International Journal of Science Education, Part B
Communication and Public Engagement

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rsed20

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To cite this article: Lynda Dunlop, Elizabeth Rushton, Lucy Atkinson, Eef Cornelissen, Jelle De Schrijver, Tetiana Stadnyk, Joshua Stubbs, Chrissy Su, Maria Turkenburg-van Diepen, Fernanda Veneu, Celena Blake, Saul Calvert, Clémentine Dècle, Kirndeep Dhassi, Rosalind Edwards, Greta Malaj, Jovana Mirjanić, William Saunders, Yara Sinkovec, Suzan Vellekoop & Xinyue Yuan (2022): Youth co-authorship as public engagement with geoengineering, International Journal of Science Education, Part B, DOI: 10.1080/21548455.2022.2027043

To link to this article: https://doi.org/10.1080/21548455.2022.2027043

Published online: 31 Jan 2022.

INTERNATIONAL JOURNAL OF SCIENCE EDUCATION, PART B
https://doi.org/10.1080/21548455.2022.2027043

Routledge
Taylor & Francis Group

Youth co-authorship as public engagement with geoengineering

Lynda Dunlop [a], Elizabeth Rushton [b], Lucy Atkinson [a], Eef Cornelissen [c], Jelle De Schrijver [d], Tetiana Stadnyk[e], Joshua Stubbs [a], Chrissy Su[a], Maria Turkenburg-van Diepen [a], Fernanda Veneu [f], Celena Blake[a], Saul Calvert[a], Clémentine Dècle[g], Kirndeep Dhassi[a], Rosalind Edwards [h], Greta Malaj[i], Jovana Mirjanić[b], William Saunders[j], Yara Sinkovec[k], Suzan Vellekoop[g] and Xinyue Yuan[a]

[a]University of York, York, UK; [b]King's College London, London, UK; [c]Odisee University College, Brussels, Belgium; [d]University of Antwerp, Antwerpen, Belgium; [e]Youth and Environment Europe, Prague, Czech Republic; [f]Centro Federal de Educação Tecnológica Celso Suckow da Fonseca, Rio de Janeiro, Brazil; [g]Leiden University, Leiden, Netherlands; [h]Whitchurch High School, Cardiff, UK; [i]University of Tirana, Tirana, Albania; [j]Oxford Brookes University, Oxford, UK; [k]Polytechnic Institute of Setúbal, Setubal, Portugal

ABSTRACT

Large-scale intervention in the Earth's climate system is increasingly present in discussions about possible responses to climate change. Young people's perspectives have tended to be under-represented despite the intergenerational consequences of policy in this field. We report on a novel approach to research and practice: the co-creation of a youth guide and policy brief by youth participants and facilitators. The model offers potential use by practitioners for engaging publics at the early stages of technoscientific innovations. Findings fall into two categories: youth priorities for geoengineering and authorial responsibility as a way of supporting youth action. Tentative conclusions from youth participants are (i) action must be prioritised now to mitigate and adapt to climate change, rather than continuing with 'business as usual'; and (ii) there is a need for proactive international cooperation on governance and research on geoengineering to understand potential environmental and social consequences of geoengineering proposals for people at different temporal and spatial scales. Greater public dialogue on geoengineering and its governance is needed, particularly involving young people. The youth guide and policy brief co-authored by participants and facilitators, and the dialogic methods used in their production, can contribute to this dialogue.

ARTICLE HISTORY
Received 29 September 2021
Accepted 5 January 2022

KEYWORDS
Geoengineering; climate change; youth; policy; participatory approaches

Introduction

The large-scale intervention in the Earth's climate system ('geoengineering' or climate engineering) refers to a range of proposed responses to climate change which generally take one of two approaches: the removal of carbon dioxide from the atmosphere (carbon geoengineering), or the reflection of solar radiation away from the Earth (solar geoengineering). The changing climate demands a response, and it is important that techno-scientific responses are considered in the context of approaches to adaptation and mitigation. Research on public perspectives on geoengineering has tended to focus on the acceptability of different techniques to adult populations. The present

CONTACT Lynda Dunlop lynda.dunlop@york.ac.uk

study aims to contribute knowledge about how to engage youth (using the European Commission definition as those young people aged 15–29) through novel participatory and co-creative methods, and to present some insights as to current youth priorities in relation to geoengineering. The approach involves young people as active subjects (rather than passive objects) in researching, exploring, synthesising and communicating (including as co-authors of this paper and a youth guide and policy brief) key messages for decision-makers. The paper presents a model for building reciprocity into the research process, avoiding polarisation and for researching how publics respond to early stage technoscientific innovation.

