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SCIENCE COMMUNICATION IN HIGHER EDUCATION:
GLOBAL PERSPECTIVES ON THE TEACHING
OF SCIENCE COMMUNICATION

Integrating sustainability into a higher education science communication course

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Abstract

The global problems we face call for universities to prioritise science communication education and training. Here, we describe how we integrated sustainability into a master-level course in science communication through three iterations. By retrospectively analysing our actions and reflections, we demonstrate how and why we progressed from education about sustainability to education for sustainability, and finally education as sustainability. We conclude by discussing our findings, and offering our implications for the teaching and learning of sustainability science communication and of science communication.

Keywords

Professionalism, professional development and teaching in science communication; Science communication teaching

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Introduction

Recent decades have seen an increased focus on the development of science communication competencies among faculty and students in higher education institutions [Massarani, Reynoso-Haynes, Murriello & Castillo, 2016; Mulder, Longnecker & Davis, 2008; Trench et al., 2014]. Today, many universities offer science communication programs and courses at the bachelor or master levels in addition to professional development courses for academic and administrative staff [Arvidson et al., 2022; Fähnrich, 2020]. These initiatives represent a diverse range of approaches, foci of attention, and intended outcomes [cf. Costa et al., 2019; Gascoigne & Schiele, 2020]. However, given that humanity is facing a number of increasingly urgent challenges related to the unsustainable exploitation of the earth's resources, we focus here on sustainability science communication, namely, science communication that places sustainability-related problems on the public agenda [Fischer et al., 2016]. This kind of communication seeks to support participants in developing a critical awareness of the relationship between humans and the natural world as well as which actions to take to help mitigate the problems in that relationship [Godemann & Michelsen, 2011]. We thus see sustainability science communication as a subset of science communication, but as

the following sections will demonstrate, it is distinct from science communication in important ways.

Public concern about the wicked sustainability problems we face has put pressure on universities to respond by acting on the problems and by shaping the societal response to them [Latter & Capstick, 2021]. This pressure may manifest itself both in terms of top-down, management-driven initiatives, and bottom-up, student and staff-driven initiatives. At the University of Copenhagen, which is the context for the present study, both kinds of drivers are present. On the one hand, the University's 2017–2023 strategy document states that "the University has a responsibility to contribute to resolving the major societal challenges as defined, for example, in the UN Sustainable Development Goals" [University of Copenhagen, 2017, p. 19]; this intention was subsequently translated into a letter that encouraged the University's Departments to implement sustainability in their courses and study programmes — but stopped short of providing what Scott [2015] describes as a conceptually grounded vision of what that implementation might look like. On the other hand, higher education students across Denmark made urgent calls for a "green curriculum" [Büchert & Rybak, 2019; Larsen, 2019], and demanded climate action from the universities [Rasmussen, 2018]. Driven by this spirited encouragement as well as our own worries about the world, we decided to critically revise an existing master level science communication course to focus on sustainability.

We faced a number of challenges. Much literature on how to re-purpose higher education for sustainability tends to focus on pedagogy rather than content; in other words, it does not address the crucial relation between sustainability education and sustainability science [Mochizuki & Yarime, 2016]. And while today, there are a few studies of how researchers communicate sustainability science [Brüggemann, Lörcher & Walter, 2020; Nicolaisen, 2022], these studies were not yet published when we decided to undertake the work of revising the course, meaning that we had neither theoretical nor empirical models of what sustainability science communication might entail.

Accordingly, we took a point of departure in the close relationship between research and teaching that characterizes much university teaching in general, and the University of Copenhagen's teaching in particular. This relationship is referred to as the teaching-research nexus [see e.g., Madsen & Winsløw, 2009], and encompasses a range of ways in which teaching and research can relate to each other [Coate, Barnett & Williams, 2001]. We thus oriented ourselves in research on sustainability science in order to understand the knowledge, values and practices that define it, and subsequently "translate" that knowledge and those values and practices to our teaching of sustainability science communication. We were particularly inspired by the work of Joachim Spangenberg [2011] who contrasts well-established normal science with post-normal science of sustainability (Table 1), thereby providing important implications for sustainability science communication.

In this text, we describe and explore three different materializations of sustainability science communication in a master level course at the University of Copenhagen. The three materializations represent sequential iterations of the course, and exemplify three different approaches to integrating science

Table 1. Features of established science and science of sustainability. After Spangenberg [2011].

Established science	Science of sustainability
Normal science	Post-normal science
Mode-1	Mode-2
Monodisciplinary	Inter- and transdisciplinary
Academic	Academic and social
Academic peers	Extended peer community
Hierarchical logic	Relational logic
Stakeholders affected	Stakeholders involved

communication and sustainability. Through our analysis of the three iterations, we point out the challenges and opportunities in sustainability science communication education that we encountered in our teaching-research nexus. We conclude by discussing the implications of our findings for teaching sustainability science communication, and more generally, for teaching science communication in higher education institutions.

Methodology

The notion of the teaching-research nexus not only guided our iterative development of the course, it also framed the inquiry into the development that we describe in the following. Because Spangenberg describes the science of sustainability as a part of critical theory that is "reflective on the process of theorizing itself" [2011, p. 279], we apply that same critical approach to our analysis of the course. On the one hand this requires us to interrogate our own objectivity as observers and more generally question the neutrality of science [cf. Treagust, Won & Duit, 2014]. On the other hand, even as we acknowledge the cultural, social, institutional (etc.) contextuality of science and knowledge production, this does not mean that we consider all knowledge to be equally valid in all contexts. In particular, we describe the iterative changes made to the course through a diversity of perspectives (the course leader, the teachers, the students, the course description), using the interaction between these accounts as a way to strive for epistemological balance following Pitard's [2015] layered vignette analysis.

