to recognize that the framework is a tool that can guide the researcher in the process of analysis. It is not used as a step-by-step linear method that automatically leads to the emergence of epistemological tenets. Like themes (Braun & Clarke, 2006, 2021b), epistemological tenets are active co-constructions on the part of the researcher, the written product, and context. In addition, using the epistemological tenets analysis framework is a recursive process, during which a researcher moves back and forth between different phases. For example, while a researcher is writing about the analysis (phase 6), they will often go back to refining and defining the epistemological tenets they characterized (phase 5), since writing often leads to further insights about the things one is writing about. They might also see reasons to characterize new discursive practices (phase 2) or epistemological tenets (phase 3), which they then further develop and refine through phases 4 and 5. So, the framework should not be seen as a rigid, step-by-step method but as a tool for a systematic approach to data analysis.

Figure 3 Phases of the epistemological tenets analysis framework



For each of the phases we offer examples. The data extracts from the theses we analyzed for the development of the framework often require specific content knowledge or elaborate introduction. So, for ease of reading, we have chosen to sometimes adapt data extracts (e.g., changing content-specific details to general terms) to make it more comprehensible or we have chosen to provide descriptions of data rather than the data extract itself. In addition, we use some fictitious examples to show the breadth of possible writing practices. Again, we acknowledge that the inferences made should be better substantiated in an article about the substantive analysis. However, that is not the focus of the current article. As a note beforehand, the researcher can use the epistemological tenets analysis framework both for characterizing epistemological tenets of one writing product (one thesis) and for characterizing epistemological tenets common in a type of writing product (a set of theses). These are different strategies that determine whether the researcher constructs patterns throughout one text or the entire dataset.

Phase 1: Analyze structure, quality, and language of arguments.

Before starting with analyzing the structure, quality, and language of arguments in phase 1, we advise researchers to take the time to familiarize themselves with the data. This involves repeated reading of the data. For more complex scientific texts, this also often involves reading secondary sources about the topic of the text to make sure you are familiar with the content.

After repeated, careful reading, the researcher proceeds to analyze the structure, quality, and language of the argument. For each argument aspect, the researcher labels parts of the text with codes that are fitting to that part. See Table 3 for an overview of all the argument aspects and their corresponding codes. It is good to note that since the codes relate to various aspects of the argument made, a single data extract can be labeled with multiple codes. There are two aims for this coding phase. The first aim is to reconstruct the argument made by the writer. To that end, the researcher identifies the different argument components: figures or tables, evidence sentences, justifications, qualifiers, and claims. The researcher can then reconstruct the argument structure, for example, by making a flowchart to visualize how the argument components relate to each other. The second aim of this phase is a more general aim of coding, that is, to organize the data into meaningful groups. These codes make it easier to navigate the data because they group similar writing practices. In the explication of coding for each of the argument aspects below, we will be concise about the argument aspects and codes that have been described in previous literature and we refer to Table 1 and the literature referenced there for details about these aspects and codes. We will focus our description on the newly defined aspects and codes (indicated with an asterisk in Table 3).

The researcher starts with labeling the argument components. We have slightly refined some of the descriptions of the argument components defined by Jiménez-Aleixandre and Federico-Agraso (2009) (Table 1) but refer to their work for a more elaborate description of how to use them as codes. An argument component that does require some more attention is “qualifier.” We identified (at least) two types of qualifiers that moderate the degree of certainty of the presented claims. With the first type, the writer points to results of earlier research to moderate the degree of certainty about the presented results. An example could be “This association has not been found previously.” With the second type, the writer points to a result of data analysis to moderate the degree of certainty of the claim made. An example of this could be “However, the confidence interval was very wide (95% CI [0.01-10.34].” Although these sentences draw on different sources, they are both moderating the degree of certainty the writer expresses about the presented claim. Therefore, they fall into the category of "qualifier" described by Toulmin (1958).

The next argument aspect that the researcher codes for is "modality." Modality has been extensively described by Hyland (Hyland, 1998, 2005; Hyland & Milton, 1997) and Plappert (2019). So, we refer to their work and Table 3 for a description of this argument aspect. What is important to emphasize here is that not all words or phrases that could function as a hedge or booster do indeed function as such. An emblematic example of a word that can be used as a booster but is not always used as such is "significant." In common language it usually refers to importance, but in academic texts it usually refers to statistical significance, which is often used in a more neutral sense. An example of a word that could but not always does function as a hedge is "possible." For example, in a phrase from thesis one "linear regression makes it possible to determine (…)," the word does not decrease the certainty of the statement, while in a phrase from thesis two, "the possible clinical impact," it does decrease the certainty. Therefore, we again emphasize that context matters in this type of analysis. Another observation about the importance of context that we want to make is about the use of the word "should." There are cases where "should" is used instead of "must," which leaves room to not do or to not believe what is expressed in the sentence, i.e., a hedging function. In that sense, it is used as "it should be so, but we are not entirely sure." On the other hand, there are cases where "should" is used instead of "can," which implies that what is expressed in the sentence ought to be done and does not leave room for other interpretations, i.e., a boosting function. In that sense, it is used as "it should be so, there is no other option." Therefore, the researcher can label one word in one context as "hedge," in another as "booster," and in yet another they can decide to not label it at all.

Next, the researcher returns to the sentences and phrases that they labeled with "justification." For each of the justifications, they determine the type of justification according to the description provided in Table 3 and Sandoval and Millwood (2007). In our analysis, we also identified justifications for which we found it clear that they were based on literature. These would be empirical justifications. However, they did not have (clear) references to that literature. Therefore, we decided to code them with both empirical and factual reference. We made sense of these writing practices during later phases of the analysis.

Then, for each sentence about data that is presented in a figure or table, the researcher determines what type of reference is made to the figure or table. A type of reference that is newly included in the epistemological tenets analysis framework compared to

Sandoval et al. (2005) is “introduction.” These types of reference to figures or tables are just that; they are introductions to it. For example, the writer indicates why the data were included, describes the experiment that led to the data, or explains how to interpret this type of graph or figure. After labeling all these sentences that relate to data presented in figures or table, the researcher determines for each figure and table the highest level of reference that is made to it in the text. The researcher does this for each claim that is supported with data from the figure or table. So, a single figure or table can be labeled multiple type of reference codes.

The next argument aspect that the writer analyzes is the “sufficiency of evidence and justification.” For each claim, they determine whether it is sufficiently evidenced and justified by the writer. When they deem it to be insufficiently evidenced, the researcher then determines the source of this insufficiency. This is a new step compared to labeling the argument aspect as described by Jiménez-Aleixandre and Federico-Agraso (2009) under the label “coordination of evidence across epistemic levels.” There can be different reasons to label a claim as insufficiently evidenced or justified that could be of interest for characterizing the possible underlying epistemological tenets. The first possibility is that the writer presents no evidence or too little evidence to support the claim. Then, there can be cases in which there is evidence presented that is not or not fully explained. Therefore, it is unclear whether this evidence supports the claim or not. A slightly different version of this is when the writer presents evidence that clearly contradicts the other presented evidence, but they do not refute it nor explicitly weigh it against positive evidence. A fifth case is when the writer builds upon a previous claim to support the new claim, while the previous claim is not sufficiently evidenced or justified. A sixth possibility is that the writer gives a claim a stronger epistemic status than the evidence can substantiate, which we call an epistemic status mismatch. The seventh possibility is that the writer uses results for which no statistical significance is reached in support of their claim. The last possibility is that the claim is formulated in such a way that it is unclear what is actually claimed by the writer. This can, for example, be the case if the writer uses a demonstrative pronoun of which it is unclear what it refers to.

Lastly, the researcher turns toward the argument aspect of “writer presence.” The researcher discerns three different types of writer presence and in their labeling, they also discern sentences about procedures and sentences about results, thus resulting in six possible codes. The first type of writer presence is the animate specific type. This is applied to sentences where the writer uses a person or group as the subject of the sentence or if a person or group is mentioned in such a way that they played a role in the interpretation. Examples of results sentences are “I/we/they/(s)he show(s) that cells are increasingly infected," "Increased infection was shown by me/[ref]," "[ref] showed increased infection," "this leaves us not yet satisfied." Examples of sentences about procedures are "I/we/they/(s)he stained cells," and "cells were stained by me/[ref]." The second type of writer presence is the animate common type. This is applied to sentences where the writer implies human involvement but does not specify which human(s) are involved. Often, it takes the form of "one/you can see," but we also apply it to sentences of the form "it can be seen that cells are increasingly infected," "what would be expected," "expectations are," and "it was hard to interpret." We see the same type of sentences about procedures. Examples are "one/you can stain cells, "the intention was to stain cells," "it is interesting to stain cells," and "adding compound X." The last type of writer presence is the inanimate type. Here, the writer uses an inanimate object, concept, or action as the subject of the sentence. In sentences about results the subject can be a research object (e.g., "cells were increasingly infected"), but it can also be data (e.g., "the data show") or a figure or table (e.g., "the figure shows"). In sentences about procedures, the subject is often a research object (e.g., "cells were stained"), or a procedure ("cell staining was done"). When writers use this third type of writer presence, they remove themselves or other people from the text. The researcher searches the whole text to label sentences about results or procedures with these writer presence codes.

Key advice for the researcher for this phase is to not spend too much time on labeling of data extracts for which it proves to be difficult to determine the code for a certain argument aspect. The researcher will revisit these data extracts in the following phases, which might help them determine the code then. Another piece of advice is to document the reasons for specific choices well. Since these codes are the ingredients for the other analysis phases, the researcher will revisit them later during analysis. In light of new insights, they might not be able to reiterate their arguments for choosing a specific code. Therefore, it is a good practice to keep track of the thought process that went into deciding which code to apply.

Phase 2: Characterize initial discursive practices.

The intended outcome of phase 2 is a list of discursive practices. In the analysis of written language, discursive practices are descriptions and interpretations of writing practices in their context. They describe the writing practice itself and the interpretation of the researcher about the meaning of this practice in its context.

The researcher starts with the interpretation of the writing practices that they labeled in phase 1. It is good to note, that one type of writing practice can have multiple connotations. For this phase, it can be helpful to use the discourse analysis questions about the constructive acts of language formulated by Gee (2014) as a lens to guide interpretation. A reformulation of these discourse analysis questions in the context of scientific texts is available as supplementary material accompanying the online article. Examples of such questions are: "How are justifications used to build or withhold credibility of used methodology?" "How are hedges and boosters used to make the research or results less or more significant and in what way?"

After interpreting the writing practices that relate to the argument aspects described in phase 1, the researcher proceeds to attend to other writing practices that do not directly relate to the argument aspects. The researcher starts to read the full text attentively again and when they encounter a writing practice that appears interesting, they label it with a first code describing the writing practice. They then go through the rest of the text to potentially identify other instances of the same or similar writing practices and label these as well. The researcher can decide to immediately write down an interpretation of the writing practice to formulate an initial discursive practice. They can also do this in a later phase and decide to first focus on labeling writing practices with descriptions of the writing practice. Then, they can look for patterns in these writing practices later to interpret their meaning in their context in terms of underlying epistemological tenets. We advise the researcher to take the time to go through the text, with the aim of labeling interesting writing practices, multiple times.

After multiple unguided rounds of labeling, the researcher will do some rounds of guided labeling. Here, the researcher can use each of the constructive acts of language as a guide and they can use the list of aspects that we have found to be interesting to attend to (Table 4). An example of a guiding discourse question for this part is: "How are specific phrases used to privilege (post-)positivist or constructivist epistemologies?" Another specific round of labeling that can be useful, is one in which the researcher pays specific attention to what is not written. An example is the detail in the descriptions of the methods used. Sometimes, when a writer leaves out information (e.g., justifications for choice of methods), this can be informative for the researcher as well. It is easy to overlook these writing practices and therefore, a specific round of coding for them can be helpful. Together, these rounds result in a (probably long) list of initial discursive practices with corresponding data extracts (one or more per discursive practice).

Table 2 Examples of writing aspects used in phase 2.

Writing aspect	**Examples**
Description of results	The writer's use of interpretative words, how the writer describes possible debates in the fields, or the words the writer uses to describe variables.
Writing about methods	The level of detail provided about methods, to what degree the writer explains the methods used, or whether the writer justifies the choice of methods.
Writing about statistics	Whether the writer describes negative results, whether the writer reports measures of spread or confidence, or whether relevance is discussed in relation to statistical significance.
Uncertainty or inconclusiveness	Whether the writer gives tentative explanations (e.g., using hedges) about inconclusive results, or whether they attend to uncertainty when describing previous research.
Writing about published or future research	How the writer writes about conclusions of published research, for example, as statements of fact, or as their own interpretation of the published results and conclusions. Whether they call for future research to attend to a current lack of empirical evidence.
Adherence to standard writing practices	Whether the writer follows written and unwritten rules of the discipline in writing style or diverges from these standard writing practices and in what way.

Phase 3: Characterize initial epistemological tenets.

The intended outcome of phase 3 is a list of initial epistemological tenets that may underlie the writing practices described in phase 2. Epistemological tenets are notions about the nature, origin and limits of knowing and knowledge conveyed and constructed through language use. An example of an initial epistemological tenet in our analysis is: "conclusions are not certain but should be certain to have value." This is a notion that might underlie the writing practice of writing a conclusion with both a hedge (decreasing its certainty) and a booster (increasing the certainty).

Again, it is important to approach this phase systematically, to give each piece of the text and each interesting aspect of epistemology enough attention. There are different ways to systematize this part of the analysis (working through the text from top to bottom, or starting with the first identified discursive practice, etc.), the important thing is to choose a system and to stick to it. In our analysis, we started at the top of the text with the first discursive practice we identified in phase 2. We looked at all the quotes coded with this discursive practice to look for patterns and to determine which epistemological tenet might underlie this discursive practice. Then, we proceeded to the next discursive practice to characterize underlying (initial) epistemological tenets for each discursive practice.

Both for characterizing discursive practices (phase 2) and epistemological tenets (phase 3), the key is to look for patterns in data extracts to identify common features in the writing practices. Identifying these patterns is the first step that helps the researcher to construct underlying notions that tie several writing practices together. This step helps to transcend mere description of writing practices by focusing on interpretation. This part is where our analysis framework leans heavily on reflexive thematic analysis, and we recommend the researcher to read about the difference between mere descriptions and interpretations in terms of views in the reflexive thematic analysis literature (Braun & Clarke, 2006). In reflexive thematic analysis, the equivalents of descriptions and underlying ideas are “topic summaries” and “themes.” However, it is good to note that in these early phases, the researcher will probably first identify a long list of narrow patterns (initial epistemological tenets). During the subsequent phases, they will pay more attention to identifying broader patterns, applicable to more data extracts at a time.

Phase 4: Develop and review discursive practices and epistemological tenets.

The aim of this phase is to further develop the initial discursive practices and epistemological tenets, to focus on finding broader underlying ideas (patterns) and to determine that they tell a convincing story. First, the researcher checks the discursive practices and epistemological tenets against the already coded data. Second, they check them against the entire text or entire dataset (depending on the single text strategy or multiple texts of the same type strategy chosen). This can result in the decision to revisit phase 2 and/or 3 to characterize new discursive practices or epistemological tenets. Third, the researcher compares the different discursive practices they constructed to see whether they can combine discursive practices that capture broader patterns in the writing practices. The same is done for epistemological tenets. When discursive practices or epistemological tenets are combined, it is important to check all corresponding data extracts again to determine whether the newly constructed discursive practice or epistemological tenet still fits with all of them. This process can also result in the decision to split discursive practices or epistemological tenets because the researcher decides they constitute different interpretative patterns. Data within each discursive practice or epistemological tenet should be coherent and meaningful, while there need to be clear distinctions between separate discursive practices and between separate epistemological tenets.