Youth engagement with geoengineering

Public perspectives on geoengineering have been investigated using surveys (Carlisle et al., 2020; Mahajan et al., 2019), deliberative mapping (Bellamy et al., 2017), focus groups and Q-methodology (Cairns & Stirling, 2014). However, there have been few efforts to include young people's perspectives (only the Ipsos MORI (2010) *Experiment Earth?* dialogue in the U.K. was found). It is important to include youth because making decisions about what levels of mitigation, adaptation and geoengineering should be employed – and how – demands the inclusion of the people affected by the decisions. This is a matter of intergenerational justice: young people will have to deal with the more extreme consequences of climate change in the future and will be sentenced to a 'massive, implausible cleanup' (Hansen et al., 2017). Concurrently, youth tend to have less economic security so are frequently more vulnerable to the impacts of climate change (Barford et al., 2021). Youth climate justice movements such as #FridaysforFuture continue to position young people at the forefront of calls for action on climate change. However, young people tend to be excluded from environmental policy-making discussions and decisions (Thew et al., 2020), and their perspectives are poorly represented in social science research on geoengineering technologies.

Social science research on climate intervention is inherently problematic because 'geoengineering' is an imprecise, umbrella term used to describe a range of technologies which vary enormously in their mechanisms, effectiveness, reversibility, impacts and risks at different scales (Cairns & Stirling, 2014). Geoengineering can be considered controversial because it is a live, or current, issue about which there is public disagreement amongst scientists and other stakeholders about *if* and *how* different proposals ought to be advanced. The emergence of geoengineering proposals in response to climate change has led to efforts to engage various publics (Bellamy et al., 2014, 2017; Sütterlin & Siegrist, 2017) and to research the public acceptability of proposals (Braun et al., 2018; Corner & Pidgeon, 2015; Cummings & Rosenthal, 2018; Scheer & Renn, 2014). Such research often involves researchers (scientists and social scientists) close to geoengineering research in the role of presenting fundamental science to audiences, including research participants which can risk implicit or explicit advocacy for proposals presented, and deferral to scientists on matters of a non-scientific nature in relation to geoengineering.

Research on the acceptability of geoengineering is problematic for several reasons. First, it might raise hopes or expectations that geoengineering proposals can provide an immediate 'fix' when current research indicates that, at present, these technologies cannot be relied on to make a significant contribution to the goals set in the Paris Agreement (Lawrence et al., 2018). Geoengineering proposals must be considered in the context of mitigation (strategies used to minimise emissions of greenhouse gases) and adaptation (minimisation of the effects of climate change), but few studies take this approach (see Bellamy et al., 2014 for a study which does). A second problem with public acceptability research relates to reductive approaches which present 'geoengineering' as a single entity (Cummings & Rosenthal, 2018) or which polarise attitudes in terms of support or opposition (Braun et al., 2018). Polarisation entrenches attitudes into opposing factions, often associated with ideological or political beliefs, which can set up oppositional relationships along pro/anti, young/old, male/female, liberal/conservative, dis/trust in science axes. This can divide public opinion (Baldassarri & Gelman, 2008) and interfere with policy discussions which require some agreement on

facts (Rekker, 2021). Research must recognise that climate change is complex, not lending itself to simple positions or solutions (Lucas, 2018). Finally, owing to low levels of public awareness, reported attitudes towards geoengineering proposals rely on self-reports of familiarity (Cummings & Rosenthal, 2018), the stimulus to describe technologies (Scheer & Renn, 2014) and framing of the issue (Corner & Pidgeon, 2015), and are unstable over time (Braun et al., 2018). There has been some debate over whether or not more harm than good might be done through public engagement with new technologies (see for example Bellaby & Clark, 2016) so there exists a challenge, described by Bellamy and Lezaun (2017) to make climate engineering the subject of public deliberation without making it 'more real' in policy terms (p. 403).

The social in social science research on geoengineering

Researchers have noted that public engagement is a necessary but insufficient aspect of opening up science and its governance (Stilgoe et al., 2014). In the context of geoengineering, limited awareness is a challenge for social science research. For example, how best to provide opportunities for participants to learn about new and emerging technologies to inform democratic processes when knowledge is uncertain or emerging, or can be framed so that the outcome is influenced (Corner & Pidgeon, 2015).