Layered vignette analysis, introduced by Pitard in science education research, has the advantage of helping to reveal multiple layers of awareness. These different layers, Pitard [2015] explains, add to the richness of the analysis by transitioning between the personal and the academic reflexive voice. However, where Pitard [2015] works with a circular framework placed in phenomenological autoethnography, we have incorporated a recursive approach (Figure 1) where we revisit the elements of the framework in our three iterations. In each recursion, we uncover contexts, thoughts, actions and occurrences that guided the subsequent iteration of the course and that demonstrate the reflexivity and theoretical influences behind these materialisations. Similar to Pitard's [2015] approach, we use vignettes as the foundation of our analysis. Although vignettes have been documented as useful in research for decades [Giovannoni & Becerra, 1979], their definition remains contested. Spalding and Philips describe vignettes as writings "based on simulations of real events from which to collect data" [2007, p. 954], and

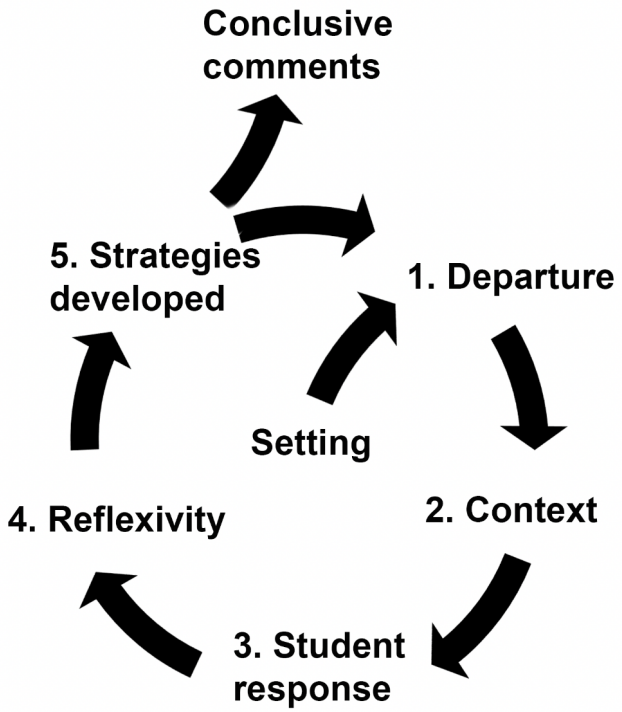

Figure 1. The recursive framework we use to analyse the iterative development of the course. The analysis consists of three circuits through the elements numbered 1–5, beginning with "Setting" and ending with "Conclusive comments". Framework inspired by Pitard [2015].

Atzmüller and Steiner call them "a short, carefully constructed description of a person, object, or situation, representing a systematic combination of characteristics" [2010, p. 128]. Vignettes have also been described as fictional scenarios [Jenkins, Bloor, Fischer, Berney & Neale, 2010; Poulou, 2001], simulations of real events [Wilks, 2004; Wilson & While, 1998], real-life stories [Barter & Renold, 2000], and as researcher-generated, anecdotal data [Pitard, 2015]. Our definition leans towards Pitard's [2015], namely a means to "return the researcher to the conditions before [any final] reflection" by recalling a pre-reflective moment.

In addition to vignettes, our recursive framework includes brief descriptions of context, student evaluations, and reflections. These elements draw on the available data sources as listed in Table 2. We begin by describing the course as it is defined administratively on the course web page, clarifying the defined workload for the students, describing the structure of the classes, etc. ("Setting"). We then move through five different elements in each iteration in order to uncover different, complementary perspectives on our efforts to integrate sustainability in the course (Figure 1). The five elements are arranged sequentially, beginning with an autoethnographic vignette written by the course leader and main teacher, describing the inner drivers behind her decision to revise the course ("1. Departure"). This is followed by a description of context of the course ("2. Context"), detailing the external elements affecting the course, such as the pedagogy employed, the contributing (and changing) teaching staff, or major occurrences (such as the COVID-19 pandemic). The third element ("3. Student Response") is an analysis of the student evaluations of the course. These

evaluations include written and oral feedback to the teaching staff halfway through the course, and a written survey with both open and closed questions at the end of the course (see appendix A for further details). The fourth element ("4. Reflexivity") is distinct from Pitard's approach. Where she describes her reflexivity layer in terms of a thoughtful examination of her contributions to the development of the relationship between her students and herself [Pitard, 2015], we use this step to present the reflections that led the course leader to consider new revisions for the course, including inspirational conversations or literature that prompted these reflections. Finally, the fifth element of the framework ("5. Strategies Developed") details how the course leader's (and teachers') reflections were translated onto new strategies for the subsequent iteration of the course.

Table 2. Data sources for the analysis, and the elements of the framework in which we use them. Please see appendix A for details about the evaluations used to collect students' responses.

Data source	Element of framework
Official course description (on university website)	Setting, Context
Official course evaluations from students, questionnaire (multiple choice and open-ended questions)	Student Response
"Halfway" evaluations from students, done in class (modified Delphi method)	Student Response
Course leader's final evaluation memo, based on student evaluations, teaching team reflections, and exam results	Departure, Reflexivity, Strategies Developed
Course leader's and teachers' reflections during and after course	Departure, Reflexivity, Strategies Developed

Following upon the first iteration, the subsequent iteration is described in a similar way, beginning with a new autoethnographic summary of the thoughts and emotions that prompted the revision. We then provide an updated description of the context of the course, and continue to go through the five elements for the second and third iterations of the course.

As a final element, we look back on the three iterations collectively to draw out conclusions and discuss our findings ("Conclusive Comments"). This element corresponds to what Pitard calls "conclusive comments on layers", and draws together the different layers to summarise the effects of her experience and how it prompted her to further develop her understanding [Pitard, 2015]. We follow this approach, but additionally draw on relevant literature to qualify and nuance our experiences of the three iterations.