We repeat the warning that Braun and Clarke (2006) give for the equivalent phase in reflexive thematic analysis: avoid staying in this phase for too long. It is easy to keep finetuning the lists of discursive practices and epistemological tenets. However, when the refining does not add substantial insight to the analysis, the researcher should stop. As Braun and Clarke mention, the process is comparable to editing a text; at some point the additional hour of finetuning does not add remarkable impact to the text anymore. That is the moment to proceed to the next phase. In addition, in this phase the researcher will probably need to overcome the fear of losing information when they decide to discard a discursive practice or epistemological tenet or decide to combine two of them. Keep in mind that the aim is to answer the research question and thus to reduce data to descriptions and interpretations that are relevant for that question. Loss of information is inevitable; indeed, it is one of the aims of analysis.

Phase 5: Refine, define, and name discursive practices and epistemological tenets.

When the researcher is satisfied with the constructed discursive practices and epistemological tenets, they move their focus toward refining the corresponding names. For each discursive practice and each epistemological tenet, the aim is to write a sentence that clearly reflects its essence. For discursive practices, we recommend the structure of "description-which-interpretation." An example from our analysis is: "Being prescriptive about how to conduct research [description] which leaves no room for the reader's views on how to conduct research [interpretation 1] and which supports the idea that choices in research design are right or wrong [interpretation 2]."

Another aspect of phase 5 is that the researcher determines the boundaries of each discursive practice and epistemological tenet. On the one hand, it must fit with each data extract that the researcher applied it to. On the other hand, it must not be too broad so that it also fits with other data extracts. However, one data extract can contain multiple writing practices and therefore, it can lead to the researcher's construction of multiple discursive practices and multiple possible underlying epistemological tenets. The names (or rather sentences) need to immediately give the reader a clear impression of what the discursive practice or epistemological tenet is about.

In addition to the names, the researcher writes down a longer description of each discursive practice and each epistemological tenet. These descriptions can include (curated) examples of writing practices that support them. We have found that examples can often more clearly show the boundaries of a discursive practice or epistemological tenet than mere descriptions. However, the researcher also needs to make sure that they explain what unites these examples, what constitutes the pattern that they established.

An example of the development of a discursive practice from our analysis is the following. We saw that students used words as "demonstrate," "fact," "known to be," and "shown." At first, we coded each of these instances as a separate discursive practice under the initial name "use of [insert word used] builds science is fact notion." Later, we saw the pattern in these practices, merged them, and replaced the specific words with "booster." In addition, we specified how the booster was used, what it gave rise to. The use of the boosters increased the perceived significance of results. Further, we realized that these writing practices might not construct the notion that science produces facts, but that they could also construct the notion that science is objective. Therefore, we renamed the discursive practice "booster to increase significance of results builds objectivity notion and science is fact notion." During further refinement in phase 5, we applied some changes to increase clarity and because of new insights in the corresponding epistemological tenets. This resulted in the current phrasing: "Using a booster which attributes value to impressiveness of research results in the process of knowledge creation."

An example of the development of an epistemological tenet from our analysis is the following. We saw patterns in how students described their methods and initially characterized two epistemological tenets that could underlie these patterns: "Scientific methods do not have to be justified," and "Research design choices are right or wrong." In a later stage of the analysis, we reformulated the first to create a positively formulated sentence "Scientific methods speak for themselves." Grouping epistemological tenets to look for broader patterns led us to decide that these two epistemological tenets describe the same idea that "Choice of research design speaks for itself." We refined its name to "Choice of research design and research methods speaks for itself" during phase 5. For a justification of the interpretative insights discussed here, we refer to our substantive article discussing our full analysis of the theses (publication in progress). The focus here is on illustrating the use of the analysis framework.

Phase 6: Weave together the analytic narrative.

In phase 6, the researcher's aim is to create a narrative about the discursive practices and epistemological tenets that they characterized and to support the narrative with data extracts and findings from previous literature. Using the data, they put forth their argument for their answer to the research question.

For the choice of data extracts, it usually works best to choose those that best show the essence of what the discursive practice or epistemological tenet is about, the most illustrative ones. In addition, it is easier for the reader when they do not need a too elaborate introduction or explanation. Still, sometimes an example nearer to the boundary of the epistemological tenet can help to explicate that boundary and to distinguish the example from another writing practice or to distinguish one epistemological tenet from another. However, the focus should not be on the data extracts themselves or the researcher's descriptions of them, the focus is the argument that the researcher puts forth about their research question, for which they use data.

The reason we include the write-up of the analysis in the analysis framework, is because we have found that it is part of the recursive process. Often during our writing, we have further refined discursive practices or epistemological tenets or have changed their names because of new analytic insights. Making the argument on paper can be a very helpful step for the data analysis itself.

An important note about write-up, is that the researcher should keep in mind that this type of analysis is interpretative and constructive. In reflexive thematic analysis, themes do not emerge from data (Braun & Clarke, 2006). Similarly, discursive practices and epistemological tenets do not emerge from a text. They are not pre-existing entities that a researcher finds in the text, they are their own interpretations of the writing practices. This also bears consequences for the vocabulary that the researcher uses in their article. For example, "the underlying epistemological tenet *is*" or "the discursive practice that emerged" do not fit with the constructivist paradigm underlying this type of qualitative analysis. Instead, the researcher can use wordings like "the epistemological tenet that could underlie this practice," or "this practice may derive/result from the notion that," or "the discursive practice we developed/identified/formulated/constructed/defined." Using this different vocabulary might be difficult for researchers unfamiliar with constructivist approaches to data analysis. Therefore, it is prudent to check the article specifically for these phrases.

Criteria for conducting good epistemological tenets analysis

Now that we have described the six phases of the epistemological tenets analysis framework, we want to emphasize, again, that the epistemological tenets analysis framework cannot be used as a step-by-step method that needs to be followed from phase 1 to 6. It is not a protocol for data analysis that needs to be strictly followed to lead to a predefined result. The analysis framework is a guide, a set of principles and instructions that helps a researcher to explore and interpret data systematically. The resulting analysis will be a product of the input of the researcher (their skills and perspective), the data (the scientific text), and the research contexts (e.g., context of data creation and context of interpretation). However, to make the resulting analysis valuable and transferable for the research community, there are some important criteria for conducting good epistemological tenets analysis.

Most of the criteria mentioned by Braun and Clarke for reflexive thematic analysis (2006, Table 2) are also relevant for using the epistemological tenets analysis framework. Here, we interpreted these criteria in the context of epistemological tenets analysis (Table 5), and highlight one of them (Braun & Clarke no. 7, Table 5 no. 5): data have been interpreted, rather than just paraphrased or described. The strength of this type of analysis (thematic or epistemological tenets) is derived from the formulation of a concept that unifies different data extracts. That concept itself is not present in the data, but it gives meaning to the data. And, by giving data meaning, the researcher can answer their research questions. An example of such a concept in our analysis is the impressiveness of results as a requirement for validity. Data extracts that are unified by this concept could be described (without interpretation) as giving increased attention to strengths of research and decreased attention to weaknesses. This would be a summary or description of what one can see in our data. Interpretation takes the analysis a step further. These writing practices (together with other writing practices) could be interpreted as an indication of an underlying notion that results need to be impressive to be valid. It is good to note again that whether this notion is an explicit idea of the writer cannot be inferred from this type of analysis, it might also be the result of certain writing conventions

Table 3 Criteria for good use of the epistemological tenets analysis framework

Process	No.	Criterion	- √ +
Overall	1*	Sufficient time has been spent on each phase of the framework.	
	2	An audit trail demonstrates continuous reflexivity.	
Analysis	3*	Each part of the text has been given sufficient attention.	
	4*	Discursive practices and epistemological tenets have been formulated through a thorough, inclusive, and comprehensive coding process rather than from a few examples.	
	5*	Data have been interpreted, made sense of, rather than just paraphrased, or described. Epistemological tenets invoke unifying concepts that transcend (descriptions of) data.	
	6	Discursive practices are interpretative and transcend descriptions of writing practices.	
	7*	All relevant data extracts for each discursive practice and epistemological tenet have been collated.	
	8*	Discursive practices and epistemological tenets have been checked against each other and against the data.	
	9*	Discursive practices are internally coherent, consistent, and distinctive.	
	10*	Epistemological tenets are internally coherent, consistent, and distinctive.	
	11*	Analysis tells a convincing and well-organized story about the writing practices, discursive practices, and epistemological tenets in the written product.	
Written report	12*	The assumptions about qualitative analysis and the researcher's specific approach to analysis are clearly explicated.	
	13*	The language used in the report is consistent with the epistemological position underlying the analysis, including an active position of the researcher (epistemological tenets do not emerge).	
	14	Epistemological tenets are not implied to be the writer's views of NOS, nor are they implied to be a part of a static, coherent epistemology.	
*Based on Braun & Clarke, 2006 - missing, √ (partially) present, + comprehensive			

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in their field of research. By characterizing notions that certain writing practices can derive from or notions that they implicitly construct, we give the data meaning with relation to our research question, we interpret the data (Table 5, no. 5). In the same vein, we add that discursive practices provide interpretations (give meaning to) writing practices by explicating how writing practices are used to say, do, and be things (no. 6).

Another criterion we add to Braun and Clarke's is the necessity of an audit trail that demonstrates continuous reflexivity. Reflexivity in this type of research has at least two benefits: increasing the evaluability of the research and gaining new insights in the research. Concerning the first benefit, reflexivity can aid evaluability of the research in multiple ways. By identifying the effects of the researcher's bias and assumptions, the reader can evaluate whether they agree with these assumptions or whether they might interpret the data differently from their own perspective. By being explicit about the contexts of the research and researcher, the reader can evaluate whether the analysis can have implications for their own context (i.e., increased transferability of results). By being open about the steps that led the researcher to their development of discursive practices and epistemological tenets, the reader can evaluate the soundness of the interpretation and argument.

We emphasize that reflexivity should be a continuous process, throughout the conception of the study and all phases of the epistemological tenets analysis. Since the researcher's assumptions and theoretical insights develop throughout the analysis, it is often difficult to recall previously held assumptions and beliefs in a later stage. However, these might still have affected the development of discursive practices and epistemological tenets and could therefore be insightful for others to evaluate their credibility. In addition, continuous reflection is important for realizing the second benefit; aiding the process of analysis itself. Structured, written reflection can help a researcher to organize and make sense of their thoughts about the data and to pinpoint where their thoughts are coming from. It can help to identify the researcher's own subjectivities early in the process. Being aware of one's assumptions and own perspective can help to explore other perspectives and other interpretations. In addition, these continuous reflections create an audit trail that can be shared to enable quality control of the analysis process. Therefore, it is important to write down the reflections, even though it might be tedious. Furthermore, in our experience, by writing them down they get a more formal character which pushes the researcher to develop their argument well, early on.

Although reflecting on subjectivities is an important part of rigorous qualitative research, the aim is not to eliminate bias (a (post-)positivist view). Subjectivity in qualitative research can be used as a tool. It can, for example, be used to be a more informed listener (Hollway & Jefferson, 2000), or, in our case, reader. When the researcher shares experiences with the research subject, for example having written theses themselves, this can help the researcher to understand the experience of the research subject. Through reflection, the researcher can be aware and make others aware of how their own experiences influence their interpretation of the research subjects' experiences. In addition, NOS researchers are more engaged with and informed about different aspects of NOS and epistemology, which allows them to develop deeper insights into epistemological tenets than other researchers would be able to (Gough & Madill, 2012). This effect is enhanced by prolonged engagement with the data (Braun & Clarke, 2021a). Lastly, reflecting on researcher and participant subjectivities can create more informed, refined, and persuasive claims about generalities or transferability (Gough & Madill, 2012).

Another strategy that can aid reflexivity is collaborative coding. Instead of independent coding to calculate interrater reliability scores, we recommend collaborative coding. Within a constructivist paradigm, the aim of collaborative coding is to enhance understanding of the data, interpretative depth, and researcher reflexivity (Braun & Clarke, 2021a). These are enhanced by inviting other perspectives, which might point attention to unexplored assumptions and alternative interpretations.

Which aspects should a researcher attend to in their reflexive journal? General aspects to reflect upon include the researcher's theoretical and conceptual understanding of the topic, and their training and experience (Braun & Clarke, 2021a). Their personal, methodological, and ideological values (Gough & Madill, 2012). And, the researcher's possible motivations, agendas, goals and (shifting) ambitions (Gough & Madill, 2012). Research process-related aspects to continuously reflect upon include research activities (what data have you collected, how have you prepared them, etc.), ideas for research activities, analysis processes (which phase have you been working on and what have you done specifically), developing concepts, discursive practices and epistemological tenets, and developing storylines. These aspects could function as a format for a daily or weekly reflection journal.

To conclude, using the epistemological tenets analysis framework is a flexible process. We outlined criteria to increase the quality and evaluability of the analysis.

Researcher subjectivity is employed rather than abolished because it makes for a more informed reader, development of deeper insights about the writer's epistemological tenets, and more informed claims about generalities and transferability. Continuous reflexivity and prolonged engagement with data are essential to increase the quality and depth of analysis and to enable external evaluation of these aspects.

DISCUSSION

What does the epistemological tenets analysis framework offer educational researchers?

The epistemological tenets analysis framework can be used as a qualitative analysis method to characterize epistemological tenets underlying scientific language use. Contrary to NOS views approaches, this approach can shed light on how language use can imply epistemological notions, which in turn could possibly affect students' views of NOS, when NOS is not explicitly discussed in class. Epistemological tenets analysis results in two types of analytic output. First, an overview of discursive practices in the written product. Second, an overview of what epistemological tenets are conveyed and constructed through them.

The epistemological tenets analysis framework is based on previously used descriptive text analysis approaches of the structure, quality, and language of arguments, discourse analysis, and reflexive thematic analysis. The unique combination of these three approaches results in a systematic approach to proceed from mere description of writing practices to interpretation of their meaning in relation to epistemological tenets. Most NOS research is focused on describing what explicit NOS views students assert or claim to support when NOS is the explicit topic of a lesson, questionnaire, or interview (Deng et al., 2011). To those approaches we add a research procedure that is focused on interpreting what epistemological tenets might be conveyed to students when NOS is not explicitly addressed. Both approaches are valuable for NOS research. We discuss the merits of the epistemological tenets approach. In short, the approach responds to calls for more attention to context in NOS research (Abd-El-Khalick & Lederman, 2023; Deng et al., 2011) and it focuses on understanding factors that could affect what views of NOS students develop during their formal education.

Descriptive explicit NOS views approaches are often focused on measuring[3] students' NOS views at one point in time or to measure them before and after an educational intervention (Abd-El-Khalick & Lederman, 2023). These approaches are valuable to assess students' current NOS views or the impact of educational interventions on explicit views. However, from these studies, it is often difficult to draw conclusions about the learning processes that affect building and revision of students' NOS views. An interpretative approach, attending to context, can increase our understanding of what epistemological tenets might be conveyed to students when NOS is not explicitly addressed. We have used the epistemological tenets analysis framework to characterize epistemological tenets conveyed and constructed in bachelor theses (publication in progress). We have also interviewed the students about their explicit NOS views and asked them to relate these to their own writing practices and scientific writing practices in general. A preliminary finding is that students sometimes have trouble with relating the consensus NOS views (Section 2.3) to the way they are taught to write. So, epistemological tenets analysis can help researchers understand difficulties that students experience with translating professed NOS views to their writing. For example, students learn that scientific theories are formed based on multiple studies and that they are not substantiated by a single study. At the same time, students are instructed to add something new and substantial with their work. As a result, students could develop the idea that a single study should be conclusive to result in new and substantial knowledge, which contradicts the tentative (yet durable) nature of science. So, the epistemological tenets analysis framework can also be used to characterize how the writing practices we teach could affect the NOS views students develop during their formal education. Although we remind the reader that this requires assessment of students' explicit views of NOS (e.g., using a VNOS instrument) as well.