Often, research involving publics happens in service of a programme of scientific research, leaving few opportunities for meaningful engagement in setting the research trajectory or defining research questions. Szerszynski and Galarraga (2013) point to the problem of subordination in interdisciplinary research, where social science is positioned in service to science, with the sciences determining the questions to be answered and social sciences given a limited role 'downstream'. As Viseu (2015) describes it 'too many in the physical and life sciences dismiss social sciences as having a "service" role, being allowed to observe what they do but not disturb it'. This constrains discussion so that less desirable questions and topics relating to the research are not considered, exacerbated by asymmetrical power positions, in which scientists determine what knowledge counts and is valuable in the field (Albert et al., 2008 discuss this issue in relation to biomedical sciences). This limits scope for publics to alter (or even stop) the direction of research in response to societal needs. Furthermore, incentives exist (associated with funding, career and status, which of course can be resisted), particularly for social scientists 'close to the science', to bring about public acceptance where science and technology are controversial. Social scientists have identified the challenges they face if and/or when they do not share the urgency of scientists to bring about acceptance of technologies (see Delgado and Åm (2018) in the context of biotechnologies). It is therefore important to conduct anticipatory social science research on geoengineering independently from scientific research and technological development, and to ensure there is space for the public (here, young people) to identify priorities and questions which must be taken into consideration alongside scientific expertise.

Research on emerging science and technologies must resist (or at least acknowledge and question) dominant power relations between natural sciences and social sciences. Edwards and Brannelly (2017) point to democratising processes in qualitative research, outlining the value of co-production and emancipatory methods which prioritise the values of marginalised groups, involve them in the design, conduct and dissemination of the research, and disrupt subject/expert positionality. As they put it, 'democratisation of research is concerned with ensuring that people who experience marginalisation influence research at every level of the process, to identify what it is that is important to research, and how the community may benefit from involvement' (Edwards & Brannelly, 2017, p. 275). In the context of climate change, there is experimental evidence that intergenerational learning (in particular from youth to adult) can be important in influencing concern about climate change (Lawson et al., 2019), indicating particular collective value in engaging with young people. In the present study, we are concerned with youth as a group marginalised from decisions about science, technology and society, in the specific context of geoengineering proposals in response to climate change.

To date, the dominant approach to research on communication and public engagement in relation to geoengineering has been to ask participants to appraise the acceptability of geoengineering proposals either with a single proposal focus (Sütterlin & Siegrist, 2017) or a comparative focus, including mitigation strategies (Corner et al., 2013), often involving presentations by research teams. Bellamy and Lezaun (2017) examine challenges associated with public engagement with geoengineering. These include problematic framings which favour fast-acting and impactful climate interventions, natural framings (including descriptions of 'artificial trees' and comparisons with volcanic eruptions) and discussions structured around specific techniques with little consideration of alternative responses to climate change (such as reducing consumption). They describe how they 'unframed' the issue by reducing the role for scientists and STEM ambassadors and describing technologies as 'proposals' or 'ideas' so that geoengineering is positioned as tentative and provisional. These approaches avoid public engagement being used to legitimise research and development in geoengineering, or making these proposals 'more real' for participants. Deliberative approaches have an important role to play but, are limited where participants are not involved in an authorial role. Involving participants as co-authors means that where there is disagreement, there must be recognition that it exists and resolution must be reached, if not on the conclusion, on the principles on which a conclusion may be reached.

In the field of climate education, there is a demand for approaches to education which prepare and empower publics to deal with uncertain environmental, economic, social and political futures in the context of the climate crisis. Whilst policy and public discourse tend to focus on knowledge transfer (Bangay & Blum, 2010) – or 'knowing more' – reviews of climate education research indicate that didactic approaches to climate change have been largely ineffective (Rousell & Cutter-Mackenzie-Knowles, 2019). Active and engaging teaching methods and deliberative discussions are important characteristics of 'effective' environmental education (Monroe et al., 2019), and Cutter-Mackenzie and Rousell (2019) have argued that innovative and effective forms of climate change education are needed to activate young people's political agency. Rousell and Cutter-Mackenzie-Knowles have called for educators to stop 'shying away from the Earth's looming runaway climate change' and to seize the moment to examine what really matters through participatory, interdisciplinary, creative and affect-driven approaches to climate change education which involve young people in responding to the scientific, social, ethical and political complexities of climate change. Their work has included the use of speculative fiction authorship as a way of engaging with climate futures through education (Rousell et al., 2017). Here, we examine co-authorship in non-fiction genres as a form of climate education in the context of climate engineering.

Materials and methods

Approach to communication and engagement

Our focus was firstly, to explore from the perspective of young people the place – if any – for geoengineering in responding to climate change and to identify perceived characteristics of good decision-making (leaving aside the decisions made). Secondly, we wanted to enable young people to communicate their perspectives and conclusions with their peers. Recognising climate change as an issue requiring international collaboration, we included young people from different countries. To this end, a series of four online, participatory workshops (see Table 1) were designed to put young people at the centre of the knowledge produced. The study was conducted entirely remotely. Countries of residence of authors (youth participants, and academic and NGO facilitators) were Albania, Belgium, Brazil, China, Czech Republic, Poland, Portugal, Netherlands and the United Kingdom, with the U.K. best represented in terms of residency.