Analysis

In the following, the three iterations of the course are described using the headings outlined in the methodology section and Figure 1.

Setting

The course Science Communication is a ten-week elective course offered for all graduate students at the Faculty of Science, University of Copenhagen. The first

seven weeks of the course are structured in seven themes. Each theme is introduced and discussed in the weekly interactive lecture (3 hrs), which concludes with the handing-over of the week's thematic assignment to the students. The subsequent weekly exercise class (6 hrs) is dedicated to the students' work on the written assignment. Students work in interdisciplinary groups (3–5 people) to respond to the assignment, and the teacher is present to offer clarification or advice as needed. Each group hands in its response to the assignment at the end of the week, and receives formative feedback during the following week.

The thematic assignments consist of three or four sub questions that progress from the fundamental levels of Bloom's revised taxonomy, i.e. comprehension and application, to the advanced levels, i.e. analysis, evaluation and creation [cf. Anderson, Krathwohl & Bloom, 2001]. The sub questions are related to ideas and concepts from the course material and lectures, but are not directly addressed by the teaching in the course. Accordingly, each thematic assignment is intended to structure students' independent group work with a given subset of course content. At the same time, the seven thematic assignments collectively parse the course content into interrelated, yet internally coherent units.

The course workload corresponds to 206 hours or $7\frac{1}{2}$ ECTS (European Credit Transfer and Accumulation System) points. Annually, about 20 students from across the natural sciences follow the course, including students from biology, physics, chemistry, geology, geography, landscape architecture, mathematics, computer science, nature management, climate change and other study programmes. The course readings include research articles and textbook chapters, but also other materials, such as examples of science communication podcasts, videos, exhibitions, etc. The course is concluded in the ninth week by a 20-minute oral examination based on one of the seven thematic assignments.

Having thus established the general setting for the course, what follows is the first autoethnographic vignette describing the course leader and main teacher's reflections about the first iteration of the course. This vignette is followed by the subsequent elements of the analysis, as set out in the methodology section and Figure 1.

First iteration: 1) departure

Around 2018, I had become so worried about the Danish government's lack of response to the problems caused by climate change and the growing biodiversity crisis that I considered leaving academia and becoming an activist. Eventually, I decided I could make a bigger difference from my privileged platform as a tenured staff member by promoting sustainability in higher education. I thus decided to reorient my research and teaching on science communication towards sustainability. I didn't know exactly what this entailed, and I couldn't find much literature to guide myself and the group of colleagues that volunteered to help me. It was clear I had to experiment with different approaches. However, I felt validated in my move towards sustainability by the pressing nature of the problems, and by the many recent demands, in a variety of media, from Danish university students for climate and sustainability related content. I thus believed the initiatives we would take, with respect to content and pedagogy, would be welcomed (MA, course leader).

First iteration: 2) context

The first iteration of the course (November 2019–January 2020) was developed by the course leader in dialogue with four colleagues from the Department, and was an attempt to infuse sustainability-related content and pedagogy into the course. While previous versions of the course had let the groups decide on the scientific content to be communicated in the thematic assignments (often based on their study programmes), the first iteration of the course required the groups to choose one of four content areas to work with throughout the course. These content areas corresponded to UN Sustainable Development Goals (SDGs) #7 Affordable and Clean Energy, #11 Sustainable Cities and Communities, #12 Responsible Consumption and Production, and #13 Climate Action. These goals were selected among all 17 SDGs because they were interdisciplinary; they were thus intended to prompt "mutual understanding of epistemologies and ontologies" [Spangenberg, 2011, p. 278] across the disciplines represented in the groups.

With respect to pedagogy, previous versions of the course were aligned with the University's principles for student-centred and research-based teaching. This included taking problem-based approaches to teaching, using real-world problems, and employing collaborative learning approaches (e.g., group work). These pedagogical principles are in accordance with approaches advocated by sustainability education scholars [cf. Brundiers, Wiek & Redman, 2010; Waas et al., 2012], and the first iteration of the course simply continued using those approaches. For instance, one of the weekly themes for the first iteration of the course was "communication with policy-makers". This theme entailed a visit from professionals from the European Environment Agency, who in that week's lecture discussed their real-world problem of providing members of the EU Commission with succinct briefings. That week's thematic assignment asked the students to author a one-page policy briefing on their chosen SDG to be given to a minister on their way to an EU meeting.

The first iteration of the course was taught by the course leader (MA), who was responsible for planning and delivering the interactive lectures and formulating the thematic assignments. She was joined by a co-teacher (MO), a newly graduated master student who had taken the course previously, and who was to guide and advise the students' group work on the assignments, as well as give formative feedback on the students' written products.

First iteration: 3) student response

The course is usually very well-liked and highly evaluated, but this iteration of the course received somewhat lukewarm feedback from the students. Having to work with a specific SDG in the course proved to be challenging, and while the students found the focus on sustainability relevant, they also pointed out its limitations and constraints. For example, one student commented that in the long run, it became "a bit tiring, and sometimes forced, to have to think about sustainability in the weekly assignments". Other students, however, seemed to recognize the value of working with concrete sustainability goals and applying them in complex contexts. As one student noted; "It was really nice to work with the highly contemporary topic of sustainability through real climate goals, and try to integrate it into different

contexts". Several students thereby mention the theme of sustainability, mostly critically, but few students seem happy about the focus on sustainability.

One thing the students seemed to agree on was the importance of incorporating practical problem-solving techniques into the curriculum. Both groups of students — those advocating for as well as those advocating against the implementation of the SDGs in the weekly assignments — took this stand, and several students stated that they needed help linking their academic knowledge to real world problems. None of them seemed to relate practical problem-solving with the SDGs.