By teaching students to adhere to certain rules and conventions in article writing, we also convey the epistemological tenets underlying these discursive practices. Using the epistemological tenets analysis framework sheds light on these epistemological tenets-constructing discursive practices, and with that, it opens up a yet unexplored focus area for NOS research. For experienced scientists, community standards for writing about science might be more dissociated from their explicit NOS views. For example, when scientists write "the difference between A and B was statistically significant ($p = 0.03$)," they probably remain aware of the fact they themselves have

[3] The difference between approaches focused on measurement and those focused on understanding, which we discuss in this paragraph, is also discussed by Gough and Madill (2012).

set the alpha to 0.05 and that this bears consequences for type I and type II errors. Students, on the other hand, are more likely to see the statistical significance as a fully objective measure which has nothing to do with researcher choice in research design since they are still learning to grasp the concept of statistical significance. So, what we teach students about scientific discourse could affect their NOS views. Therefore, the epistemological tenets analysis framework can be used by educational researchers to characterize epistemological tenets that might be implicitly taught through writing practices. These insights can then be used to improve explicit-reflective NOS teaching and learning.

Some remarks on applicability of the framework

We have developed the epistemological tenets analysis framework using university bachelor theses. It is good to note that these writing products are not only a product of the student, their background, experience, and views. They are also a product of an internship, and therefore of the training and feedback the student's supervisor has given them and of the instructions given within the course. Therefore, the researcher using the framework should take these contextual factors into account in their analysis. The epistemological tenets analysis could for example be complemented by interviews with the students. These could serve to map their experiences with supervision during the internship. In addition, interviews can explore students' professed NOS views to compare them with the epistemological tenets conveyed through their writing. Lastly, specific writing practices can be discussed to ask students about their reasons for writing in a specific manner.

Although we have developed the framework using theses, we believe that it has broader applicability. Other writing products, where students use scientific data to support claims, can also be used for epistemological tenets analysis. Many of the descriptive text analysis approaches used in phase 1 of the framework have also been used on different argumentation assignments. We advise researchers to consider which of these argument aspects (Table 3) are applicable to the assignment they want to analyze and to consider the contextual factors in play with that assignment.

In addition, the framework could be used to characterize the epistemological tenets conveyed and constructed through science teachers' language use. The writing practices and NOS views of teachers and thesis supervisors could be an important factor affecting the NOS views that their students develop. The results of an analysis of epistemological tenets underlying science teachers' language use could be used to improve science teacher education programs and professional development programs for university teachers.

Lastly, we believe that it can also be valuable to use the framework for characterizing the epistemological tenets conveyed and constructed through scientists' language use in published research articles. An analysis of the epistemological tenets conveyed and constructed through scientists' language use could shed light on notions that are implicitly propagated through research articles or popular science writing. These might affect students' NOS views but could also affect NOS views of the general public when they read about science. Therefore, epistemological tenets analysis might be an interesting approach for people interested in science communication, public engagement, or trust in science.

To conclude, the epistemological tenets analysis framework can be used to characterize epistemological tenets underlying scientific language use. We encourage the reader to use the framework and the outlined quality criteria (Table 5) along with more explicit approaches focused on professed NOS views. A combination of both approaches can help to understand how professed, explicit views relate to scientific (writing) practice.

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CHAPTER 6

Learning (how) to listen: a key aspect in training future scientists for meaningful dialogue with society

An adapted version of this study is published as "Reincke, C. M., Pieterman-Bos, A., Bredenoord, A. L., & van Mil, M. H. (2024). Learning (how) to listen: a key aspect in training futire scientisits for meaningful dialogue with society. *International Journal of Science Education, Part B: Communication and Public Engagement*, 1–16."

ABSTRACT

The current paper presents the findings of an educational design study conducted within the realm of science communication training. Within this study framework, we implemented the active listening observation scale (ALOS) in a science communication training based on (deliberate) experiential learning. Our investigation centered on determining the efficacy and mechanisms through which the ALOS facilitated the acquisition of active listening skills. This was achieved through semi- structured interviews conducted with participants who, as part of our training regimen, participated in numerous dialogue sessions with a non-scientific audience. Through reflexive thematic analysis, it was observed that the ALOS facilitated learning in three distinct manners. First, the ALOS enhanced active listening cognition, by aiding participants in identifying active listening as a spectrum of behaviors serving various functions. Second, the ALOS enhanced the enactment of active listening behaviors by reinforcing the deliberate character of the experiential learning process. Lastly, the ALOS enhanced active listening affect, by assisting participants in recognizing active listening as key in fostering meaningful dialogue. We contemplate our findings within the context of the imperative to advance training initiatives explicitly tailored to fostering meaningful dialogue with society. Moreover, we underscore the necessity to refine science communication training from a pedagogical perspective.

INTRODUCTION

The escalating demand for scientists to interact with audiences beyond academia has coincided with a surge in scholarly attention toward science communication training (e.g., Baram-Tsabari & Lewenstein, 2017a; Kuchel, 2020; Newman, 2020). A burgeoning array of studies is dedicated to providing guidance for both current and prospective training initiatives. Some of these studies yielded standards describing the competencies or skills that should be prioritized in science communication training (e.g., Bray et al., 2012; Mercer-Mapstone & Kuchel, 2017). Others provide guidance at the conceptual level, such as defining science communication learning, and proposing related learning objectives (Baram-Tsabari & Lewenstein, 2017b; Lewenstein & Baram-Tsabari, 2022). Nonetheless, to date, there remains a lack of broad consensus regarding what constitutes 'the right' training (Barel-Ben David & Baram-Tsabari, 2020; Newman, 2020).

Moreover, there is concern regarding the translation of new theoretic insights into practical application. Previous research has shown that the majority of contemporary training practice still adhere to a more traditional, educational perspective of science communication. For instance, most current training programs in both North America and Europe predominantly emphasize skills and tactics associated with message transmission, while placing minimal emphasis on fostering dialogue (Dudo et al., 2021; Trench & Miller, 2012; Yuan et al., 2017). This observation may elucidate why it is common for most scientists, when interacting with a non-scientific public, to predominantly adopt an informing role (Dudo & Besley, 2016; Hamlyn et al., 2015; Jensen & Holliman, 2016; Metcalfe, 2019).

Within the community of science communication scholars, there is widespread consensus that science communication entails more than simply 'informing an uninformed public' (see, e.g., Bucchi & Trench, 2021; Davies, 2022). Effective science communication, as is generally understood, entails two-way dialogue, is mutually beneficial, and involves building relations (Cooke et al., 2017; Illingworth, 2017; Nisbet & Scheufele, 2009). This necessitates scientists to assume diverse roles. In a previous study, we identified three distinct responsibilities or roles for scientists in contemporary science communication (Reincke et al., 2020, 2022). In addition to sharing knowledge, we ascribed to scientists a responsibility to listen to and learn from members of the public, and a responsibility to invest in relationships. Each of these responsibilities involves a range of skills, necessitating com- prehensive training for their development. Recently, the scholarly field of science communication training has advocated for an expansion of research focus (Baram-Tsabari & Lewenstein, 2017a; Barel-Ben David & Baram-Tsabari, 2020; Kuchel, 2020). In addition to examining training content, which pertains to determining what should be taught, there is advocacy for research to delve into training pedagogy, addressing the methodologies of teaching. This entails investigating aspects such as training effectiveness, actual learning processes, and the characteristics of educational design. However, research in this domain, specifically tied to the context of science communication training, remains largely insufficient (Barel-Ben David & Baram-Tsabari, 2020; Rubega et al., 2021).

In summary, although the scholarly field of science communication training demonstrates evi- dent progress, substantial change in training practice, let alone in science communication practice itself, keeps lagging. Yet, imperative to such transformation is the reliance on scholarly research that not only tackles training content but also delves into training pedagogy. In this paper, we present the results of an educational intervention study conducted within the framework of an elective course on science communication. The objective of this study was to examine the learning and training of an important skill in modern science communication: listening (Escobar, 2011; Jackson et al., 2005; Reincke et al., 2022). Throughout the duration of the course, biomedical students, poised as future scientists[4], engaged in dialogues with teenagers from multiple high schools, positioned as representatives of society, regarding the ethical and social implications of advancing biomedical science. To support our students in developing their listening skills, we provided them with an observation scale directed at monitoring active listening competency. We investigated whether and how this observation scale positively influences the acquisition of listening skills.

[4] Students enrolled in a biomedical sciences Bachelor program in The Netherlands are trained to become scientists. The biomedical sciences Bachelor program at our university is highly research oriented. Approximately 97% of students continue with a Biomedical Research Master after their Bachelor program.

LISTENING

Defining listening

Listening is generally understood as a multidimensional construct, involving cognitive, behavioral, and affective processes (Worthington & Bodie, 2018). Cognitive processes entail activities such as receiving and interpreting messages. Behavioral processes encompass actions undertaken in response to messages. Affective processes involve aspects such as motivation to engage in listening. Scholarship on listening is dispersed across various disciplines and fields of study, including audiology, psychology, and interpersonal communication. Notably, there exist discernible differences among disciplines or fields regarding the emphasis placed on cognitive, behavioral, and affective dimensions (Worthington & Bodie, 2020). In this study, listening was examined from the perspective of interpersonal communication, where significant research has been dedicated to the behavioral aspects of listening (Manusov, 2020). This is not surprising, given that interpersonal listening, in contrast to scenarios such as listening in a lecture hall or to the radio, places substantial emphasis on how individuals interact by manifesting listening behaviors. These behaviors may be verbal (e.g., asking questions and paraphrasing) or nonverbal (e.g., nodding and maintaining eye contact).

Furthermore, we chose to conceptualize listening, consistent with prevalent communication research, as a form of skilled performance (Hargie, 2019; Worthington & Bodie, 2018). By adopting this perspective, we liken listening skills to psycho-motor skills. Analogous to psycho-motor skills, listening skills are contextual, purposive, and trainable. In addition, they involve competence at cognitive, affective, and behavioral levels (Hargie, 2019). Effective listening necessitates understanding how (and why) to listen (cognition), possessing a willingness to engage in listening (affect), and actively enact associated listening behaviors (behavior) (Wolvin & Coakley, 2000).

A frequently mentioned training strategy in the context of listening is deliberate practice (Rost, 2020). Deliberate practice can be defined as the systematic and purposeful repetition of a skill or component of a skill, resulting in gradual performance enhancement. Typically, in deliberate practice, the overall performance is deconstructed into distinct components, each with clearly delineated performance objectives, facilitating the assessment of improvements in related performance. Learners improve their abilities by repeatedly executing the same task or practice activity, while receiving informative, actionable feedback (Ericsson, 2020; Ericsson et al., 1993).

Active listening as a form of good listening

Research on interpersonal listening describes different types or forms of listening. A conceptually well-developed form, which is often associated with good listening, is active listening (Manusov, 2020; Stewart & Koenig Kellas, 2020). While there may be variations in the precise definition of active listening, most scholars agree that this type of listening comprises three fundamental aspects. First, active listening involves demonstrating nonverbal engagement with the speaker (e.g., through eye contact or vocal affirmations). Second, it involves paraphrasing to reflect the speaker's message without judgement. Lastly, active listeners ask questions to seek clarification or encourage further elaboration (Weger et al., 2010, p. 1014). Generally, the goal of active listening is to gain understanding and to communicate involvement and interest (McNaughton et al., 2008).

STUDY CONTEXT

This study was conducted within the framework of a 10-week (part-time) elective course on science education and communication, offered as part of the undergraduate biomedical curriculum at Utrecht University. Throughout this course, predominantly third-year undergraduate biomedical students, engage in visits to several high schools across the Netherlands. During these visits, they intro- duce innovative biomedical research topics into the classroom and engage in discussions regarding their implications. Through experiential learning methodologies, augmented by elements of deliberate practice, students cultivate a range of communicative and didactic skills. They establish their own specific and measurable (SMART) learning objectives, practicing related behavior and skills through iterative cycles of experiential learning during school visits, and subsequently reflect on their performance based on peer observation and feedback. During the academic year 2021–2022, we introduced a new component to the course known as the 'Embryolab', designed specifically to enhance students' dialogue skills, with a particular emphasis on listening. In the Embryolab, students engaged in dialogues with high-school students regarding socio-ethical issues associated with human embryo research and the genetic modification of human embryonic DNA. An important aim of the Embryolab is to facilitate mutual learning between university students, who are prospective scientists, and high-school students, who represent members of society.

On average, each student participates in 3–4 Embryolabs while being observed by a peer. They focus on achieving 4–6 (self-chosen) learning objectives, with 2–3 of these objectives centered on active listening. Additionally, each student observes 3–4 Embryolabs conducted by a peer. Following each Embryolab session, peer observation notes are discussed in a feedback session. Progress in skill development is documented in a reflection report, for which students receive grading upon completion of the course.

STUDY DESIGN

In this study, we adopted a methodology rooted in educational design research (EDR). EDR integrates the enhancement of educational theory with the creation of interventions aimed at promoting educational practice (McKenney & Reeves, 2018). It progresses through three stages: 'analysis and exploration', 'design and construction', and 'evaluation and reflection' (McKenney & Reeves, 2014). This research focuses on the evaluation and reflection phase.

Educational intervention and study approach

Within our course, peer feedback serves as a fundamental component. However, crafting meaningful feedback can be a challenging task. To facilitate the development of active listening skills, we introduced students to the active listening observation scale (ALOS). The ALOS is a validated observational tool utilized for assessing active listening behaviors demonstrated by a participant during an interaction (Vickery, 2018). It comprises 14 items encompassing various micro-level behaviors associated with active listening, categorized into nonverbal behaviors, verbal behaviors, and general behaviors. Each item is evaluated on a 5-point Likert scale indicating the frequency with which the target exhibits the specific behavior, ranging from 'never' to 'very often'. Originally devised by Fassaert et al. (2007), the ALOS was designed to assess the active listening skills of physicians during patient consultations. To facilitate scoring, each item included a brief description accompanied by a set of associated example behaviors. Minor modifications were made to tailor the ALOS to our training model (i.e., the Embryolab). This involved adjustments to both the word- ing within some of the items (e.g., 'patient' was replaced or modified to 'participants') and, in some cases, the item explanation (e.g., 'is good in leading the conversation' was contextualized within a group conversation, emphasizing aspects such as encouraging multiple voices to be heard). Furthermore, all ALOS items were provided with writing space and the prompt to note relevant situations and quotes. The modified ALOS, as used in the peer observation process during Embryolab sessions, is presented in Figure 1. ALOS-based peer observation involved both item-scoring and the documentation of situations and quotes.

Participants and data collection

To investigate the extent to which the ALOS contributed to the acquisition of active listening skills, we conducted semi-structured interviews with participants enrolled in our course during the academic year 2021–2022. Following the conclusion of the course, and the determination of their final grades, we extended invitations to students to participate in our study. Those who expressed interest provided written consent. We enrolled ten participants in our study, at which point data saturation was achieved (i.e., interviews 9 and 10 did not yield any novel insights regarding our research question). This aligns with recommendations for determining sample size, particularly applicable to studies with relatively homogeneous samples and a narrow study aim (Guest et al., 2006). The participants comprised third – or fourth-year undergraduate students of biomedical science. All interviews were conducted between December 2021 and May 2022. Two of the participants were interviewed one-on-one, while eight participants were interviewed online via Microsoft Teams. We employed a semi-structured interview guide developed based on our theoretical framework, the purpose of our study, and our own educational expertise. Key topics covered in the interviews included ALOS content (e.g. the relevance of items), the process of observing and constructing feed- back using the ALOS, experiences of being observed and receiving feedback with the help of the ALOS, and personal development in active listening skills. Interviews lasted between 40 and 70 min, with an average duration of 47 min.