During the workshops, participants were responsible for finding the knowledge to be used in discussions, and for co-creating outputs. Internet research tasks were introduced with reference to social science research literature, pointing out the importance of identifying framings and vested

Table 1. Workshop design: purpose and outputs.

Workshop theme	Purpose	Main methods	Tools	Output
Workshop 1: Science	To establish a shared understanding of solar and carbon geoengineering technologies on land, sea, air and space.	'Experts and envoys', online research, questioning, group discussion	Mural Online Collaboration tool (introductions), Zoom chat (expectations), Zoom breakout rooms (group research), Jamboard (reflections)	Presentations by young people addressing the following questions and participants' own questions: How does the approach work? How effective is it? What are its predicted effects – and are these greater for some people/places than others? What are the risks? What are the costs? What are its impacts over time? Is it reversible? Who is responsible?
Workshop 2: Ethics	To create and explore social and ethical questions associated with geoengineering and climate change.	Philosophical dialogue, analysis of case studies, consensus-building	Zoom annotate (to indicate answers to questions); Zoom breakout rooms (group discussions); Google Slides (decision-making about different proposals); Google docs (writing shared principles)	Questions created by young people (see table 2); Set of shared principles on if/under which circumstances geoengineering should be researched or deployed, and identification of assumptions on which these principles are based.
Workshop 3: Society	To identify and communicate key messages for young people and policy-makers.	Writing workshop – critical review, writing, editing, feedback	Mural Online Collaboration tool (identification of key concepts, people, feelings, questions, conflicts); Google docs (writing youth guide and policy brief); Zoom breakout rooms (group work and discussion).	Youth guide written by young people: • to explain geoengineering • To explain the link between geoengineering and the climate crisis • to identify questions that need to be considered when taking a position on geoengineering.
Workshop 4: Policy	To identify priority audiences and actions to disseminate the youth guide and policy brief.	Writing, review, action planning.	Google Slides and Zoom annotation tool (action planning); Google docs (writing policy brief, reflection and review); Zoom breakout rooms (group work and discussion).	Policy brief written by young people; publication and dissemination action plan [link to be provided following peer review].

interests. For example, during the workshop 1 ('Science') small groups (groups of 3–4 people) were tasked with researching one set of geoengineering proposals and at the outset, were informed that social science research (e.g. Corner & Pidgeon, 2015) suggests that support for geoengineering is slightly – but significantly – more positive where it is framed as analogous to a natural process. Participants were advised to pay attention to framing and how this might shape communication, as well as other important details such as aims of the organisations producing online materials, their geographical perspective and how geoengineering proposals were positioned in relation to mitigation and adaptation.

Underpinning our approach was the recognition that the youth participants had a key role in knowledge creation. Reciprocity was designed into the intervention in three key ways: (i) giving

Table 2. Priority questions about geoengineering.

Type of question	Examples of questions generated by participants
Nature of the problem	• Is climate change the biggest threat to the population? • Is geoengineering a distraction from other climate measures? • Is it possible to live without harming the planet? • Is destruction of nature part of human nature? • What is the best way to protect global ecosystems?
Technical	• Which methods are most effective?
Social	• How could different geoengineering methods impact society? • Who is responsible for climate change? • Who would be responsible for geoengineering? … and who is accountable? How?
Political	• How are decisions about geoengineering made? • Who decides which methods should be researched? • Is a global regulatory framework for geoengineering needed? • Which sort of governance suits geoengineering best?
Ethical	• Should we enter into geoengineering not knowing the consequences? • Can equality produce better science? • Who should benefit from geoengineering?
Economic	• Are capitalism and consumerism the cause of environmental damage? • Who should pay for geoengineering?

authorial responsibility for producing presentations, creating questions and writing a youth guide and policy brief on geoengineering, (ii) teaching processes including critical research literacy and how to write a youth guide and policy brief so that young people could research, interpret and communicate for themselves on this or other themes; and (iii) creating opportunities for participants to identify priority actions (if any) following the workshops. In exchange, participants volunteered their time, effort and ideas. Sharing authorial responsibility implied the need and opportunity for all to contribute to the design, analysis and drafting process, and understand and approve the outputs.

Climate change can be a polarising topic (Colvin et al., 2020) so we needed to create an online space where people could disagree (indeed, where constructive disagreement was encouraged, and the reasons for it probed) but which did not contribute to the problem of polarisation. To this end, structured social and play time was incorporated into the online workshops, as well as small group discussions in different groups to allow participants to learn about each other and work together. Workshops were introduced with the motivations of the facilitators: the belief that it is important for young people to be informed about geoengineering, what geoengineering means for people and the planet, to consider how geoengineering proposals relate to other responses to the climate crisis (including mitigation and adaptation measures) and, to be equipped to participate in social and political dialogue. Polarisation was avoided by not asking participants to take a stand (including comparative stances) on acceptance geoengineering proposals, common in surveys and deliberative mapping processes. This meant that participants did not have a stand to defend. Instead, desirable principles for decision-making were identified and examined.