One student also expressed difficulties in incorporating their specific field of science into the course, claiming that their discipline was very different from the others, and difficult to involve in the weekly assignments with the SDGs. Unfortunately, we do not know which field this student came from, but it is interesting to note that the student perceived the difficulty relating to the SDGs to be due to their discipline, and not their own approach to the subject. Finally, a student said they were missing input from other disciplines, suggesting that it would have helped if an engineer had joined them.

About half of the students (53%, n=19) responded to the final evaluation survey. When asked whether they found the course useful, one student (5%) disagreed, four students (21%) neither agreed nor disagreed, three students (16%) agreed, and two students (11%) strongly agreed.

First iteration: 4) reflexivity

Initially, I had felt the need to redesign the course to focus on sustainability was legitimate and even self-explanatory, given the demands from students across Denmark. Accordingly, I simply presented the students with examples of these demands in the first lecture, and didn't think I needed to provide more of an explanation. However, the idea of sustainability didn't seem to resonate that much with them. I got the clear impression that some of them would have preferred to work with content from their own study programmes, and found the SDGs constraining. I was dismayed by the lower-than-usual ratings from the students in the course evaluation.

Certainly, using the four SDGs as the scientific content in the course was challenging at times. Although I was able to replace many of the previous cases and problems with new sustainability-related ones, this wasn't always feasible. One example was the theme about museum exhibitions. In the thematic assignment, students were asked to select an exhibition at the Natural History Museum of Denmark and analyse how it presented content related to "their" sustainability goal. This became an awkward exercise, because none of the exhibitions explicitly dealt with sustainability, and students struggled to respond to the assignment in a meaningful way. Difficulties such as these may also have hindered the group work; at least, I observed more disagreements than usual in the groups during the course.

It was clear that forcing students to work with content they couldn't relate to their study programmes was not a good way of implementing sustainability in the

course, and that I had to find a different approach. In retrospect, I realized I had fallen into the trap of "telling it" rather than "showing it", and thus failed to create the conditions for the students' intrinsic motivation to guide their engagement with the content. Further, because my preparation for the first iteration of the course had identified mainly pedagogical rather than content-related strategies for sustainability teaching, I already knew that moving forward, I wouldn't find published examples of content suited for the course.

On a more positive note; using real-world problems in the course worked very well. Although this was not a new initiative, the themes that involved science communication professionals and their daily experiences and challenges were very engaging to the students. The themes that authentically combined sustainability content with real-world problems were perhaps those that were best received by the students (MA, course leader).

First iteration: 5) strategies developed

To prepare for the second iteration of the course, the course leader revisited the Theory of Didactical Situations (TDS). TDS holds that learners cannot learn the "why" of a skill or an object of knowledge simply by way of teacher authority. In other words, understanding why (and how) science communication should engage with sustainability problems requires a personal conviction and internalisation which by definition cannot be transferred from others without losing its value [cf. Brousseau, 2002]. Rather, this conviction and internalisation should come from learners' independent problem analysis and solution development.

In response, the course leader began to research how science itself was responding to the demands of sustainability [as described, e.g., by Spangenberg, 2011; Funtowicz & Ravetz, 1993; Dürr, Dahm & zur Lippe, 2005] in an attempt to find examples of content and problems to use to promote engagement and buy-in. In other words, instead of forcing students to work with content that was a priori defined as sustainability-related (i.e., the SDGs), the next iteration of the course was to let the students experience which kinds of scientific and communicative approaches are called for by the sustainability problems we face, and generate responses as a reaction to that experience.

Second iteration: 1) departure

I was excited to try the new content and cases I had developed, because I felt they were much more in alignment with how I wanted to teach. I was also a bit apprehensive because I wanted the ratings of the course to go back up, and wondered whether the new content would help achieve this.

I was determined to keep sustainability as the focus of the course, but the experiences from the year before prompted me to introduce sustainability in more subtle ways, for instance by talking about specific climate or biodiversity problems we face rather than, for instance, the SDGs. I still planned to mention sustainability in my opening lecture, however, and kept the SDG logo on all my slides. The week on communication with policy-makers stayed, and I added a theme on post-truth as well, despite struggling to find suitable materials for the lesson. This time,

I wanted the students to get the skills they needed to address wicked sustainability problems, but without force-feeding them my perspective (MA, course leader).

Second iteration: 2) context

The second iteration of the course (November 2020–January 2021) was developed in dialogue with three of the four colleagues that contributed to the first iteration, and additionally, the first author (SVS) who had at this point joined the course as a part-time lecturer. In this iteration, we discontinued the mandatory focus on the SDGs, and went back to letting students draw on content from their own study programmes. In addition, we identified a number of key problems from news and social media that could be used for students' problem-based development of sustainability science communication skills, and that also helped students acknowledge the value and utility of developing those skills.

For instance, reading Funtowicz and Ravetz [1993] focused our thinking on post normal science where "facts are uncertain, values in dispute, stakes high and decisions urgent" (p. 744). The ongoing COVID-19 pandemic provided a pertinent and topical example of post normal science, and thus, one of the new problems we developed for the course was based on a televised press briefing on the Danish authorities' response to the COVID-19 pandemic [TV AVISEN Ekstra, 2020]. In this briefing, a person posing as a journalist confronted the authorities with what seemed to be evidence that the SARS-COV-2 virus did not exist. We wanted to use this case as a starting point for letting the students experiment with different positions (as science sceptic and/or confronted expert). After the role play, we would discuss the different ways of responding to post-truth claims in science communication, hoping the experience would leave the students with a more nuanced perspective on the problem.

Another example is based on Spangenberg's [2011] emphasis on the importance of the extended peer community in sustainability science. Citizens, policy-makers, and other interested/affected parties all contribute to the scientific process in this vision of sustainability science, and this seemed to be an important practice to include from a communications perspective. Citizen science seemed to be a pertinent case for this, and while it was already established as a theme in the course, for the second iteration we emphasized the co-creative, participatory aspects of citizen science. In particular, we wanted students to reflect on the potentially democratic and emancipatory consequences citizen science can have for non-scientist participants [cf. Wals & Peters, 2017].