Data analysis

All interviews were digitally recorded and transcribed verbatim. Transcripts were analyzed using NVivo 12 Pro (Lumivero, 2017) and Braun and Clarke's six-step framework for reflexive thematic analysis (RTA) (Braun & Clarke, 2019; 2021).

Figure 1. Adapted ALOS (adapted and reprinted from Fassaert et al., 2007).

Nonverbal behaviors	
Uses inviting body language, e.g., raising eyebrows, smiling, facing/making eye contact, open/interested body attitude. SITUATIONS, QUOTES, AND OTHER COMMENTARY	1 2 3 4 5
Acknowledges emotions and feelings non-verbally, e.g., nodding, smiling, sympathizing eye contact, supportive humming. SITUATIONS, QUOTES, AND OTHER COMMENTARY	1 2 3 4 5
Verbal behaviors	
Adjusts language, e.g., avoids jargon and academic language, uses familiar terms and contexts. SITUATIONS, QUOTES, AND OTHER COMMENTARY	1 2 3 4 5
Uses exploring questions (explorative, often open-ended questions that do not invite any particular answer but open up a conversation and/or elicit a wide range of answers). SITUATIONS, QUOTES, AND OTHER COMMENTARY	1 2 3 4 5
Dilates (verbally) upon feelings and emotions, e.g., acknowledges/names/checks feelings and emotions, asks for clarification/asks further. SITUATIONS, QUOTES, AND OTHER COMMENTARY	1 2 3 4 5
General behaviors	
Listens attentively, e.g., uses silences to give others a chance to think or to elaborate, notices (non)verbal signs, paraphrases, encourages (e.g., humming, nodding, asking for clarification/asking further). SITUATIONS, QUOTES, AND OTHER COMMENTARY	1 2 3 4 5
Shows *not* to be distracted, e.g., not: checking notes or laptop screen too frequently, or thinking too much ahead and missing what is said. SITUATIONS, QUOTES, AND OTHER COMMENTARY	1 2 3 4 5
Is *not* detached, e.g., not: greeting/introducing oneself/responding in an uninterested way or without making contact, avoiding eye contact. SITUATIONS, QUOTES, AND OTHER COMMENTARY	1 2 3 4 5
Gives sufficient time and space, e.g., allows many participants to react (also to each other), avoids cutting off unnecessary, takes/gives time as needed and/or sticks (longer) to wherever energy centers. SITUATIONS, QUOTES, AND OTHER COMMENTARY	1 2 3 4 5
Creates an open and safe atmosphere, e.g., allows to fully express, welcomes each contribution and every opinion, avoids and prevents unnecessary interventions or immediate refuting, makes oneself equal. SITUATIONS, QUOTES, AND OTHER COMMENTARY	1 2 3 4 5
Leads the conversation in a good way, e.g., deliberates on the agenda, takes initiative when necessary (e.g., by actively inviting others to contribute, or summarizing/comparing contributions), but stands aside when the conversation goes, involves as many participants as possible, restates (interim) conclusions, evaluates the conversation. SITUATIONS, QUOTES, AND OTHER COMMENTARY	1 2 3 4 5
Is obviously relaxed and confident, e.g., easily approaches others, not: signs of nervousness, such as restless movements of head/arms/legs, ticking/clicking with pen. SITUATIONS, QUOTES, AND OTHER COMMENTARY	1 2 3 4 5
Is ***not*** off-hand or hasty, e.g., does not talk at high speed and/or with a lack of silences, does not neglect questions. SITUATIONS, QUOTES, AND OTHER COMMENTARY	1 2 3 4 5
Spends time on social talk, e.g., discusses or asks about issues not related to the goal of the Embryolab, in light of fostering relations, e.g., participants' background/interests, energy status, schedule for the day, etc. SITUATIONS, QUOTES, AND OTHER COMMENTARY	1 2 3 4 5

1 = Never/Seldom 2 = Rarely 3 = Sometimes 4 = Regularly 5 = Often/Always

The analysis in our study was primarily conducted by the first author, with occasional contributions from the second author, particularly aimed at testing assumptions and exploring potential data interpretations.

In the initial phase, interview transcripts underwent repeated examination by the first author, followed by the generation of initial codes using a predominantly inductive analytical approach in the second phase. Furthermore, deductive coding was employed to ensure that initial coding contributed to the formation of themes relevant to the research question. Subsequently, in the third phase, codes were organized under candidate themes, and an initial thematic map was devised, which underwent discussion with the second author in several meetings. During the fourth phase, codes were refined and enhanced as necessary, and the initial thematic map was further developed. This iterative process led to the characterization of three overarching themes, which were subsequently deliberated upon with all authors. In the fifth phase, these overarching themes were elaborated upon and subdivided into associated subthemes, with relevant quotations being gathered. Finally, in the sixth phase, during the report writing process, definitive names were assigned to themes and subthemes, and a selection of the most informative quotes was made.

RESULTS

We characterized three overarching themes recurrent throughout our entire dataset, representing learning processes across the three different dimensions of listening competency as described in 'Listening' section (i.e., cognition, behavior, and affect). We will elaborate on our approach to constructing our analysis in accordance with the three-dimensional model of communicative competency. Subsequently, we will engage in a detailed discussion of each theme, presented in separate paragraphs.

During the initial review of the interview transcripts, we identified two overarching patterns in students' accounts of their engagement with the ALOS during the acquisition of active listening. The first pattern concerned the utilization of the ALOS for enhancing knowledge and comprehension of active listening principles. The second pattern involved the application of the ALOS in the practice of active listening behaviors. In addition, this phase of analysis yielded a diverse collection of codes delineating students' discussions regarding active listening within the context of dialogue, which served as the overarching purpose of the Embryolab. Particularly, we scrutinized how active listening influenced the dynamics of dialogue, for example in terms of fostering depth of conversation. Subsequently, we identified a relatively deeper underlying pattern inherent in these codes, suggesting the involvement of the ALOS in students' development in terms of active listening affect (i.e., fostering a willingness to listen). At this juncture, we realized that the students' experiences with the ALOS potentially contributed to learning across all three dimensions of listening competency. In the first identified pattern – the ALOS in relation to the development of knowledge and comprehension of active listening – we recognized the cognitive dimension: understanding how to listen. In the subsequent pattern – the ALOS in relation to the practice of active listening behaviors – we recognized the behavioral dimension: implementing listening behaviors. We constructed three themes, consistent with the three dimensions of listening competency. Subsequently, we will elaborate on each of these themes, elucidating related subthemes.

Theme 1: The ALOS enhances active listening cognition

In reviewing their personal development regarding active listening competency throughout the course, all participants indicated to have experienced a gradual increase in awareness of the essence and potential impact of active listening in interpersonal communication. This points to an enhancement in active listening cognition. We identified two overarching mechanisms through which the ALOS appears to have enhanced this development, which will be explained in two related subthemes below.

Recognizing active listening as a multifaceted skill with multiple, specific behaviors

Firstly, a frequently reported learning outcome regarding active listening involved the development of a nuanced understanding of its components. As articulated by respondent 10 (R10), '*well, that [active listening] is more than just nodding yes.'* The utilization of the ALOS helped students to appreciate active listening as a multifaceted skill with multiple, specific behavioral components, as illustrated by the expressions of R5 and R3 below:

> '*…because all the time you see those things on [the ALOS] you think oh yeah, that is also part of it [of active listening].' [R5]*

> '*Which various aspects are important for good listening [….]. And that they can all be broken down into little separate things that you can pay attention to'. [R3]*

Furthermore, many participants reported that the ALOS had helped them in discerning the specific behaviors they could engage in to actively listen themselves. For example, R5 commented:

> *'Yes, mainly, it made me aware of how, say, specifically what you can do to […] listen actively.' [R5]*

Similarly, R2 explains how the ALOS facilitated their understanding of the item '*listens attentively*'; delineating how it is translated into tangible behavior:

> *'…by linking a word to it […]: notices nonverbal signals, or encourages […], then you are more aware of oh this is how I listen attentively.' [R2]*

Actively observing peers with the help of the ALOS and witnessing their demonstration of active listening behaviors was regarded as the most effective method for fostering learning in this regard. Numerous participants underscored the informative nature of witnessing instances of proficient (or deficient) execution of items outlined in the ALOS:

> '*…by observing others and then kind of writing down how they're doing on the base of the ALOS, […] I think we were able to learn a lot from each other that way by just witnessing good examples of things described in the ALOS.' [R7]*

Indeed, seeing active listening drawn up within the ALOS, including peer observation guided by the ALOS, facilitated students' comprehension of the multifaceted essence of active listening, both in conceptual understanding and practical application. This approach enabled them to identify the specific behaviors integral to active listening as a skill and to recognize the particular behaviors they could engage in to actively listen themselves.

Recognizing multiple, specific active listening functions

Secondly, various segments within the transcripts, dispersed throughout and spanning across interviews, indicated that students had developed (more) insight into the function(s) of active listening. Moreover, most students demonstrated substantial diversity and/or specificity in this regard. For instance, R1 described experiencing that the ALOS items *'listens attentively'* and *'creates an open and safe atmosphere'* can encourage high-school students to engage in the conversation, as they perceived being genuinely heard. More specifically, R2 recalled that the example behavior ‘paraphrasing’ within the item *‘listens attentively’* had proven beneficial in assessing mutual understanding:

> *‘That paraphrasing, for instance, that was also very useful for us because then the high- school student could indicate whether we understood them correctly and if not, they could explain further.’ [R2]*

Moreover, R6 recalled that the item *‘using exploring questions’* had contributed to balancing conversation and fostering deeper reflection on the topic at hand, thus making them less one-sided:

> *‘I found that exploring questions let them think more thorough about their answer. I often had that high-school students were very biased at first […], and then I said: what if the situation were like that, and, what if it [a genetic condition] ran in your family, for example. And then I got the impression that you could bring new insights to them, so that they were like oh you can look at it that way too. So there were really different angles in the conversation and, because of that, it just turned into a more extensive conversation, with more discussion points.’ [R6]*

Therefore, through the practical application of active listening and experiencing its effects within conversation, students gained insight into the specific functions of individual and/or combined active listening behaviors. Although not explicitly mentioned, the ALOS seems to have played a supportive role in this regard, which is twofold. Firstly, by incorporating the ALOS into the (peer) observation process, participants were compelled to concentrate on various specific behaviors, facilitating the identification of specific effects within the conversation. Secondly, using the ALOS as a guide to train active listening skills compelled students to address numerous distinct, specific behaviors and thereby once more experiencing specific effects. This process may have fostered students’ understanding of the functions of individual items and/or example behaviors, as well as their grasp of active listening as a comprehensive skill.

In summary, seeing active listening drawn up within the ALOS and observing peers guided by the ALOS enhanced students’ active listening cognition. This specifically pertained to knowledge and understanding of which behaviors constitute active listening, their translation into actual behavior, and their specific functions.

Theme 2: The ALOS enhances enactment of active listening behaviors

Amongst participants, there was a notable consensus that active listening skills are most effectively acquired through practical application, namely, through experiential learning. Generally, participants attributed the highest value to the combination of 1) actively practicing active listening skills, and 2) receiving subsequent feedback. Some participants mentioned the act of observing peers and providing feedback to them as comparably or even more effective in enhancing their own performance. For example, R7 indicated to have learned a lot by just observing peers, analyzing their actions, and concurrently identifying areas for improvement or alternative approaches:

> ‘*You have that list in front of you and you're closely paying attention, how does someone do it, and where should it improve, where should it be different. And the moment you start observing that with someone else, you will automatically do better yourself, I think, because it's just, those things are now in your head and you've seen other people do good things, and then you automatically take it over.' [R7]*

Therefore, the practical application of active listening skills coupled with receiving feedback based on observations, alongside the practice of observing peers and offering them feedback, were recognized as important ways for acquiring active listening skills. Upon closer examination of personal learning experiences, it became evident that the ALOS had provided students with additional support, further enhancing these learning methods. We identified three positive effects of the ALOS, each contributing to the optimization of the deliberate character of students' experiential learning concerning active listening.

Setting specific learning objectives

During the Embryolab sessions, students were instructed to focus on two or three personal learning objectives per session, with at least one pertaining to active listening. In sharing their experience of working with the ALOS, we found that it played a substantial role in aiding students in selecting and delineating their active listening learning objectives. Almost all students mentioned that they had utilized the ALOS as a source of inspiration and/or a guidance to formulate their personal active listening learning objectives. Additionally, the ALOS was considered very helpful in deconstructing active listening into separate, tangible aspects, and operationalizing these aspects into specific behaviors for which students could establish specific learning objectives. For example, R3 mentioned experiencing challenges in formulating specific and measurable (SMART) learning objectives, and acknowledged benefiting from the example behaviors listed in the ALOS:

> *‘Like for me, let's say I wasn't very good at formulating SMART, […] while here, within those headings, it's already a bit more obvious, it’s already divided into examples’ [R3]*

As mentioned in section 2.1, an important condition for effective deliberate practice is that the task or practice activity possesses a defined performance goal. The development of clearer performance goals can go hand in hand with setting specific learning objectives. For instance, R10 reported focusing on the ALOS item *‘creates an open and safe atmosphere.’* By deciding to operationalize this aspect of active listening, along with a general performance goal, into the more specific example behavior *‘allowing to fully express,’* they established a more precise performance goal for themselves:

> ‘*It was pretty clear like, ok I want to achieve this, for example […] that the high-school students feel safe, that there is a safe atmosphere in the classroom. And then it read several points, allows to fully express, welcomes every contribution, avoids unnecessary interventions […]. And then it was very easy to just say like ok, now I’m going to, for example, pay attention to, specifically, that I give high-school students more time to express. And by that thus, create a safe atmosphere.’ [R10]*

Therefore, by helping students to set more specific active listening learning objectives, the ALOS had played a role in fostering the development of clearer performance goals. This, in turn, enhanced the deliberate practice of aspects of active listening encapsulated within these learning objectives.

Identifying areas for improvement

From the interviews, it was gleaned that a prevalent method for observing peers involved primarily concentrating on those items of the ALOS that were part of one or more of the observed individual's learning objectives. Nevertheless, many students mentioned their efforts to also record noteworthy observations, often of a negative nature, regarding ALOS items not related to the given learning objectives. Consequently, the ALOS had served as a screening tool to identify areas for improvement within active listening. Frequently, this guided students in their choice of generating new learning objectives. A good example of this is R1, who mentioned receiving valuable feedback on their facial expressions that they otherwise would have missed:

> *'So, for example, what was shocking for me is that I had never paid attention to my facial expressions at all […] because I thought well that's going well, [...] I found out anyway ow, actually I don't do that at all. So to me that was a positive thing.' [R1]*

Generally, deliberate practice focusses on those aspects of performance (e.g., skills, or skill components) in which a learner demonstrates deficiency, thereby aiming to improve overall performance (Ericsson et al., 2007). By using the ALOS as a screening tool, students identified areas in which their active listening performance was lacking. Consequently, they were able to concentrate their deliberate practice on those aspects requiring the most improvement, thereby enhancing their active listening competency comprehensively.