Methods

A series of four 5-hour participatory online workshops was designed. Each workshop focused on a different dimension of geoengineering and resulted in the creation of a spoken or written product (specifically, a presentation, set of questions, youth guide, policy brief) which informed the

subsequent workshop. The data upon which this paper is based are the youth guide and policy brief (Blake et al., 2021) produced in workshops 3 and 4, informed by workshops 1 and 2 (Table 1).

Over the series of workshops, the following geoengineering proposals were discussed: space mirrors, stratospheric aerosol injection, cloud thinning, ocean fertilisation, ocean liming, bioenergy with carbon capture and storage and large-scale afforestation, alongside mitigation methods.

Facilitators

Facilitators ($n = 10$) came from a range of academic disciplinary backgrounds including chemistry, education, environmental science, geography, politics, philosophy, psychology, science journalism, and social sciences (with some facilitators drawing on more than one disciplinary background). The team included partners from academia (researchers and undergraduate and post-graduate students) and an environmental non-governmental organisation (NGO). This NGO partner aims to mitigate climate change through awareness raising and capacity building amongst youth, enhancing international cooperation and knowledge-sharing and strengthening the participation of youth in environmental and climate decision-making processes. Facilitators had varied nationalities and were based in a range of international contexts (Belgium, Brazil, the Czech Republic and the United Kingdom). None of the facilitators were (nor have been) involved in the design, funding, testing or deployment of geoengineering proposals.

Participants

The workshops were open for applicants and those selected for participation met the following characteristics: they could commit to the four workshops taking place on Zoom, were living in Europe or were studying or working at a European institution. No prior understanding of geoengineering was required. Participants were recruited online via professional networks of the facilitators, via social media and mailing lists. All applicants who met the criteria were offered a place ($n = 16$). A total of 13 young people aged 17–27 (average age 21) participated in the workshops. Young people were of a range of nationalities (Albanian, British, British Asian, Chinese, Dutch, French, Portuguese, Macedonian, Serbian, Slovak) and currently-resident in a range of countries (Albania, China, Czech Republic, Poland, Portugal, Netherlands and the United Kingdom). It is important to include young people from geographically diverse contexts in research which might inform decisions about geoengineering because these decisions tend to have far-reaching spatial and temporal consequences. However, there were no participants from the most climate-vulnerable countries such as the Pacific island countries. Most were students (school, undergraduate and postgraduate were represented), and others were in employment or did not state an affiliation. Disciplinary backgrounds varied and included architecture, chemistry, education, environmental science, geography, governance and sustainability, and sociology. Participants met for the first time on Zoom during the workshops.

Procedures

The study was approved by the appropriate ethics committee in the lead institution (ref. 20/18). Participants gave voluntary informed consent prior to participating in the workshops and were asked for consent prior to recording sessions. The four workshops were held on Saturday 24th April, Sunday 25th April, Saturday 8th May and Sunday 9th May Workshops were held over two weekends with a break in between for the May Day holiday in many countries. The two-week break between workshop weekends gave participants and facilitators time to process new information before co-creating the youth guide and policy brief. Each workshop consisted of four one-hour sessions running from 10.00 to 15.00 CEST with a one-hour break. Sessions were structured to include social, active and interactive components to minimise fatigue associated with being online for long periods. The language of the workshops was English.

Each one-hour session in the workshops consisted of social or team-building. Participants rotated between groups over the four workshops so that everyone worked with each other over the two weekends and so that there was geographical diversity in group discussions. Collaborative tools including