The second iteration of the course was taught by the course leader, who was responsible for delivering most of the lectures and formulating the thematic assignments. Lectures were also prepared and delivered by the first author (SVS) and two other teachers (a PhD Fellow, HE, and another part-time lecturer, TI). The latter (TI) additionally guided the students' group work and provided them with formative feedback on their products. Also worth mentioning is that the COVID-19 pandemic caused all teaching to be converted to online formats about halfway through the course. By this point in the pandemic, however, the students and teachers were all familiar with the online teaching. Fewer students than usual signed up for the course, which was probably a reaction to the pandemic and the Danish government's strategy of isolation at home.

Second iteration: 3) student response

In the second iteration, student evaluations returned to the previous high level of satisfaction with the course. The students especially praised the course for teaching valuable and practical knowledge on science communication in the evaluations. The course was also commended for allowing the students to be creative in their science communication. For instance, one student mentioned the role play activity as an "eye-opener", while another enjoyed the chance to design their own citizen science project. The chosen themes were generally seen as interesting and relevant, and the students even expressed vexation over missing a week, and thereby a theme, due to illness (in fact, COVID-19) among the teaching staff. The incorporation of relevant guest lecturers and the use of varied teaching methods were also appreciated by the students.

A majority of the students (73%, n=11) answered the final evaluation survey. When asked whether the students found the course useful, one student (9%) agreed and seven students (64%) strongly agreed. While these responses seem to collectively point to a successful revision of the course, it is worth noting that one student who was otherwise very happy with the course ended by asking: "Whatever happened to the sustainability content in the course? Where did it go?"

Second iteration: 4) reflexivity

The second iteration of the course felt like a marked improvement on the first iteration — at least in terms of students' ratings and feedback. Further, I experienced none of the resistance from the students that characterised the first iteration; on the contrary, the approach of letting students develop their own responses to the presented problems and cases (based on the Theory of Didactical Situations) seemed to prompt the intrinsic motivation I had hoped for. I felt that I had succeeded in building sustainability into the course without forcing it upon the students… but perhaps I had succeeded too well? It seems that the sustainability content had become transparent to the students, whose only mention of it in the course evaluation was to wonder what had become of it. Eventually, I had to ask myself whether I could honestly claim to have taught a course about sustainability science communication if the sustainability content was so implicit that it disappeared? (MA, course leader)

Second iteration: 5) strategies developed

Due to the success of the second iteration of the course, we first didn't want to make major alterations or adjustments. However, when the first author was employed as a postdoctoral researcher at the department, with corresponding free research time, we (first and second authors) took the opportunity to continue our study of research literature about sustainability science communication. In this study process, we encountered texts that emphasized arts-based approaches to communicating about climate change and other wicked sustainability problems, and these approaches resonated with us because they seemed to help explain what had worked in the second iteration of the course.

We were inspired by Heinrichs' epistemological argument for prompting evocation in sustainability science communication through arts-based methods [Heinrichs,

2018], and Moser's points about what communication of and for "transformative changes" might entail [Moser, 2019, p. 141]. These texts in particular gave us important perspectives on the effectiveness of the second iteration's more experimental themes and exercises. For instance, although we were happy with the role play exercise in the second iteration because it prompted students to develop their own justifications for using dialogic and participatory modes of science communication, our reading about arts-based methods, and specifically performance, as a form of knowledge production [Leavy, 2014] qualified our understanding of its outcomes and how to better facilitate the exercise.

Around the same time, the University of Copenhagen offered a number of small grants (DKK 50.000, about € 6.700) for integrating climate and sustainability challenges in study programmes and courses. We decided to take the opportunity to further develop the course by applying for one of the grants to experiment with arts-based ways of integrating sustainability in science communication. We were lucky enough to be awarded a grant, which allowed us to employ a part-time research assistant to observe the third iteration of the course and carry out interviews with the participants. This meant that we were able to further integrate our teaching and research, taking fuller advantage of the teaching-research nexus.

Third iteration: 1) departure

This was by far the most work I had ever put into a course — and I felt excited to do so. I felt creative and innovative when working on our approach, and it felt great to have more people help develop the course. While colleagues had provided input on the first and second iteration, it was a very different experience to have a group around me dedicated to designing the arts-based experiments for the third iteration.

Because the arts-based experiments we designed were completely untested, I felt that we were engaging students in science-in-the-making. I was excited to let the students join in on creating new knowledge, rather than just reading about it. However, I did have my worries about how students — who were all from the natural science study programmes — would react to our arts-based approaches and the lack of definitive conclusions from the teachers. Many of these students are used to lecture-style teaching about established science, so what would happen when we showed them a science fiction film and asked them to reflect on how it could be used for sustainability science communication? As a researcher, this felt like the right way to go, but as a teacher, I was equal parts curious and apprehensive to see my students' responses (MA, course leader).

Third iteration: 2) context

Our aim to reach new levels of teaching-research integration took up just as much focus for the third iteration (held November 2021–January 2022) as developing the arts-based methods did. Again, we were guided by the teaching-research nexus, and looked to sustainability research for foundational ideas that could be transposed to teaching — in this case, ideas that lent themselves to arts-based teaching methods. In particular, we appreciated Spangenberg's [2011] claim that in sustainability science, sources of intelligence should be extended to include

non-scientific knowledge. We expanded this point of view with Heinrichs' [2019, p. 5] assertion that "humans are not only cognitive information processing machines but multisensorial beings constituted by complex, interrelated cognitive, emotional, affective, corporal conditions." Drawing these perspectives together, we wanted to involve the students much more in the knowledge-production process by acknowledging and utilizing the full range of their disciplinary, experiential, sensory and emotional capabilities. In terms of the University's model for the research-teaching nexus (Figure 2), we thus wished to progress from the levels of research-based teaching to the level of research integration.