Making observation and feedback specific

For deliberate practice to be successful, it is essential that a learner receives constructive feedback. In our course, feedback consisted of both written observations and/or quotes, and feedback discussions. During the interviews, students mentioned a few characteristics of the ALOS that were indicative of its supportive role in the observation and feedback processes. For example, R1 indicated that the ALOS had facilitated structure in feedback discussions. Moreover, R6 remarked that the prompt accompanying each ALOS item to record example situations and quotes assisted in documenting such information effectively. Furthermore, R9 indicated that the scores assigned to each ALOS item had given them insight into their learning progression over time. Yet, one particular feature of the ALOS stood out distinctly in this regard. Nearly all students mentioned the significant benefits they derived from the example behaviors listed with each ALOS item. Mostly, these example behaviors helped students to focus their observations and feedback, thereby enhancing specificity. For example, R4 indicated that certain ALOS items were rather abstract, but that the example behaviors listed with these items provide helpful guidance to focus attention and be specific in feedback:

> *'The ALOS obviously gives a nice guideline to give feedback. […] For instance regarding the first one: uses inviting body language, that is very*

open. But as an extension of that it lists a whole lot of examples such as raising eyebrows, smiling and support. So then you can pay very specific attention to those things and write down situations in which someone can do better' [R4]

Furthermore, R9 explained how the example behaviors enable one to distinguish between different aspects of the same ALOS item, which enhanced feedback specificity:

'[…] very clear examples are included, which automatically makes for that feedback to become a bit more concrete. Because it is very easy to say, for example, well you did this well, but you could have focused a little more on this specific part. So I think that the ALOS helps a lot with that, that it more easily, more automatically, makes [feedback] a little more specific.' [R9]

Generally, feedback specificity is positively associated with feedback informativeness (Scheeler et al., 2004). Therefore, the ALOS can be said to have enhanced feedback informativeness, consequently aiding in optimizing the deliberate practice of active listening skills.

In summary, the ALOS enhanced enacting active listening behaviors by optimizing deliberate practice of active listening skills in three key ways. Firstly, it facilitated the establishment of more specific learning objectives, which in turn aided in developing clear performance goals. Secondly, it served as a screening tool to concentrate deliberate practice on aspects of active listening requiring the most improvement. Lastly, the inclusion of example behavior in the ALOS helped to make observation and feedback more specific, resulting in greater informativeness.

Theme 3: The ALOS enhances active listening affect

An important question we had, independent of the significance of the ALOS, pertained to whether students perceived value in prioritizing training for listening skills. Although we had anticipated a moderate level of comprehension, the insights gleaned from the interviews exceeded our expectations. Students unanimously conveyed genuine motivation to enhance their active listening skills. An important reason for this positive affect seemed to be that they had recognized active listening as key in fostering meaningful dialogue. We will elaborate on this aspect further in the corresponding subtheme below, including how the ALOS seemed to have bolstered this perception.

Recognizing active listening as key in fostering meaningful dialogue

For most students, the Embryolab marked their inaugural foray into engaging in dialogue with individuals outside their peer group about biomedical subjects and their associated socio-ethical implications. Many students commented that prior to this experience, they harbored reservations about their proficiency. However, they found solace in the framework of active listening, specifically in its application as delineated within the ALOS, offering them guidance on how to navigate the dialogue. For example, R4 described active listening as a “good guide” for steering a dialogue effectively:

> *‘I think [active listening] makes students more aware of how to properly, say, run a dialogue. I think it is a good guideline.’ [R4]*

Therefore, through their engagement in dialogue with high-school students aided by active listening and the ALOS, students honed their skills. As elucidated in theme 1, the utilization of the ALOS both for refining their own active listening abilities and for peer observation compelled participants to address or scrutinize various specific behaviors, facilitating the identification of their impact on the conversation. Consequently, as their overall active listening competency improved progressively, students likely gained insight into how active listening can positively shape the trajectory of a dialogue. Broadly, we discerned four effects of active listening, which will be delineated further below.

Firstly, certain students noted that active listening empowered them to transition away from merely providing information and instead foster bidirectional communication. For instance, R1 mentioned that focusing on active listening helped to truly engage in listening, thus preventing them to approach the Embryolab as an educational activity:

> *‘I think that the function of active listening in the Embryolab is really about consciously creating a dialogue with the high-school students. And in that way not teaching, but engaging in a conversation with them about the topic. And that active listening is very important in that, because otherwise it will still become teaching. Since, consciously putting effort in listening to someone else, this will make that you do indeed listen.’ [R1]*

Similarly, R8 emphasized that focusing on active listening had stimulated them to overcome their tendency to simply disseminate information and, instead, adopt a receptive stance conducive to learning:

> *'That you listen carefully to what the high-school students say, and from there, that you can ask further questions or, just hear properly. That you refrain from, say, throwing out all sorts of information yourself. That you also, from that information, take things in yourself, and then be able to proceed from there. Or just, recording that information and then it ends, so to speak, that it is of use to you.' [R8]*

A second effect reported by students resulting from practicing aspects of active listening was its ability to encourage high-school students to participate in the conversation. Particularly, the ALOS item *'creates an open and safe atmosphere'* was highlighted for its role in fostering this participation (see also theme 1). For example, R2 explained that simply by conveying an atmosphere where all ideas could be freely expressed, high-school students were already more inclined to participate:

> *'…that you just really let on like, everything can be said here, and that kind of thing, that was important. Because the moment we said you can say anything, and feel free to respond to each other and things, and don't hold back, then we also noticed that the conversation ran more smoothly.' [R2]*

Similarly, R6 recalled experiencing that creating a comfortable environment for high-school students often empowered them to express their opinions, even when they differed from those of their peers:

> *'Often, I noticed that high-school students followed each other in their opinion, or maybe just had the same, really the same opinion […]. But by stimulating them, and putting everyone at ease, I think more of them dared to share their own opinion. And also, dared to step away from the opinion of the popular students that contributed anyway, things like that, so that you involve everyone.' [R6]*

A third frequently mentioned effect of practicing active listening was the perceived ability to deepen conversations. By prioritizing listening, students found themselves more engaged and capable of asking insightful follow-up questions, thus fostering deeper reflections on the discussed topics. As recalled by R6:

> ‘*You listen, so you can respond meaningful to it, so that you also, on the spot, can think of questions that truly relate to the answer [...]. So I think it is actually to go deep.’ [R6]*

Similarly, R5 indicated:

> ‘*So, through active listening, that you know what high-school students think. Finding out their opinion actually. By listening, but also by properly stimulating them to think it through. [...] That you can thus really find out that opinion. That you listen like, ok what is it you think exactly, and then discover the deeper ground of it.’ [R5]*

Finally, some students conveyed the idea that active listening served as a tool for building relationships. For instance, R9 noted that high-school students showed more enthusiasm when they felt genuinely listened to. Similarly, R10 suggested that active listening could empower individuals to feel more engaged with a topic and encouraged them to voice their opinions:

> *‘That you feel involved. And that you think, yes, my opinion is important too. A lot of people, I think, feel a bit as if they are powerless in what's going to happen for the future. And what you also hear now: “Well why should I vote, because it's just one of so many votes?” [...]. And you break through that by actually saying: “Hey, I want to listen to your opinion. I think it's important what you think.” Then people will start to think about it.’ [R10]*

In summary, throughout their deliberate experiential learning facilitated by the ALOS, students acknowledged the pivotal role of active listening in fostering meaningful dialogue. Within our course, students found that active listening facilitated their transition away from a purely informative role, encouraged dialogue partners to actively contribute, deepened conversations, and fostered stronger relationships. Collectively, these experiences resulted in an enhanced motivation to engage in active listening within the context of our course.

Conditions for optimal ALOS use

While our findings indicate the beneficial role of the ALOS in learning active listening skills, participants in our study also highlighted certain constraints associated with the instrument. Firstly, many students emphasized the comprehensiveness of the ALOS. Attempting to focus on all 14 items simultaneously proved challenging, if not impractical, and consequently impacted the quality of observation. Secondly, students noted overlap between items. In certain cases, this made it challenging to discriminate between them when recording observations. Additionally, some participants highlighted a lack of clarity in certain ALOS items. For instance, they found it difficult to understand the criteria for defining an exploratory question within the item 'uses exploring questions.' However, as the course advanced, students developed strategies to address these limitations. For instance, as discussed in theme 2, they utilized the ALOS as a screening tool or concentrated on no more than two ALOS items and only recorded observations that were particularly notable for other items.

Moreover, numerous students underscored the importance of feedback conversations as an essential follow-up activity to address observational notes or written feedback. These conversations were deemed invaluable for not only clarifying or expanding upon written feedback but also for posing questions, discussing differing perspectives, and offering suggestions for improvement. Similarly, most students noted that the scores assigned to each item were only meaningful when accompanied by observational notes or feedback conversations.

Based on the findings outlined above, we propose two recommendations for (future) education integrating the Active Listening Observation Scale (ALOS) to facilitate the training of active listening skills through deliberate experiential learning. Firstly, to maintain student focus, it is crucial to utilize the ALOS either as a screening tool to pinpoint areas requiring improvement or to focus on observing no more than two items simultaneously. Secondly, while the ALOS can serve as a tool for assessing behavior through scoring, we strongly recommend integrating observational notes and feedback conversations as essential components for monitoring and guiding the development of active listening skills.

DISCUSSION

This study demonstrates the effectiveness of the ALOS in bolstering the development of active listening competency within the realm of science communication training. Within our training framework, we observed a positive impact of the ALOS across all three dimensions of listening competency. At the cognitive level, the ALOS facilitated students' understanding of active listening as a nuanced skill encompassing various specific behaviors and functions. Regarding behavior, the

ALOS contributed to the deliberate character of the experiential learning process. Finally, at the affective level, the ALOS aided students in recognizing active listening as a crucial skill for fostering dialogue. Before delving into the implications of our findings, it's essential to address the primary limitations of our study.

Study limitations

One primary limitation is the specificity of our investigation within a particular training context, which restricts the generalizability of our results to other settings. Additionally, our conclusions rely solely on student interviews, representing a form of self-reporting that may be subject to biases such as social desirability, potentially impacting the validity of our findings (Baldwin, 1999). Furthermore, our study's scope was limited to students' self-reflections based on ALOS observations of their peers' active listening skills. Incorporating the perspective of conversation partners would provide valuable insights. Future research could benefit from including data from ALOS-based observations conducted by high-school students themselves, thereby enriching our understanding of active listening in dialogue settings. Another limitation to consider is the dual role of the researcher as both course examiner and lecturer. Despite efforts to mitigate the influence of students' grading dependency, there remains a possibility of social desirability bias in participants' responses during the interviews. This bias could have resulted in students portraying the ALOS more positively than they might otherwise have done.

Implications and future outlook

Our study and its findings hold significance in the context of advancing science communication training programs aimed at fostering meaningful dialogue with society. Furthermore, our results offer insights to inform science communication training pedagogy. Despite the growing recognition of listening as a crucial skill in such endeavors (e.g., Baram-Tsabari & Lewenstein, 2017b; Yuan et al., 2017), there remains a paucity of understanding regarding its specific role in science-society interactions, particularly in terms of practical integration within training programs.

Dudo et al. (2021) conducted interviews with trainers of North American science communication training programs, revealing that listening is predominantly associated with challenging scientists to move away from deficit-based views of science communication, wherein it serves merely to address knowledge gaps. However, the interviewees struggled to articulate the specific relevance of effective listening within this framework. Additionally, when discussing communication outcomes, they frequently emphasized the significance of listening in fulfilling the informing role. As the authors comment, this conflicts with propagating dialogue-oriented forms of science communication (Dudo et al., 2021). Yet, it may be exactly such inconsistencies in talking and thinking about science communication that mirror the complexity of changing the culture of science communication training.

The participants in our study highlighted the role of active listening in moving beyond the traditional informing role in science communication. They described how active listening facilitated encouraging contributions from others, deepening conversations, and fostering relations. However, it remains unclear how they specifically connected these positive effects to the broader goals and aims of science communication. Future research could delve into students' beliefs regarding the components of effective science communication and how they perceive the role of active listening within this framework. In the meantime, it is crucial to ensure that students continue to recognize the significance of dialogue, including a willingness to learn, within the broader context of best practices in science communication.

Aside from that, we found it encouraging that participants associated active listening with building relationships, particularly in the context of public perceptions of power and voice (see also theme 3), which can in turn influence trust dynamics (Besley et al., 2021; McComas & Besley, 2011). In recent years, trust-related issues have garnered increasing attention in science communication research (see, e.g., Weingart & Guenther, 2016). Research in interpersonal communication has demonstrated that effective listening is linked to various positive relational outcomes, including the establishment of trust (Weger et al., 2014). Consistent with this, suggestions have been put forward in science communication training contexts to prioritize active listening as a learning objective aimed at fostering trust (Barel-Ben David & Baram-Tsabari, 2020). The findings of this study aim to encourage further exploration into the role of active listening in promoting constructive interactions between science and society, characterized by meaningful dialogue and strong relationships. As one of our participants aptly stated, 'simply beginning to listen can quickly lead to positive outcomes'.

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CHAPTER 7

General Discussion

KEY FINDINGS

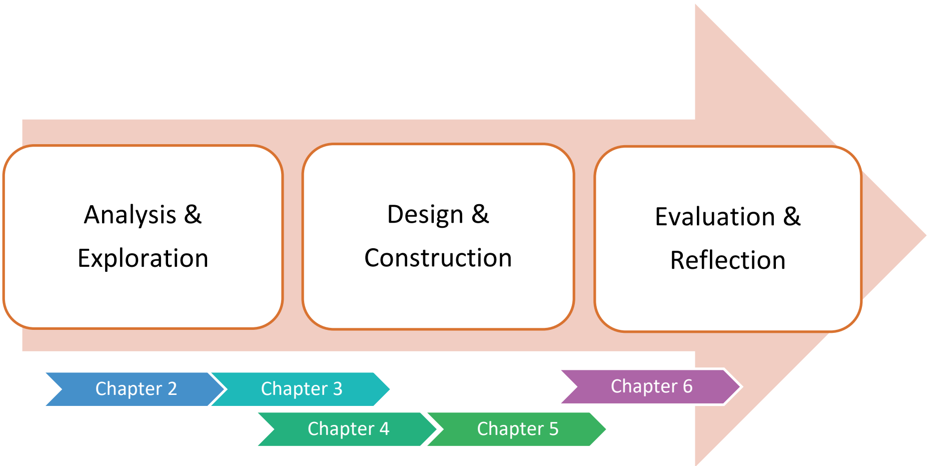
This thesis focused on the central question of **how to equip undergraduate biomedical students for meaningful dialogue with society about the socio-ethical implications of biomedical research and innovation.**

This central question was investigated by addressing three sub-questions:

1. What constitutes a constructive role for biomedical scientists in dialogue with society focused on the socio-ethical implications of biomedical research and innovation?
2. Which competencies are involved in fulfilling this role properly, and how does this match the existing competencies of undergraduate biomedical students?
3. Based on these understandings, which competencies need to be addressed in training in the context of biomedical sciences education, and how?

Below, I will look into each sub-question by combining the findings from chapters 2-6. Collectively, these chapters cover all three phases of EDR. Figure 1 presents the relationship between the chapters and EDR phases in general.