Mural Online Collaboration (https://www.mural.co/), Google docs and slides (https://www.google.com/), and Zoom (https://zoom.us/) annotate, breakout rooms and chat were used to enable participants to work together, and the records from these tools as well as audio-recordings were used as a source of data for both qualitative analysis (to identify themes of importance, key controversies and questions) and authoring of the outputs. Outputs were prepared iteratively, with concepts and questions from earlier sessions recorded and inserted into a document, groups assigned to draft sections of the document, edit other sections of the document, and review the final product. The choice of a guide and policy brief as outputs enabled participants to articulate points of agreement and encouraged identification of fair processes, regardless of their orientation towards geoengineering proposals. Checks were built in to ensure the products represented a true reflection of the dialogue during the workshops, and of the priorities of participants. These included (i) discussion and deliberation over the sequence of 4 workshops; (ii) preliminary gathering and analysis of ideas following each workshop shared with participants, with time and opportunities to discuss live and comment and edit text; (iii) opportunities for discussion, writing, editing and feedback on written outputs, to identify and resolve disagreements and imprecisions both during and after the workshops; (iv) feedback and approvals sought following the workshops on the final products (youth guide, policy brief, research article), including consent to co-author. The role of the facilitators during the workshops was to stimulate discussion, provide the outline and summarise key points based on discussions during the science and society workshops and to design the final document based on participants' text and comments in response to each other. All facilitators and participants agreed that the final product was a true and accurate reflection of the issues discussed over the sequence of workshops. Following the workshop, participants were invited to participate in an online interview on their experiences and their learning from the workshop; all 13 consented and were interviewed.

Results

We outline here youth perspectives on geoengineering based on the ideas presented in the youth guide and policy brief (Blake et al., 2021, see supplemental material) summarised according to their articulation of the problem, the principles identified as important when tackling climate change, the controversies associated with geoengineering, and key messages, recommendations and questions to consider. Data excerpts are drawn from drafts of the youth guide and policy brief, online contributions over the 4 days of the workshops, and post-workshop interviews with 13 participants. They are presented as unattributed to reflect the co-constructed nature of the work. In the words of one participant co-author:

It came out of a lot of discussions, it's very much like a group thing … points that were written down were not just … something that someone wrote down as their point, it came out of a discussion because of something they heard someone else saying and someone else might add to that, and so I don't think there was anything there that was just one person's work … just by kind of being there you had a shared responsibility.

Youth perspectives on geoengineering

The nature of the problem

Underpinning the youth guide and policy brief was the need for the inclusion of youth in long-term decision-making about environmental interventions:

> At the moment I think a lot of political decisions focus on who has money and power, which young people don't tend to have

During the workshops, diverse views on climate change and geoengineering methods were articulated. Some viewed climate change as a social and political problem connected to

contemporary capitalism and called for radical changes to social and political systems, for example, from a note in the Zoom chat:

> We need to dedicate time and energy and brain power, merging various perspectives together, to try to rethink our political and economic system(s) entirely instead of trying to find middle-way (green capitalist) solutions that perpetuate the status quo:p (it's time to go beyond the capitalist v. communist, democratic v. authoritarian binaries)

Others defended the same systems as the best – although imperfect – ways of organising societies and prioritised working within these systems. There was broad consensus that the global community needs to take immediate action to reduce carbon emissions, and whilst perspectives on preferred mechanisms varied, geoengineering proposals were seen as – at best – as part of a temporary solution. As one participant commented in an early draft of the guide and policy brief:

> Perhaps alter to focus more on how it is a last-ditch effort to buy us more time to adapt to, and mitigate, climate change?

There was concern that responses to climate change tend to be presented as individual changes rather than collective (social and political) action. There was an understanding that geoengineering is a complex and controversial area of research where there remains great uncertainty as to the effects, feedbacks and permanency of proposals, and a lack of credible and reliable information that is accessible to and comprehensible by the public. This raises questions as to the extent to which communities are able to make informed decisions about geoengineering proposals that are presented to them, and to how risk is communicated. As one of the authors put it in editing the youth guide:

> Perhaps could we also maybe indicate the lack of research in certain techniques, which arguably are what lead to us categorising them as high risk? (So should we define our concept of risk in this context?)

Principles for intervention

- As part of the Society workshop, a number of principles were identified by participants as desirable characteristics of interventions to tackle climate change. These included:
- The demand for transparent and inclusive decision-making about responses to the climate crisis with clear lines of responsibility and accountability for decisions taken (or not) today. This should include public scrutiny of geoengineering proposals. As one group noted in early drafts: Decisions about geoengineering should not be top-down.Inevitably will have top-down but can we make it more informed decision.Transparency, public consciousness, accessible communication??
- The need to act now to mitigate and adapt to climate change, not continue with 'business-as-usual' and use climate intervention technologies as a final resort.
- The prioritisation of interventions which have well-understood consequences, and which are reversible, effective and affordable. This is in order to minimise risk to people and the planet (e.g. to aquifers, biodiversity, ecosystem health and services) – including potential harms arising from uncertainties about the impacts of climate interventions.
- A need to recognise the interconnectedness of people in different places through proactive international cooperation and regulation of geoengineering research and use. The authors discussed differential impacts in different places, for example:Maybe we should demonstrate with an example? Like how Russia will largely benefit from climate change due to the melting of permafrost, allowing more land to be cultivated. Whereas other countries such as island nations and Bangladesh will suffer greatly from rising sea levels, monsoons etc.