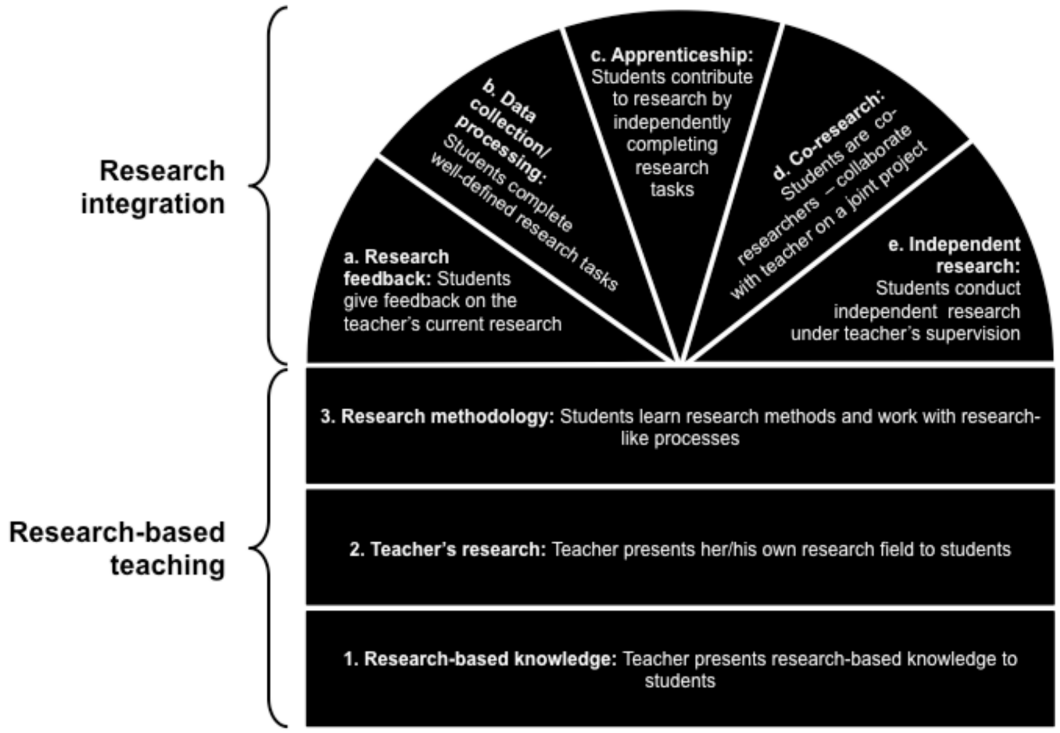

Figure 2. The formal model for research-teaching integration used at the University of Copenhagen. Redrawn from University of Copenhagen [2023].

Where the previous two iterations of the course had been at the levels of research-based teaching (Figure 2), we now wanted the students to give "research feedback" in the course. We thus wanted to present the students with "science in-the-making", rather than just presenting them with the set conclusions of "ready-made science" [cf. Latour, 1987]. We did so by presenting the students with the arts-based experiments we had planned, and reminded ourselves and other teaching staff to be explicit about when they had reached the frontiers of established knowledge in those experiments. Furthermore, as an extracurricular activity, we invited the students to "co-research" (Figure 2) with us by inviting them to collaborate with us on a joint project. Accordingly, after the third iteration of the course had been completed, we invited the students to help us analyse the data our research assistant had gathered and write a manuscript for publication in a peer-reviewed journal [Vitting-Seerup et al., 2023].

In addition to working more systematically with research-integration in the course, the grant also allowed us to form a small advisory board consisting of a colleague from the Faculty of Humanities (KMB) and a professional science communicator

from the European Environment Agency (BK), respectively, who we enlisted to help us make the arts-based experiments transdisciplinary in nature and relevant for practical science communication. Our colleague from the Faculty of Humanities also helped us find several students from the rhetoric study programme who were interested in following the course alongside our students from the natural sciences, but unfortunately, we were not able to formally enrol them due to the different course structures of the faculties. Four students from the rhetoric programme did, however, choose to participate in one or more of the arts-based experiments, even though we were not able to enrol them.

With the help of our advisory board, we (first and second author) planned four experiments that used arts-based approaches in different capacities: Personal letter-writing as a first step for creating a policy brief, science fiction as a means to imagine (and enact) sustainable futures, art-science exhibitions' potentials for innovation, and finally a second round of our role play, designed to let the students take the point of view of a science sceptic.

The teaching staff in the third iteration came to consist of the two authors, a guest lecturer from the Natural History Museum of Denmark, and our advisory board member from the European Environment Agency. Joining the course was also a research assistant, making observations during class and interviewing a select group of students after the course had ended [for more on this data collection, see Vitting-Seerup et al., 2023].

Finally, it is worth mentioning that the national situation regarding COVID-19 allowed for classroom teaching in the first part of the course, but two of our experiments, focusing on science fiction and art-science exhibitions respectively, had to be converted to online teaching at the last minute due to reinstated COVID-19 stay-at-home restrictions.

Third iteration: 3) student response

The third iteration of the course received an overwhelmingly positive evaluation with the students praising the course structure, the variety of learning materials, and the engaging lectures. The weekly themes and interdisciplinary collaboration were particularly well-received, and the students also emphasised the importance of the group work and the feeling of co-creation in the learning process. In previous years, the intensive group work had not always been so well-regarded, but in this third iteration, it was as though the students all saw the point of the interdisciplinary group work.

In the halfway and final evaluations, the students further expressed a sense of ownership over the materials and reflections they produced, and how they felt that their contributions were valued by teachers and group members alike. The sense of community that evolved among students was also clearly noted among the teaching staff. During the final evaluation, one student said "It felt like we were all in this together." In other words, the overwhelming sentiment was that the course was a great success. One student even wrote; "Definitely one of the best courses I have had during my now 6 years at Aarhus, Copenhagen and Melbourne unis!".