Figure 4: Overview of EDR phases and Chapters

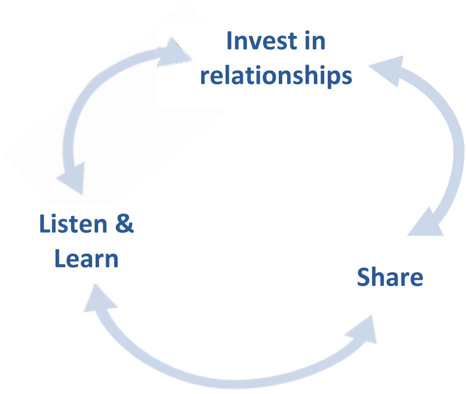


Biomedical scientists in dialogue with society: three responsibilities

The first sub-question was predominantly answered in Chapters 2 and 3. Chapter 2 offers a first reflection on how scientists could contribute to making interactions with society constructive and meaningful. I start by explaining the gap between theory and practice in public science communication. Science communication scholars have long stressed the importance of fostering equal dialogue between scientists and the public. In practice, however, most science communication continues to be restricted to the dissemination of knowledge. Scientists often approach interactions with society as educational events, wherein they perceive their role as confined to 'informing an uninformed public'. The latter is generally understood as a traditional approach to science communication, often referred to as the 'deficit model'. On the contrary, science-society interactions that seek to promote equal dialogue can be understood as a modern approach to science communication. The 'dialogue model' is presented as an example of such a modern approach. In Chapter 2, I argued that incomplete theory may be one of the reasons that the gap between theory and practice continues to exist. Overall, there appears to be a lack of clarity regarding what constitutes a constructive role for scientists in contemporary science communication. As long as this ambiguity persists, it is unlikely that scientists will expand their role beyond that of mere informers to encompass other roles and responsibilities. Based on a reflection on theoretic principles underlying the dialogue model, combined with insights on goals and objectives of modern science communication, I proposed three responsibilities or sub-roles for scientists in interaction with members of society. These are the responsibility to share tailored knowledge and insights (in short: share), the responsibility to listen and learn to the knowledge and insights of conversation partners (listen and learn), and the responsibility to invest in relationships with conversation partners (invest in relationships). While each responsibility can function in its own, they are also interlinked and presumed to mutually reinforce one another (see Figure 2). As stated in Chapter 2:

"… the third responsibility can be seen as the result of the first and second, but also as a catalyzer of both. In other words, relationships may be built in the process of sharing and listening and learning, but at the same time may foster sharing and listening and learning: this should become a self-enhancing process."

Figure 5: Responsibilities for scientists in dialogue with society



Subsequently, I explored each responsibility by interpreting them in light of a relevant and actual practice example of dialogue between science and society: the Dutch dialogue on human germline genetic modification (HGGM). At the time of writing the section that constitutes Chapter 2, this dialogue had just come to an end. Based on the findings, I provided initial recommendations for scientists how to position themselves and how to act in the context of societal dialogue about the broader implications of biomedical research and innovation. These recommendations are further discussed below.

In Chapter 3, I presented a more thorough analysis of the Dutch dialogue on HGGM which led to converting the initial recommendations into a coordinated set of prompts for behavior, each accompanied by examples of concrete actions and/or practice situations. This analysis consists of two phases. In Phase 1, I analyzed a white paper as generated by one of the organizing parties of the Dutch dialogue, containing 'ten lessons for conducting societal dialogue on HGGM'. I examined if and how each responsibility could be recognized in these lessons. Related findings led to the formulation of three prompts for behavior per responsibility, with for each possible examples of concrete behavior (see Table 1).

In Phase 2, I used the prompts and examples of concrete behavior as an observation scheme to analyze three separate dialogue sessions in practice (i.e., as conducted in the context of the Dutch dialogue). Each prompt was consolidated with at least one relevant practice situation as observed in real-life. For example, the prompt to 'Assist in stimulating in-depth dialogue' was consolidated with a practice situation in which one of the invited scientists stimulated public attendants to approach HGGM from a financial point of view:

"What if we consider HGGM as a means to reduce healthcare expenses?"

Table 1: Behavioral prompts per responsibility and examples of concrete behavior

Responsibility	Prompts and examples
SHARE	**Select knowledge relevant to the dialogue goal**
	- Prepare for a session by studying dialogue partners' backgrounds
	- Invite dialogue partners to explore what knowledge they consider relevant to the goal
	Present knowledge in a meaningful context and accessible language
	- Connect to the values, ideas and experiences of dialogue partners
	- Use techno-moral scenario's to sketch the moral impact of technologies)
	Be cautious when sharing personal considerations, such as (personal) positions
	- Refrain from acting authoritative and persuasive towards others
	- Be transparent about the reasoning behind a position or viewpoint
LISTEN & LEARN	**Consider interactions with the public as opportunities to learn**
	- Make an effort to understand different forms of knowledge and varying perspectives
	- Encourage others to say more, e.g., by asking (further) questions
	Be patient and supportive
	- Allow for moments of silence and convey non-verbal involvement
	- Actively invite others to contribute
	Assist in stimulating in-depth dialogue
	- Introduce different perspectives and viewpoints
	- Help identify and explore borderline cases
INVEST IN RELATIONSHIPS	**Assist in creating an ambiance of relevance and safety**
	- Be modest and refrain from dominating the conversation
	- Emphasize that complex issues such as HGGM can only be addressed by combining many forms of knowledge, including values and emotions
	Preserve trust
	- Balance between showing expertise and being transparent (e.g. about interests) and honest (e.g. about uncertainties in knowledge)
	- Refrain from using expertise to persuade and/or to compensate for gaps and uncertainties in knowledge
	Convey respect for all dialogue partners and every contribution
	- Display genuine curiosity and ask open questions
	- Check back at understanding

The combination of responsibilities, prompts for behavior, and concrete actions presents a model for describing the role of scientists in dialogue with members of society, and provides the answer to sub-question 1. Although the model could serve as a guide for scientists to adopt a constructive role in contemporary science-society interactions, I fully realize that it can be challenging to manifest concerning behavior. This would require new skills, as well as new ways of thinking about knowledge (i.e., they have to learn to value non-scientific forms of knowledge), both of which expose the need for training. Building on this, the model could be leveraged to guide the formulation and implementation of science communication training initiatives. For example, the behavioral prompts could translate into targeted learning goals or competencies to be incorporated within the training curriculum.

From responsibilities to competencies, to focus areas for training

Sub-question 2 was predominantly addressed in Chapters 4 and 5, while building upon Chapter 3. As a first step, the nine prompts for behavior as presented in Chapter 3 were taken to represent the core competencies for scientists in dialogue with society. To date, there is no single definition for the concept of competency. In this thesis, I have chosen to define competency as the combination of knowledge, skills and attitudes, which is a commonly used framework in the context of education. Following this, each prompt for behavior can be seen as involving three components. For instance, the prompt ‘convey respect for all dialogue partners and every contribution’ involves:

1) *knowing* how to convey respect for all dialogue partners and every contribution;
2) having the *skills* to convey respect for all dialogue partners and every contribution;
3) (e.g.) being *motivated* to convey respect for all dialogue partners and every contribution.

In Chapter 4, I investigated, amongst first-year students enrolled in the Utrecht biomedical sciences program, how they performed on the knowledge component of each competency. Specifically, I analyzed their ability to identify and name examples of concrete behavior for each behavioral prompt (or competency) in a specific context of public dialogue. The findings of this study suggest, firstly, that students experience difficulty with decomposing complex, multicomponent communicative acts into concrete behaviors. Examples include ‘respect’ and ‘listening’. Secondly, I observed that nonverbal communicative behaviors were highly underrepresented. This suggests that students either prioritize verbal communicative behavior or that they tend to overlook nonverbal aspects of communication. Both findings were combined to form a first focus area and a training recommendation to assist students with the process of comprehending complex communicative acts and operationalizing them into concrete behavior, as well as to emphasize the importance of nonverbal communication. Thirdly, it was established that students might hesitate to share personal considerations when interacting with a non-scientist public (prompt 3 within the responsibility to share), and fourthly, that some students have a rather traditional view of science communication (i.e., a view that is in conflict with the dialogue model). The latter manifested in student expressions conveying the idea that scientists are better than non-scientists, and that scientific knowledge is more worthy than non-scientific forms of knowledge. Following deeper-level analysis, it was identified that for both observations (i.e., students' hesitation to share personal consideration and students' views conflicting with the dialogue model), a parallel could be drawn with ideas about the nature of science. To elaborate, upon examining the responses provided by some of these students and the specific behaviors they articulated, we noted uniformed views regarding certain aspects of the nature of science (NOS). This led to the formulation of a second focus area, with a second training recommendation to prioritize fostering informed NOS views, while connecting to building knowledge and understanding of models of science communication. Interestingly, this second recommendation does not solely involve the knowledge component of competency but, perhaps even more so, the attitudinal component. When students develop more informed NOS views, for example, when they learn to accept science as socially and culturally embedded, or understand that science is essentially theory-driven, this may enhance their willingness to consider interactions with the general public as opportunities to learn. It may also contribute to viewing scientists and non-scientists as equal partners in dialogue, which in turn may positively affect their willingness to respect the contributions of non-scientists.

Chapter 5 offers a further exploration of biomedical students' views of NOS, specifically whether and how biomedical sciences education might (unintentionally) contribute to students developing uninformed NOS views. It presents an analysis framework to characterize implicit notions relating to NOS underlying scientific language use. These notions, referred to as 'epistemological tenets', could affect students in that they might translate them into uninformed views of NOS. Subsequently, the analysis framework and its potential to inform the development of educational interventions directed at stimulating explicit reflection on NOS is discussed. The latter is considered effective in helping students develop more informed views of NOS.

Chapters 4 and 5 mark the end of the 'Analysis and Exploration' phase. The problem is now distinctly delineated within its specific context. Furthermore, progress has been initiated in the 'Design and Construction' phase, which will be further developed in Chapter 6.

Active listening as a key competency for meaningful dialogue: towards evidence-based training

Sub-question 3 was answered partly in Chapter 3, but predominantly in Chapter 6. In the process of designing and conducting the study as presented in Chapter 3, and writing up the results, I noticed that the responsibilities to listen and learn and to invest in relationships had an important overlap with a specific form of listening, that is, ‘active listening’. In the context of interpersonal communication, active listening is generally associated with good listening. The goal of active listening is to increase understanding and to convey involvement, both of which are at the heart of the responsibility to listen and learn. Furthermore, active listening has been associated with generating trust and respect (Ferrari, 2012; Mineyama et al., 2007; Weger et al., 2014), both of which are defining aspects of the responsibility to invest in relationships. Lastly, several examples of concrete behavior as listed for the combined responsibilities (Table 1) are also known as active listening behaviors. These include, for example, asking questions, checking back on understanding, and conveying nonverbal involvement. Over the years, listening competency in the context of science communication has gained increased interest. Moreover, listening is increasingly mentioned as an important learning goal for science communication training (e.g., Baram-Tsabari & Lewenstein, 2017; Dudo et al., 2021).

In Chapter 6, I examined active listening training in the context of an undergraduate course on science communication for biomedical students. Based on the assumption that active listening is challenging to operationalize into concrete behavior and to effectively train in practice, I offered participants in the course the active listening observation scale (ALOS). The ALOS lists 14 behaviors associated with active listening. I investigated if and how the ALOS enhanced participants’ development of active listening competency. Thematic analysis of interviews conducted with ten participants suggested positive development on all three levels of listening competency: cognition, skills, and affect. The ALOS seemed to have played an enhancing role for each level. On the cognitive level, the ALOS aided in identifying active listening as a range of behaviors with various functions. On the skills level, the ALOS enhanced the enactment of active listening behaviors by improving elements of practice. Lastly, on the affective level, the ALOS assisted in recognizing active listening as key to fostering meaningful dialogue. Therefore, training active listening with the help of the ALOS offers an effective way to enhance the dialogic character of science-society interactions.

Chapter 6 starts with elements of the ‘Design and Construction’ phase but then mainly describes the ‘Evaluation and Reflection’ phase. Chapter 6 marks the end of the EDR as presented in this thesis. Based on 1) (elements of) a problem as defined in the Analysis and Exploration phase (i.e., the need for training listening competency, as well as the need to enhance this training by helping students to decompose listening into tangible behavior), 2) the development of a training intervention in accordance with the identified problem in the ‘Design and Construction’ phase, and 3) the testing of this intervention (i.e., the ALOS) in the ‘Evaluation and Reflection’ phase, it can be concluded that training active listening with the help of the ALOS provides an effective way to enhance the dialogic character of science-society interactions. From here, subsequent iterations of each phase could be carried out to further refine theoretical understandings and practical applications. Moreover, additional elements of the problem could become subject to new EDR cycles. For example, interventions targeted to NOS education in the context of science communication training could be developed and tested. Through that, it could be investigated how emphasizing NOS-related learning objectives could facilitate students’ receptivity to divergent perspectives, or their ability to make thoughtful choices about sharing personal considerations. Furthermore, additional elements of the trajectory from prompts for behavior to demonstrating adequate behavior could be investigated. For instance: how capable are students in terms of converting descriptions of concrete behavior into actual behavior in a practice setting? And how can we best support them in overcoming potential challenges? These and other possible questions, however, lie outside the scope of the current thesis.

BROADER IMPLICATIONS AND CONTRIBUTION TO THE FIELD

In this dissertation, I have looked into societal dialogue surrounding the socio-ethical implications of biomedical research and innovation as a specific realm of science communication. In the current section, I aim to shed light on how this thesis resonates within the broader domain of science communication.

At the time of writing, news of measles outbreaks in parts of the Netherlands has just surfaced, reflecting a gradual decline in vaccination rates over recent years. This has prompted daycare centres to consider implementing mandatory vaccination policies. Scientists are increasingly called upon to engage in public discourse. With the COVID-19 pandemic only just under control, a new vaccination debate may be imminent. How can the insights from this thesis guide involved scientists in navigating their roles?

Let me start by exploring the differences between science communication in the context of measles outbreaks and that in the context of biomedical research and innovation. To do so, I will draw upon a recent analysis by Priest (2018). In this work, discussing the ethical challenges of communicating controversial science, Priest argues for a distinction between democratic and strategic approaches to science communication. Within this framework, democratic science communication could be seen as aiming to foster an open and inclusive dialogue between scientists and the general public. It seeks to empower individuals to engage with scientific information, make informed decisions, and participate in scientific discourse. Strategic science communication on the other hand, focuses on achieving specific goals, often related to policy advocacy, public perception management, or influencing behavior change. It involves careful planning, targeted messaging, and persuasion. While strategic science communication may serve noble causes such as promoting public health or addressing environmental issues, ethical considerations arise regarding transparency, honesty, and the potential for unintended consequences or manipulation of public opinion (Priest, 2018). In the same work, Priest elaborates on this distinction by linking it to the factor urgency, noting that while democratic communication is typically preferred, during crises like COVID-19 or climate emergencies, strategic communication might gain acceptance due to the pressure to act quickly - which may undermine moral standards. Relating this to the context of biomedical research and innovation on the one hand, and measles outbreaks on the other, for which (only) the latter can be called urgent, it is reasonably assumed that science communication in the context of the first is democratically oriented, while the second might lean toward a strategic approach. Nonetheless, as I contend, the core principles for effective science communication are the same for both cases. Hence, the insights outlined in this dissertation could still be used to inform the measles case. I will clarify this by highlighting two aspects of the expert role as presented in this thesis.

Firstly, in the measles case, similar to the context of biomedical research and innovation, scientists should realize that providing information about the benefits of vaccination will not necessarily foster positive attitudes towards vaccination and/or increase vaccination uptake. Emphasizing facts may even backfire in terms of trust (Nyhan et al., 2014). It fails to address the diverse factors influencing decision-making in vaccination, such as personal values and religious beliefs, risking entrenching opposing views and hindering progress (e.g., Dubé et al., 2013; Smith et al., 2017). Secondly, scientists should be careful not to equate the goal of influencing behavior with outright persuasion. In this thesis, mostly in Chapter 4, I advocate for sharing personal considerations, including viewpoints and positions, yet, without adopting an authoritative tone or persuasive techniques. In the measles case, scientists merely focusing on persuasion risk undermining their ability to remain open, and to genuinely listen to divergent perspectives. Instead, when scientists acknowledge the value of learning from different forms of knowledge and various points of view, they will be more willing to engage in true dialogue. Even if parties maintain differing viewpoints, mutual understandings may increase or strengthen, paving the way for (more) collaborative problem-solving. Whilst challenging, as pointed out in Chapter 6, focusing on active listening can provide useful guidance. For instance, it prevents scientists from falling back into a deficit-based mode of communication, such as restating facts that are irrelevant to the public at hand.