It is therefore considered important that interventions be either highly localised or result in equitable impacts on people and places.

Controversies

Geoengineering was considered controversial because its outcomes are uncertain when compared to strategies for mitigation and adaptation; stakeholders will be affected differently (there will be 'winners' and 'losers'); and because there is 'political conflict of interests between sustainability and economic growth' (with the latter tending to favour actions which do not deal with the root causes of climate change).

Consensus on the desirability of geoengineering approaches is unlikely to be achievable, but there was seen to be a need for greater public awareness of the options available for dealing with climate change and for the democratisation of decision-making: 'teamwork and discussion is the massive way forward'. Whilst the majority of the participants and facilitators were from the global North, there was attention to absent voices, for example in discussion about important people and organisations, 'the most vulnerable people and groups in society' were identified (e.g. those without means to make more sustainable choices in everyday life; those who are dependent on the climate for their life and livelihood) in discussions about the desirability of different responses to the climate crisis, and sensitivity to the structural (social, political and economic) barriers to ways of living which reduce greenhouse gas emissions.

Key message

The key message emerging from the youth workshops is that geoengineering must be considered in the context of other responses to the climate crisis, including adaptation and mitigation strategies, so that effective long-term solutions can be identified through research. The impacts of climate change and geoengineering strategies change over space and time. This means that the use and governance of geoengineering proposals must involve the perspectives of adults and youth from all parts of the globe, with greater attention to intergenerational justice in decision-making and to empowering through policy rather than expecting individuals to be able to respond to the climate crisis through individual choices. Proposals for geoengineering must be transparent, open and accessible to public scrutiny and regulation. Proactive international cooperation is needed now to create the structures to respond collectively and equitably to the climate crisis. As one participant noted during the 'Politics' workshop:

> Mitigation first, geoengineering later; empowering first, shaming later.

Questions to consider

Priority questions created during the workshop included scientific questions which participants saw as important to know before making decisions about different geoengineering technologies. These are presented in Table 2.

There was a recognition that these questions required different types of answers, and these were addressed to varying degrees over the course of the workshops. These questions represent potential research trajectories for environmental ethicists, political scientists, social scientists and scientists as well as points of departure for public dialogue on geoengineering proposals.

Discussion and conclusions

The conclusions we reach here result from public engagement research which goes beyond deliberation to result in policy perspectives created by youth, for youth. We avoided polarising and

reductive approaches to understanding (youth) public perceptions of geoengineering which set up oppositional relationships along pro/anti, young/old, male/female, liberal/conservative, dis/trust in science axes. This has been achieved by creating a space – a type of online deliberative assembly of young people – for public engagement with geoengineering science, ethics and politics, and for examining how these interact with society. Participants were not required to take and defend a position, but rather to work through differences and disagreements to identify principles that can be agreed upon to inform decision-making about geoengineering. Avoiding position-taking means that people have time and space to develop and change their thinking, without the need to adhere to an oversimplified position on a complex issue. Creating space and time for participants to develop relationships with each other and across different languages and cultures, allows for disagreement to happen in a context of trust and intellectual challenge.

In common with Flynn et al. (2011), who also investigated upstream public engagement (but in the context of hydrogen energy) we found questions manifesting critical trust like 'why this technology, who is controlling it, and can they be trusted?' to be important in considerations of geoengineering. However, in contrast to the ambivalence and scepticism they observed, the youth co-authors in the present study described ways in which they intended to participate in further discussion around geoengineering – and the opportunities presented as a result of the early stage of the science – to construct the political and regulatory environment. The products (youth guide and policy brief) of the workshops are openly accessible and can be used to stimulate further discussion and engagement or form the basis of future social science citizen science investigations with young people leading these projects. Youth members of the author team have presented the document at an international online 'safe climate' youth summit, have translated the brief into two languages and are planning further engagement via social media and institutional networks.

In common with the youth in the U.K. *Experiment Earth* dialogue by Ipsos MORI (2010), the youth guide and policy brief co-created in this study favours dealing with the root causes of climate change (high atmospheric greenhouse gas concentrations). There is also some correspondence with the findings of Bellamy et al. (2017) who found that geoengineering proposals performed less well than mitigation. Similarly, our youth guide recommends that 'mitigation must be prioritised over geoengineering. We must reduce our greenhouse gas emissions.' (Blake et al., 2021). Youth participants framed their discussion around 'good interventions to tackle climate change' and, were broadly consistent with the Oxford Principles (Rayner et al., 2009) which call for geoengineering to be regulated as a public good, public participation in geoengineering decision-making, disclosure of geoengineering research and open publication of results, independent assessment of impacts and governance before deployment. The characteristics of good climate interventions can also be considered consistent with Bellamy et al. (2017) and Macnaghten and Szerszynski's (2013) conditions for acceptance of geoengineering proposals. This includes: effective governance (characterised by youth as transparent, with clear lines of responsibility and accountability), side effects (characterised by youth as having well understood consequences, minimising risks to people and the planet and reversibility of impacts), efficacy (characterised by youth as effectiveness), and democracy (characterised as inclusive and transparent decision-making). In addition, young people valued equitable impacts on people and places, or local control (where impacts and consequences were very localised), and affordability. There was a particular concern for the nature of local and global decision-making and regulatory processes, and the need to consider differential outcomes in order to minimise harms to people and the environment and ensure equitable outcomes.