However, only one student mentioned sustainability in the evaluation, and in the same tone as we witnessed in the first iteration of the course, namely by expressing difficulties with relating their specific field of study to sustainability. Like earlier, we do not know which field this student came from, but this repeated point could indicate that certain students or disciplines have a culture that frames certain research domains as essentially fundamental rather than applied. The comment does, however, indicate that sustainability was indeed a visible theme in this iteration of the course.

A majority (76%, n=17) formally enrolled students responded to the final evaluation survey. When asked whether they found the course useful, one student (6%) disagreed, two students (12%) agreed and ten students (59%) strongly agreed. Two of the 17 formally enrolled students subsequently elected to help analyse the data from the experiments and co-author the final article.

Third iteration: 4) reflexivity

Where I expected the science students to demand clear-cut answers, they seemed to love our science-in-the-making approach, and gave thoughtful input on the wicked sustainability problems we presented them with. I was also surprised at how many students joined the analysis- and writing workshops. While eventually not all students elected to become co-authors of the manuscript, they seemed to have no objections to the idea of us testing new formats in the course, and almost all of them attended our presentation of the preliminary results.

Not all experiments went equally well, but I still see this iteration of the course as mainly a success. It was, however, quite clear to me that one needs a full team of people to do something like this. As course leader and the main teacher, my focus was very much on developing the pedagogical and content-related aspects of the course — once the course was running, I didn't think too much about how it was also a research project, but focused on the participants' interactions and progression. However, I did think about the research angle in the planning phase and also, when I read the participants' weekly assignments, because their reflections prompted a number of ideas for further research! I also hope I have contributed as a teaching researcher by helping the students to validate the in-the-making ideas they have jointly arrived at — although in retrospect, this aspect could be strengthened.

It was primarily the postdoctoral researcher and the research assistant who ensured the data was collected, while I was focused on teaching the course. I know it's not sustainable to have two extra people involved to this extent in the course, so future versions of the course will have to be scaled back (MA, course leader).

Third iteration: 5) strategies developed

We considered the course a success, as the students seemed to not only acquire the sustainability science communication skills we had set out (see the section *Second Iteration: 2) Context)*, but also to acknowledge the value of acquiring those skills. This assessment is supported by the overwhelmingly positive student evaluations, and by the positive feedback we received from colleagues and the Department

management. We, the two authors, have both been invited to give seminars and keynote presentations based on the experiments we conducted and the findings presented here. Even so, it is not feasible to continue the experimentation with new ideas in the labour-intensive setup described here (including the advisory board, data collection, and other extracurricular activities). Future versions of the course will thus reprise the arts-based experiments that worked best, and gradually phase in new ones, based on students' suggestions and ideas.

Conclusive comments

In this text, we have discussed the iterative development of a science communication course. Specifically, we have described our efforts to incorporate sustainability knowledge, values and practices into science communication theory and practice for students in natural science study programmes. While we have not found the perfect model for doing so, we want to conclude this account by sharing some reflections that came out of this work, with respect to both sustainability science communication and science communication education more broadly.

Sustainability science communication

We have described how we struggled to find research on how to repurpose science communication for sustainability, and how the research we did find tended to focus on pedagogical, more content-general recommendations rather than content-specific insights. This meant that we had to carry out the *didactic transposition* [cf. Evans & Achiam, 2021] of sustainability science content to sustainability science communication on an ad hoc basis – and as the three iterations of the course demonstrate, some of these transpositions worked better than others. In the following, we draw on the research of Mochizuki and Yarime [2016] and others to retrospectively qualify the successes and failures of our efforts.

Mochizuki and Yarime [2016] describe the relationship between education and sustainability in terms of education *about* sustainability, education *for* sustainability, and education *as* sustainability. In our reflections about the development of the course, we noted how these three relationships seem to correlate with our three iterations. Indeed, our first iteration, which required students to choose one of four SDGs to work with, could be described as education *about* sustainability. This practice aims to increase learners' awareness of sustainability by transmitting to them already-established knowledge about the problems at stake [Mochizuki & Yarime, 2016]. By taking a point of departure in the SDGs, the first iteration of the course described existing sustainability challenges, and encouraged the students to look at the challenges defined by the SDGs from their respective disciplines.

The second iteration of the course could be described as education *for* sustainability. This practice critiques existing disciplinary frames of reference and critically examines existing solutions from an interdisciplinary perspective [Mochizuki & Yarime, 2016]. Barth [2015] argues that selecting content for this kind of sustainability education should ideally capture both the relevance of the content from a science perspective and its educational significance. Although we had not read Barth when we were developing the second iteration, still, we developed teaching materials that embodied complex and dynamic socio-scientific problems (e.g., science denialism in the COVID-19 pandemic, or democratisation of science)

that called for interdisciplinary solutions. This approach, Mochizuki and Yarime [2016] argue, tackles the root causes of sustainability rather than its symptoms; in our case, we noted how giving students topical, complex problems motivated them to engage with sustainability to a much greater extent than simply presenting them with the a priori defined SDGs.

Finally, Mochizuki and Yarime's [2016] notion of education *as* sustainability involves epistemic change through exploration, reflection and deliberation. This approach entails carefully planned exchanges between participants that represent different ways of knowing; exchanges that engender mutual understanding and eventually allows the participants to collaborate on interventions or solutions to a problem [Mochizuki & Yarime, 2016]. We attempted to materialise such exchanges by involving practitioners and colleagues from other disciplines and inviting in students from other faculties, but most importantly by using arts-based approaches to prompt transdisciplinary work [cf. Heinrichs, 2018; Leavy, 2014]. Specifically, we drew on the ability of art to promote more empathetic and equitable connections between the participants and emphasise inquiry over ready-made facts [Heras et al., 2021]. As discussed in the preceding, this approach seemed to resonate very much with the students, who eagerly engaged in our somewhat experimental approach.