Indeed, in this sense science communication in the context of measles does not truly differ from that of biomedical research and innovation. In both cases, scientist should remain reflexive to the needs of different audiences, and critical to their own aims and strategies, preventing them from ignoring essential principles of effective science communication. With that, I endorse a recent contribution of Sarah Davies (2022), emphasizing the significance of transparency, trust, and accountability in science communication, particularly during emergencies when public confidence in institutions is crucial. As she states: “Emergency situations should not, I believe, result in a wholesale switch to strategic communication that seeks to persuade and convince citizens of the views of ourselves, of scientists, or of governments. Indeed, it is likely that such an approach is counter-productive”.

In summary, the principles of effective science communication, in combination with the recommendations for scientists as outlined in this thesis, remain applicable across diverse context. Consequently, the insights provided regarding science communication training may extend beyond the specific scope of this thesis to inform the broader field of training.

CONCLUDING REMARKS

In conclusion, this thesis has addressed the pivotal question of how to prepare undergraduate biomedical students for engaging in meaningful dialogue with society regarding the socio-ethical implications of biomedical research and innovation. Through an in-depth exploration of three sub-questions, it was determined what constitutes a constructive expert role in science-society interactions, which competencies are required for fulfilling this role, and how these competencies can be addressed through training. From defining responsibilities to identifying key competencies and designing evidence-informed training interventions, each phase of the research process has contributed to a deeper understanding of the challenges and opportunities in science communication.

The findings underscore the importance of embracing a dialogic approach to science communication, characterized by equal knowledge exchange and mutual learning between scientists and society. By emphasizing the responsibilities to listen and learn and investing in relationships, scientists can foster meaningful engagement with the public. Training for related competencies should involve enhancing cognitive understanding of abstract concepts such as respect and listening as well as fostering informed views of the nature of science, particularly in the context of undergraduate science education. The Active Listening Observation Scale (ALOS) offers a practical avenue for enhancing active listening competency among biomedical students, thereby facilitating more dialogic science-society interactions. This evidence-informed approach to training highlights the significance of intentional practice and reflective learning in developing skills.

Looking beyond the specific context of biomedical research and innovation, the principles and recommendations outlined in this thesis resonate with broader challenges in science communication. Whether addressing crises like vaccination debates or navigating emerging technologies, the importance of transparency, trust, and genuine dialogue remains paramount. As such, the insights gained from this research have implications not only for biomedical education but also for advancing science communication training more broadly. However, empirical studies in different contexts are needed to validate and extend results. This should include investigating the views and experiences of members of society as partners in dialogue, alongside those of (future) scientists.

In moving forward, further research and iterative cycles of educational design study will be necessary to refine theoretical understanding and practical applications. By continuing to build upon this foundation, we can work towards fostering a more inclusive and equitable dialogue between science and society, ultimately contributing to the advancement of knowledge and the betterment of humanity.

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APPENDIX

English Summary

Nederlandse Samenvatting

Woord van dank

About the Author

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ENGLISH SUMMARY

Introduction

The rapid evolution of biomedicine and biotechnology is accompanied by increasingly complex socio-ethical dilemmas. Breakthrough discoveries such as gene modification techniques, bio-printing, and neurotechnology, while celebrated for their potential to enhance medical and health care, have raised significant concerns about their societal implications. This has led to calls for enhanced regulation of research and innovation processes, informed by comprehensive ethical reflection on possible outcomes and applications. Over the past few decades, policy initiatives such as the Ethical, Legal, and Social Implications (ELSI) framework and the Responsible Research and Innovation (RRI) framework have been established to guide this reflection, and to ensure the realization of ethically sound governance policies regarding new and emerging technologies. Essentially, these frameworks emphasize early and proactive anticipation of socio-ethical issues involved with research and innovation, for example through stakeholder engagement and stimulating public dialogue. Yet, both have proven difficult to achieve. For example, fostering meaningful science-society dialogue has been challenging due to circulating misinformation, mutual feelings of distrust, and (perceived) power imbalances. Moreover, scientists have struggled with their role when interacting with a non-scientific public, or their lack of crucial communication competencies. Both have become important areas of interest within research and practice of science communication training.

Since the early 21st century, various studies in the field of education and training have informed the development of science communication training programs. Generally, it is believed that early-stage training, integrated into undergraduate science programs, is most beneficial. Despite a growth in training initiatives in the past decades, there is little consensus about what constitutes the ‘right’ training. Research has highlighted essential competencies for science communication, such as contextualizing a message, or listening to audience concerns, and proposed comprehensive training frameworks. However, there is still little understanding which competencies contribute to establishing equitable and meaningful dialogue. Let alone which training methodologies contribute effectively to developing these competencies amongst (future) scientists.

This dissertation seeks to address these gaps by exploring effective training strategies for undergraduate biomedical students, equipping them for meaningful science-society dialogue. It investigates critical competencies for this role and how they can be taught effectively within undergraduate biomedical education. The project employs an educational design research approach (EDR), involving iterative cycles of analysis, design, and evaluation to develop practical and theoretical insights for improving science communication training.

Part 1: Biomedical scientists in dialogue with society: roles and competencies

Part 1 of this thesis addresses the frequently observed discrepancy between theoretical frameworks and the practical execution of public science communication. Historically, scientists have adhered to the "deficit model," which frames science communication as a means to restore public trust by filling knowledge gaps. Towards the end of the 20th century, the deficit model came under heavy critique, fueling the emergence of the "dialogue model." The latter emphasizes interactive dialogue and mutual learning as key elements of science communication. Despite widespread calls for change, this transition in communication models has been challenging to implement in practice. Against this background, **Chapter 2** proposes three responsibilities for scientists that help them align with the dialogue model's principles in contemporary science-society interactions:

1. **Share Tailored Knowledge and Insights**: Scientists should offer knowledge that is relevant to the public's needs and context, ensuring that it is understandable and applicable.
2. **Listen and Learn**: Scientists should listen to and learn from the public's knowledge and perspectives, recognizing the value of non-scientific forms of knowledge.
3. **Invest in Relationships**: Scientists should build and maintain relationships with public conversation partners to foster ongoing, meaningful dialogue between science and society.

These responsibilities are designed to be mutually reinforcing. For example, by sharing relevant knowledge and conscious listening, scientists can build stronger relationships. This in turn, should enhance their ability to select relevant knowledge and to practice open, non-judgmental listening. **Chapter 2** also reflects on a real-life case of science-society dialogue: the Dutch dialogue on human germline genetic modification (HGGM). It offers initial recommendations for scientists how to implement each responsibility in practice.

In **Chapter 3**, a thorough analysis of the Dutch HGGM dialogue is presented, involving text analysis of dialogue guiding principles and real-life observations of expert behavior. In phase 1, the initial recommendations per responsibility are translated into concrete behavioral prompts: three for each responsibility. For the responsibility to share these are to select expert knowledge that is relevant to the goal; to present expert knowledge in a meaningful and accessible language; and to be cautious in sharing personal considerations. For the responsibility to listen and learn these are to consider interactions with members of the public as opportunities to learn; to be patient and supportive; and to assist in stimulating in-depth dialogue. Lastly, for the responsibility to invest in relationships these are to assist in creating an ambiance of safety and relevance; to preserve trust; and to convey respect for all contributions and every point of view. These prompts are further consolidated in phase 2 using observational data, which identifies example actions from dialogue sessions that align with these prompts. The combined framework of responsibilities, prompts for behavior, and concrete actions is discussed for its potential to guide scientists in contemporary interactions with society, particularly in dialogues on biomedical socio-scientific issues.

Part 2: Designing and testing science communication training for biomedical science students

In part 2, the focus shifts to education and training of science communication. **Chapter 4** explores focus areas for science communication training in the context of biomedical science education, specifically training directed at developing competencies associated with the dialogue model. A key question is: which of these competencies are most challenging for biomedical students to learn to apply in practice? To investigate this, first-year students are asked to engage in a thought experiment, assuming the role of an expert scientist in a public dialogue. Using the framework of responsibilities and behavioral prompts outlined in Part 1, students are tasked to formulate examples of concrete communicative behavior for each of the nine prompts. Thematic analysis of 121 student responses leads to the identification of two primary focus areas for training: 1) helping students to operationalize complex communicative acts, such as respect and listening, into concrete verbal and non-verbal behavior, and 2) prioritizing fostering informed views of the nature of science (NOS) when addressing understanding of models of science communication.

Together, these insights contribute to improving students' receptivity to the dialogue model's principles and enhance their ability to apply these in practice.

Chapter 5 builds on this by exploring how biomedical education influences students' views of the nature of science. It presents a framework for analyzing implicit NOS notions in scientific language (referred to as "epistemological tenets"). These tenets might (unintentionally) contribute to the development of uninformed NOS views among students. The chapter suggests educational interventions that could foster explicit reflection on NOS, helping students develop more informed views and adhere to the dialogue model when engaging in science-society dialogue.

Lastly, **Chapter 6** examines training interventions for developing active listening competency. Active listening, which enhances understanding and conveys involvement, is crucial for fulfilling the responsibilities to listen and learn and invest in relationships. This chapter investigates the potential of the Active Listening Observation Scale (ALOS) to enhance active listening training. The ALOS is implemented in a science communication training course for third-year biomedical students. In this course, that is based on a combination of experiential learning and deliberate practice, students engage in group dialogues with high-school students while focusing on active listening. Thematic analysis of interviews conducted with participants to the course suggests that using the ALOS leads to positive developments on all three dimensions of active listening competency: cognition, skills, and affect. The ALOS helped students to identify and practice active listening behaviors, to recognize their importance, and to improve the quality of dialogue. These findings highlight the importance of active listening in overcoming the deficit model and fostering genuine dialogue between scientists and the public.

Conclusion and Discussion

Chapter 7 summarizes the key findings concerning the thesis' central question *how to equip undergraduate biomedical students for meaningful science-society dialogue about the implications of biomedical research and innovation?* Structured around the three sub questions it reiterates and reflects upon the full chain of studies with associated findings: from defining roles and responsibilities (sub question 1), to identifying key competencies and focus areas for training (sub questions 1 and 2), to designing and testing evidence-informed training interventions (sub question 3). Recurring themes include the importance of understanding dialogic science communication, the critical role of active listening, and helping future scientists internalize and manifest relevant behavior.

In discussing the broader implications of this thesis, the findings and conclusions are interpreted in light of recent measles outbreaks in the Netherlands as an entirely different science communication context. While biomedical research and innovation is relatively stable, the measles case can be seen as a crisis necessitating urgent action. This may require alternative communication strategies. However, as **Chapter 7** concludes, the principles and recommendations outlined in this thesis are thought to remain applicable across contexts, from vaccination debates to emerging technologies. Effective science communication always requires reflexivity toward audience needs and critical reflection on communication approaches. It is precisely through fostering meaningful interactions with (diverse groups in) society that scientists can contribute most optimally to advancing knowledge and societal well-being.

NEDERLANDSE SAMENVATTING

Inleiding

De snelle ontwikkelingen in de geneeskunde en biotechnologie gaan gepaard met steeds complexere sociaal-ethische dilemma's. Baanbrekende ontdekkingen op het gebied van DNA-modificatie, bio-printing en neurotechnologie worden weliswaar geprezen vanwege hun potentieel om de gezondheidszorg te verbeteren, maar vragen tegelijkertijd om voorzichtigheid vanwege maatschappelijke gevolgen. Dit leidt onder andere tot een steeds luidere roep tot het aanscherpen van de regulering van onderzoeks- en innovatieprocessen, bij voorkeur gestuurd door brede ethische reflectie op mogelijke uitkomsten en toepassingen.

In de afgelopen decennia zijn diverse beleidsinitiatieven geïntroduceerd om ethische reflectie te bevorderen en daarmee de ontwikkeling van verantwoord bestuursbeleid te ondersteunen. Voorbeelden hiervan zijn het Ethical, Legal, and Social Implications (ELSI) kader en het Responsible Research and Innovation (RRI) raamwerk. Beide initiatieven onderschrijven het belang van vroege signalering van sociaal-ethische vraagstukken rondom nieuwe en opkomende technologieën, in combinatie met proactieve anticipatie. Bijvoorbeeld door het betrekken van stakeholders en via het stimuleren van publieke dialoog. In de praktijk blijken beide echter een uitdaging. Het creëren van een betekenisvolle dialoog tussen wetenschap en samenleving wordt bijvoorbeeld bemoeilijkt door de verspreiding van desinformatie, en ondervindt hinder van (vermeende) machtsongelijkheid en/of gevoelens van wantrouwen ten opzichte van de wetenschap. Daarnaast blijken wetenschappers onvoldoende bekend met hun rol in ontmoetingen met de samenleving en/of ontberen zij cruciale communicatieve vaardigheden. Voornoemde belemmeringen zijn stuk voor stuk belangrijke aandachtsgebieden binnen het veld van de wetenschapscommunicatie, zowel in onderzoek als in training.

Sinds het begin van de 21e eeuw wordt veel onderzoek gedaan naar onderwijs en training van wetenschapscommunicatie, met als doel diverse trainingsprogramma's te ontwikkelen en te evalueren. In het algemeen wordt aangenomen dat vroege training, bij voorkeur als integraal onderdeel van de opleidingsfase, het meest effectief is. Ondanks een groei in het aantal trainingsinitiatieven in de afgelopen decennia bestaat er tot op heden geen eenduidig beeld van wat geldt als de 'juiste' training. Onderzoek heeft zogenoemde essentiële competenties vastgesteld, zoals het contextualiseren van kennis, of het luisteren naar de zorgen en wensen van de maatschappij. Daarnaast heeft onderzoek geleid tot aanbevelingen voor het ontwerpen van trainingsprogramma's. Het blijft echter onduidelijk welke competenties daadwerkelijk bijdragen aan het tot stand brengen van een gelijkwaardige dialoog. Laat staan welke trainingsmethoden effectief bijdragen aan de ontwikkeling van deze competenties bij (toekomstige) wetenschappers.

Dit proefschrift beoogt de bestaande kennislacunes te verkleinen door trainingsstrategieën te onderzoeken welke bachelorstudenten biomedische wetenschappen kunnen helpen een betekenisvolle dialoog met de samenleving te voeren. Achtereenvolgens wordt onderzocht welke competenties studenten hiervoor nodig hebben en hoe zij deze effectief kunnen aanleren binnen de bachelor biomedische wetenschappen. Het onderzoek is gebaseerd op belangrijke principes van educational design research (EDR). EDR wordt gekenmerkt door zich herhalende cycli van analyse, ontwerp en evaluatie. Deze iteratieve aanpak levert zowel praktische als theoretische inzichten ten behoeve van onderwijs en training op het gebied van wetenschapscommunicatie.