There are several limitations to the research. In its current form, the series of four in-depth workshops is not readily scalable as a way of understanding public (youth) perspectives on geoengineering owing to the considerable time commitment (16 hours total contact time) and high facilitator to participant ratios (10:13). However, the approach shows potential for use in the contexts of other emerging technologies where there is a need for lay participants to understand complex and uncertain science and technology where there is a risk of polarisation and division. Whilst the number of participants (13 young people and 10 facilitators) is small, the size of the group facilitated in-depth

discussion and the creation of relationships which encouraged criticality and disagreement which would not be possible with large group sizes. Perspectives gained from small numbers of participants can provide depth, nuance and novel insights into underexplored phenomena (Lawrie, 2021), here, youth perspectives on geoengineering and authorship as an engagement strategy. The perspectives gained through the production of the youth guide are policy brief are likely to be a valuable starting point for those interested in examining youth perspectives on geoengineering at a larger scale and in other contexts. Whilst the conclusions might not be generalisable to youth beyond the participants, there was considerable geographical diversity and disagreement amongst participants that we are confident that the perspectives presented in the youth guide are likely to be relatable. It is important to acknowledge however, that the majority of participants and facilitators were based in Europe, and whilst discussion turned to the global South and the importance of inequitable outcomes, those living in those locations were absent from the workshops. This is in common with much other social science research on geoengineering, although Delina (2020) reports on an international, interdisciplinary workshop held in Indonesia which resulted in the identification of priority research directions for the region.

Although this research project was dialogic in its methods, the researchers are not involved in the design, funding, testing or deployment of geoengineering proposals, so the work is not dialogic in the sense that it is not a conversation – yet – between decision-makers in science and youth. However, the products authored by research participants provide a pathway for such conversations to happen in the future.

This study is novel in several respects: its participants (international youth from different disciplinary backgrounds, at different stages of their youth), its methods (participatory, co-productive online workshops) and its approach to positionality and authorial responsibility. The contributions of this study are twofold. Firstly, it has created knowledge about youth perspectives on geoengineering in the context of the climate crisis. Recognising that young people have diverse perspectives on the role of geoengineering (as evidenced through workshop conversations), young people have articulated priorities for decision-making on geoengineering proposals through authorship of a youth guide, policy brief and set of questions, to extend the conversation to other groups of young people. This is important because youth are under-represented in social science about geoengineering, yet they will bear disproportionate responsibility for dealing with the consequences of climate change. Secondly, this research has reported on a novel participatory method for engaging young people with emerging technologies which avoids polarisation and builds reciprocity into the research process. The findings indicate that a co-production approach can cultivate youth engagement with complex and controversial technoscientific issues. In the immediate term, the significance of the study lies in how social science research can be designed and implemented to avoid both advocacy and polarisation in order to facilitate more constructive public dialogue on contemporary issues of global importance, and where there are differences of opinion. Furthermore, this research informs policy-makers about the priorities young people have for how decisions should be made about geoengineering proposals. Co-authorship with youth research participants not only builds a sense of responsibility and commitment, but builds capacity amongst the participants for their contribution to upstream considerations of emerging science and technology.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by University of York ESRC Impact Acceleration Account.

Supplementay material

Supplemental data for this article can be accessed at youth guide and policy brief (https://www.york.ac.uk/media/policyengine/documents/Geoengineering.pdf).

ORCID

Lynda Dunlop http://orcid.org/0000-0002-0936-8149
Elizabeth Rushton http://orcid.org/0000-0002-6981-8797
Lucy Atkinson http://orcid.org/0000-0002-6384-2227
Eef Cornelissen http://orcid.org/0000-0002-7585-5447
Jelle De Schrijver http://orcid.org/0000-0003-2292-504X
Joshua Stubbs http://orcid.org/0000-0002-0703-2342
Maria Turkenburg-van Diepen http://orcid.org/0000-0002-2841-3339
Fernanda Veneu http://orcid.org/0000-0002-1082-1836
Rosalind Edwards http://orcid.org/0000-0001-7196-9693

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