Although Mochizuki and Yarime [2016] themselves make no judgment about the relative merits of the three approaches, we certainly found education *as* sustainability to be the most progressive way of integrating sustainability in the course, and the one that engendered the most positive feedback from students. Further, the close-knit integration between sustainability science and arts-based approaches to communication that resulted from our collective work in the third iteration of the course [cf. Vitting-Seerup et al., 2023] lends support to the claim that sustainability communication calls for radical, transdisciplinary approaches [Racimo et al., 2022], rather than the more mainstream deficit and dialogue models of science communication. We suggest that this is the most important implication of our work for sustainability science communication.

Science communication

As set out in the introduction, there is generally an increased interest in promoting science communication competencies in higher education institutions. This interest is based in part on a realisation that maintaining a democratically competent citizenry relies on constructive public engagement with science [Arvidson et al., 2022], in part on an acknowledgement that scientists and science communicators do not always have the skills required to navigate the blurred boundaries of science and society [Barendse, Rerimassie, Roedema & Kupper, 2021]. Even though we acknowledge that our work is specific to *sustainability* science communication, we believe we can suggest some modest implications for the domain of science communication education.

A recent national report generated by the Swedish Research Council and Örebro University [Arvidson et al., 2022] outlines key features of progressive science communication courses:

- Courses should tackle the importance of knowledge as a process and the changing landscape of knowledge diffusion through society, and emphasise open science and transparency in communication.
- Courses should focus on the drivers and logics behind different forms of communication, including how target group perspectives influence the choice of communication methods.
- Courses should emphasise the development of practical skills in science communication across different media and genres.

We would argue that a number of these features emerged as knock-on effects from our work to integrate sustainability into the science communication course. First, the wicked sustainability problems we face (e.g., zoonotic pandemics or the biodiversity crisis) are ongoing, and the science is not yet established or settled. This means that drawing on sustainability problems in science communication education brings the process or in-the-making aspects of science to the fore, and demonstrates how such "unfinished" knowledge diffuses through society, as for instance in our exercise about the Danish press briefing during the COVID-19 pandemic.

Second, many sustainability problems call for communication models that go beyond the mainstream deficit and dialogue approaches, because different kinds of expertise and ways of knowing are crucial resources for socio-technical change [Irwin, 2014; Spangenberg, 2011]. In other words, sustainability problems can be considered as drivers for more inclusive communication formats. Thus, we suggest that incorporating sustainability problems into science communication education prompts learners to interrogate the problems at stake and independently arrive at more equitable and participatory ways to communicate. As we argued in the preceding [based on Brousseau, 2002], creating the conditions for learners to autonomously experience the need for participatory communication approaches is more convincing than simply requiring them to employ such models as an academic exercise.

Third, the experimental arts-based turn we took in the third iteration of the course was an eye-opener for us with respect to how to utilise different communication genres and media. Recall how our experiments included letter-writing, role play and science fiction; these experiments allowed our students to try a range of communication formats that are perhaps not often a part of science communication courses. The advantage was that the students could experience in practice how arts-based genres and media could encompass a much wider range of interaction and engagement.

In conclusion, we make the somewhat speculative suggestion that integrating sustainability into courses or training programmes can have the add-on effect of foregrounding the important features of science communication discussed by Arvidson et al. [2022] such as the contingent nature of scientific knowledge and its diffusion through society, the conditionality of different forms of communication, and perhaps the diversity of genres and media available for equitable and participatory engagement with science.

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Appendix A. Course evaluation forms

The official course evaluation form, distributed to all BSc and MSc students taking courses at the Faculty of Science, University of Copenhagen, includes the items described in the following.

Multiple choice questions

- My average weekly workload on this course was (incl. lessons, preparation, written work, etc.); (Less than 10 hours; 10–15 hours; 16–25 hours; 26–30 hours; More than 30 hours; I don't know)
- Given my background, the academic level of the course is; (Far too low; Too low; Suitable; Too high; Much too high)
- In my opinion, the workload on the course is; (Far too light; Too light; Suitable; Too heavy; Much too heavy)
- I believe that I have acquired the competencies described in the course objectives (link to learning objectives); (Strongly disagree; Disagree; Neither disagree nor agree; Agree, Strongly agree)
- In my opinion, the individual sub elements (lectures, exercises, etc.) of the course were logically connected; (Strongly disagree; Disagree; Neither disagree nor agree; Agree, Strongly agree)
- In my opinion, the teaching material was relevant to the course; (Strongly disagree; Disagree; Neither disagree nor agree; Agree, Strongly agree)
- In my opinion, I have received relevant academic feedback on my oral and written work on the course; (Strongly disagree; Disagree; Neither disagree nor agree; Agree, Strongly agree)
- In my opinion, I have had access to the necessary information about the course; (Strongly disagree; Disagree; Neither disagree nor agree; Agree, Strongly agree)
- Overall, I find that the course has been useful; (Strongly disagree; Disagree; Neither disagree nor agree; Agree, Strongly agree)

Open-ended questions

- What was good about the course? Why?
- I would like to suggest the following improvements.

In addition to the official evaluation form, distributed to the students at the end of the course, we carried out an evaluation halfway through the course. This evaluation used a modified Delphi approach, in which all students were asked to anonymously write what they thought worked well in the course and what they thought could be improved in the course. We used the free software Padlet.com to create two electronic message boards where the students could anonymously post their responses. The students were then encouraged to read other students' responses, and upvote the ones they agreed with, using Padlet's "thumbs up" function. Finally, we left the room so as to not affect the students' responses. This provided us with both qualitative (students' open-ended responses) and quantitative (number of upvotes) data about the course.

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