Deel 1: Biomedische wetenschappers in dialoog met de samenleving: rollen en competenties

Deel 1 van dit proefschrift richt zich op de veel voorkomende discrepantie tussen theoretische kaders en de praktische uitvoering van wetenschapscommunicatie. Van oudsher zijn wetenschappers gewend te opereren volgens het zogenoemde 'deficit model'. Dit model richt zich primair op het overdragen van kennis en beschouwt wetenschapscommunicatie voornamelijk als middel om het vertrouwen in de wetenschap te behouden of te vergroten. Tegen het einde van de twintigste eeuw raakte het deficit model onderhevig aan zware kritiek, hetgeen heeft geleid tot de opkomst van het nieuwe 'dialogue model' (hierna: dialoogmodel). Het dialoogmodel benadrukt het belang van een wederkerige dialoog tussen wetenschap en samenleving, waarin beide partijen van en met elkaar leren. Toch blijkt het in de praktijk moeilijk om dit model ten uitvoer te brengen. Tegen deze achtergrond worden in **Hoofdstuk 2** drie verantwoordelijkheden voorgesteld die wetenschappers moeten helpen om in lijn met het dialoogmodel te handelen:

A

1. **Deel kennis en inzichten op maat**: Wetenschappers moeten relevante kennis delen, passend bij de behoeften en context van publieke gesprekspartners, en ervoor zorgen dat deze begrijpelijk en toepasbaar is.

2. **Luister en leer**: Wetenschappers moeten luisteren naar en leren van de kennis en perspectieven van publieke gesprekspartners, en zodoende de waarde van niet-wetenschappelijke vormen van kennis erkennen.

3. **Investeer in relaties**: Wetenschappers moeten investeren in hun relatie met de samenleving. Een goede relatie is cruciaal voor het voeren van een voortdurende, betekenisvolle dialoog.

De drie verantwoordelijkheden versterken elkaar onderling. Bijvoorbeeld: door gerichte kennis te delen en actief te luisteren, kunnen wetenschappers diepere relaties opbouwen, wat hen helpt effectiever relevante kennis te selecteren en op een open, niet-oordelende manier te luisteren. Om deze verantwoordelijkheden verder te concretiseren staat in **Hoofdstuk 2** de Nederlandse DNA-dialoog als praktijkvoorbeeld centraal. Deze dialoog onderzoekt hoe de Nederlandse samenleving denkt over kiembaanmodificatie (het aanbrengen van genetische veranderingen die aan het nageslacht worden doorgegeven). Door reflectie op de rol van wetenschappers in deze dialoog worden aanbevelingen gedaan op welke manier de voorgestelde verantwoordelijkheden in de praktijk kunnen worden geïmplementeerd.

In **Hoofdstuk 3** wordt een meer grondige analyse van de DNA-dialoog gepresenteerd, welke bestaat uit tekstanalyse van richtlijnen voor het voeren van een goede dialoog en praktijkobservaties van wetenschappers betrokken bij een of meer dialoogsessies. In fase 1 worden de aanbevelingen uit **Hoofdstuk 2** vertaald naar concrete aanwijzingen voor gedrag; voor elke verantwoordelijkheid drie. Voor de verantwoordelijkheid om kennis en inzichten op maat te delen betreft dit het selecteren van kennis die aansluit bij het doel, het aanbieden van deze kennis in betekenisvolle en begrijpelijke taal, en het voorzichtig omgaan met het delen van persoonlijke overwegingen. Voor de verantwoordelijkheid om te luisteren en te leren bevatten de aanwijzingen: de interactie zien als kans om te leren van het publiek; geduld te betrachten en ondersteunend te zijn in het gesprek; en helpen de dialoog te verdiepen. Ten slotte, voor de verantwoordelijkheid om te investeren in relaties betreft dit het waarborgen van een veilige omgeving en het creëren van een gevoel van relevantie, het kweken en behouden van vertrouwen, en het overbrengen van respect voor iedere bijdrage en elk standpunt. In fase 2 worden alle negen aanwijzingen voor gedrag onderbouwd met praktijkvoorbeelden van gedrag zoals waargenomen in een of meer dialoogsessies. Het complete raamwerk van verantwoordelijkheden, aanwijzingen voor gedrag en concreet voorbeeldgedrag is bedoeld om wetenschappers te begeleiden in hun interacties met de samenleving, met name interacties in het kader van sociaal-ethische vraagstukken rondom biomedisch onderzoek en biomedische innovatie.

Deel 2: Ontwerpen en testen van training in wetenschaps-communicatie voor studenten biomedische wetenschappen

In deel 2 verschuift de focus naar onderwijs en training in wetenschaps-communicatie. **Hoofdstuk 4** verkent aandachtsgebieden voor wetenschaps-communicatietraining in de context van biomedisch onderwijs, met name training gericht op competenties die verband houden met het dialoogmodel. Een belangrijke vraag daarbij is: welke van deze competenties vinden studenten biomedische wetenschappen relatief moeilijk om aan te leren en toe te passen in de praktijk? Om deze vraag te onderzoeken worden eerstejaarsstudenten gevraagd om deel te nemen aan een gedachte-experiment, waarin zij de rol aannemen van een wetenschapper in een publieke dialoog. Vervolgens krijgen zij de opdracht om vanuit dit perspectief, bij elk van de verantwoordelijkheden en gedragsaanwijzingen zoals geschetst in Deel 1, voorbeelden van concreet communicatief gedrag te formuleren. Thematische analyse van de antwoorden van 121 studenten leidt vervolgens tot de identificatie van twee primaire aandachtsgebieden voor training, te weten: het ondersteunen van studenten bij het operationaliseren van complexe communicatieve handelingen - zoals respect overbrengen en luisteren - in concreet verbaal en non-verbaal gedrag, en het combineren van begrip van interactiemodellen binnen de wetenschaps-communicatie met onderwijs gericht op het vormen van geïnformeerde ideeën over de aard van wetenschap. Deze aanbevelingen helpen studenten om belangrijke aspecten van het dialoogmodel beter te begrijpen en ze effectiever toe te passen in de praktijk.

Hoofdstuk 5 bouwt hierop voort door te verkennen welke invloed biomedisch onderwijs heeft op het vormen van ideeën over de aard van wetenschap onder studenten. Het presenteert een raamwerk voor het identificeren en analyseren van zogenoemde ‘epistemological tenets’: noties over de aard van wetenschap welke impliciet aanwezig zijn in wetenschappelijke taal en teksten. Deze epistemological tenets kunnen (onbedoeld) bijdragen aan het ontwikkelen van relatief slecht geïnformeerde ideeën over de aard van wetenschap. In Hoofdstuk 5 worden tevens onderwijsinterventies besproken die expliciete reflectie op ideeën over de aard van wetenschap stimuleren, waarbij het epistemological tenets raamwerk een rol zou kunnen spelen. Zo worden studenten aangemoedigd om beter geïnformeerde ideeën over de aard van wetenschap te ontwikkelen en het dialoogmodel toe te passen in hun interacties met de samenleving.

Ten slotte wordt in **Hoofdstuk 6** een trainingsinterventie ontwikkeld en onderzocht voor het aanleren van de competentie actief luisteren. Actief luisteren bevordert begrip ten aanzien van de ander en brengt betrokkenheid over. Beide aspecten zijn essentieel om te kunnen luisteren, leren en investeren in relaties. Dit hoofdstuk onderzoekt de Active Listening Observation Scale (ALOS) als mogelijk hulpmiddel om het trainen van actief luisteren te versterken. Het beschrijft de implementatie en het testen van de ALOS binnen een cursus wetenschapscommunicatie voor derdejaars studenten biomedische wetenschappen. In deze cursus, gestoeld op principes van ervaringsleren en ‘deliberate practice’, voeren studenten groeps-dialogen met middelbare scholieren, waarbij de nadruk ligt op de competentie actief luisteren. Thematische analyse van interviews met deelnemers aan de cursus wijst op een positief effect van de ALOS op alle drie de dimensies van actief luisteren: cognitie, vaardigheden en attitude. Zo helpt de ALOS studenten met het herkennen en oefenen van de verschillende gedragingen die betrokken zijn bij actief luisteren, met het erkennen van het belang van actief luisteren, en met het verhogen van de kwaliteit van hun dialoogsessies. Deze resultaten benadrukken de rol van actief luisteren in het faciliteren van een gelijkwaardige dialoog tussen wetenschap en samenleving, en daarmee in het ontstijgen van het deficit model.

Conclusie en discussie

Hoofdstuk 7 vat de belangrijkste bevindingen samen met betrekking tot de centrale vraag van dit proefschrift: *hoe kunnen studenten biomedische wetenschappen worden toegerust voor het voeren van een betekenisvolle dialoog tussen wetenschap en samenleving over implicaties van biomedisch onderzoek en biomedische innovatie?* Gegroepeerd rond de drie deelvragen wordt de complete keten van onderzoeken met bijbehorende bevindingen herhaald en beschouwd: van het definiëren van rollen en verantwoordelijkheden (deelvraag 1), tot het identificeren van sleutelcompetenties en aandachtsgebieden voor training (deelvragen 1 en 2), tot het ontwerpen en testen van evidence-informed trainingsinterventies (deelvraag 3). Terugkerende thema's in elke fase betreffen het belang van kennis en begrip van de belangrijkste kenmerken van wetenschapscommunicatie volgens het dialoogmodel, de cruciale rol van actief luisteren, en de noodzaak tot ondersteuning van (toekomstige) wetenschappers bij het leren begrijpen en toepassen van hiermee samenhangend gedrag.

Bij het bespreken van de bredere implicaties van dit proefschrift wordt getracht de bevindingen en conclusies te interpreteren in het licht van een geheel andere wetenschapscommunicatie context: de recente uitbraken van de mazelen in Nederland. In tegenstelling tot de relatief stabiele aard van wetenschapscommunicatie rondom biomedisch onderzoek en biomedische innovatie, kunnen mazelenuitbraken worden gezien als een crisissituatie, hetgeen directe actie vereist en een andere communicatiestrategie. Desondanks, zo concludeert **Hoofdstuk 7**, zijn de principes en aanbevelingen beschreven in dit proefschrift toepasbaar op uiteenlopende contexten van wetenschapscommunicatie; van vaccinatiedebatten tot innovatieve technologieën. Effectieve wetenschapscommunicatie vereist voortdurende reflectie op de behoeften van verschillende doelgroepen en kritische evaluatie van de gekozen aanpak. Juist door het aangaan van betekenisvolle interacties met (diverse groepen in) de samenleving kunnen wetenschappers optimaal bijdragen aan kennisontwikkeling en maatschappelijk welzijn.

About the author

Born in Lochem, the Netherlands, in 1977, Cathelijne M. Reincke has cultivated a diverse and enriching career rooted in the intersection of health sciences, education, and science communication. Her academic journey began at Maastricht University, where she pursued Health Sciences with a dual specialization in Biological Health and Movement Sciences. Her time as a research intern in New Zealand helped hone her research skills and international perspective on health sciences. Graduating in 2002, she embarked on her first professional role as a research assistant at Maastricht University Medical Center's Department of Human Biology. This early experience provided her with a strong foundation in scientific research and inquiry.

In 2003 Cathelijne relocated to Utrecht where, two years later, she started a PhD program at the Department of Clinical Neurophysiology at University Medical Center Utrecht (UMCU). Despite an unfortunate premature end to her PhD due to personal circumstances, she remained resilient and returned to the UMCU in 2008. This time, she found her niche in the field of education, joining the Centre for Education and Training. Over the next few years, Cathelijne held various roles in educational affairs, education policy, and teaching in Medicine and Biomedical Sciences.

In 2017, Cathelijne started as a lecturer and examiner for the Biomedical Sciences course "Communicating through the DNA Lab." It was in this role that she discovered a deep passion for science communication and societal dialogue. Cathelijne became dedicated to exploring how interactions between science and society could become more equitable and meaningful. In 2019, she further formalized this interest by starting a PhD program focusing on training strategies for equipping biomedical sciences students to engage in science-society dialogue about biomedical research and innovation.

In her current role as a lecturer and researcher at UMCU, Cathelijne continues to teach and guide students in the biomedical sciences program. She is particularly passionate about experimenting with new educational methods and strategies that foster students' listening competency and perspective taking skills.

Woord van dank

Dit proefschrift gaat niet alleen over dialoog; het is ook het resultaat van dialoog. Veelvuldige dialoog, soms kort dan weer lang, met veel verschillende gespreks-partners. Van naasten – mijn partner, familie, vrienden en vriendinnen – tot collega's – waaronder de Oog voor Impact onderzoeksgroep, het BMW-team, en de LSER-community. Graag wil ik aan jullie allemaal mijn oprechte dank uitspreken. Voor alle tijd, betrokkenheid, ideeën, en expertise. Jullie hebben mij keer op keer geïnspireerd, gesteund, en geholpen me verder te ontwikkelen.

Een speciaal woord van dank wil ik doen toekomen aan Wim Dictus en Gönül Dilaver – de voormalige, respectievelijk huidige opleidingsdirecteur van de bachelor biomedische wetenschappen – voor het mogelijk maken van dit PhD traject en voor het in mij gestelde vertrouwen. Ook wil ik apart mijn dank uitspreken aan Anne-Wil, voor de inspirerende samenwerking bij het ontwikkelen en implementeren van het Embryolab, en aan Elianne, voor de talrijke overlegsessies, het altijd kritisch meedenken, en de zeer waardevolle feedback.

Tenslotte wil ik mij richten tot de drie hoofdpersonen van de dialoog rondom dit proefschrift: Annelies, Annelien en Marc. Annelies, we hebben nauw samengewerkt op verschillende studies en artikelen. Ik heb ontzettend veel geleerd van onze sparsessies en van je veelomvattende kennis. Het was fijn om te ontdekken dat we een passie delen voor diepgravende analyses. Heel veel dank voor je trouwe betrokkenheid in elke fase; bij uitdaging en bij succes. Annelien, ik heb diepe bewondering voor de manier waarop je jouw rol als promotor hebt voortgezet na je vertrek bij het UMCU. Ondanks je overvolle agenda, en op het laatst zelfs een dubbele positie als rector magnificus en bestuursvoorzitter van de Erasmus Universiteit Rotterdam, wist je altijd snel en zeer opbouwend te reageren op mijn vragen en teksten. Ik ben je daar zeer dankbaar voor, net als voor je vertrouwen in mijn capaciteiten en keuzes. Marc, vanaf het begin heb je mij alle vrijheid en vertrouwen gegeven bij het vinden en verdiepen van mijn onderzoeksfocus. Achteraf gezien is dit het meest leerzame aspect geweest van mijn gehele PhD traject. Ik wil je hiervoor ten zeerste bedanken, evenals voor je altijd inspirerende begeleiding, je expertise in en toewijding aan onderwijs(onderzoek), en je steun in moeilijke tijden.

Cathelijne, Utrecht, 2024

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LSER dissertation list

1. De Jong, L.H. (Lubberta). Unraveling programmatic assessment: Issues of Validity in highstakes decision-making. *06-09-2022.*

2. Kurysheva, A. (Anastasia). Admissions to graduate studies: Selection methods for life and natural sciences masters' programs at a European research university. *15-11-2022.*

3. Vermond-Engel, D. (Debbie). Towards learning healthcare systems: Collaboration and boundary crossing in research and practice. *02-02-2023.*

4. Van Dijk, E.E. (Esther). Teacher Expertise of Academics in Research-Intensive Universities: A Task-Based Approach. *02-06-2023.*

5. Eijkelboom, M.C.L. (Charlotte). Learning from Patients: Understanding student experiences with patient involvement in medical education. *13-09-2023.*

6. Kools, F.R.W. (Farah). Navigating Translational Medicine in Academia: How Can Translational Scientists Be Rewarded and Supported in Their Careers? *23-04-2024.*

7. Schellekens, L.H. (Lonneke). Assessment to support student learning in higher education. From theory to practice. *04-09-2024.*

8. Reincke, C.M. (Cathelijne). Equipping biomedical students for science-society dialogue. Exploring competencies and training strategies. *15-11-2024.*

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