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Future-Oriented Science Education: A Delphi Study of Policymakers' Views from Four European Countries

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Abstract

Future-oriented skills have become increasingly important in science education. These skills include critical thinking, problem solving and managing complexity. While policymaking has a direct bearing on the *what* and the *how* of a future-oriented perspective in science education, previous research focused on a narrow group of stakeholders such as teachers and students. Little is known about what policymakers perceive as significant future-oriented skills to be included in the science curriculum. By policymakers we mean government officials, legislators, educational administrators, and other influential figures who are key decision-makers in the educational eco-system. The exploratory empirical study reported in the paper employed the Delphi method by administering three sets of questionnaires over two years to policymakers from four European countries. Diverse opinions were transformed into agreed priorities and recommendations for research and policy evaluation. The study did not aim to provide definitive answers but rather to widen the discussion on futurising science education and thereby opening up new research questions about policymakers' views. The paper contributes to the scarce research on policymakers' views in science education. Implications for future research and curriculum reform are discussed.

Keywords Future-oriented · Policymakers · Delphi study · European education

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Introduction

It is now widely accepted within the science education community that science education should instil in students a lifelong love of learning. This requires not only teaching students how to learn but also inspiring them to be curious and passionate about science throughout their lives (Levrini et al., 2019). In an increasingly interconnected world, future-oriented science education must also include a global perspective (Laherto & Rasa, 2022). Students should be aware of the global context of scientific issues and understand that challenges like climate change, pandemics and biodiversity loss do not respect national borders and require international cooperation (Högström et al., 2024).

Cultural awareness is also important, as different societies have different perspectives on science and technology. Lee et al. (2020) highlighted that intolerance of uncertainty, scientism, a sense of rivalry, and reaching an expedient and easy consensus can be commonplace in science lessons. By revealing and understanding these tensions and phenomena, the authors recognised that science teaching and learning needs to address not only students' epistemological views and attitudes toward science, but also help learners navigate the norms of classroom culture. By exposing students to diverse viewpoints and encouraging them to think critically about how cultural values influence scientific priorities, educators can help them become more informed and empathetic global citizens (Bossér & Lindahl, 2020).

Although there is generally agreement that science education needs to align with a 21st century skills, what is more contentious is what science curriculum needs to constitute. The lack of consensus implies that any curriculum renewal is likely to be misunderstood, and its effectiveness discounted. Countries in Europe and Asia have reported delays in reforming national curricular due to unreconciled views held by stakeholders (Organisation for Economic Co-operation and Development [OECD], 2020). Furthermore, although research in science education has attempted consensus work using the Delphi approach, those studies exclusively relied on teachers, students, scientists and teacher educators in exploring potential content of curriculum reform (e.g. Blanco-López et al., 2015; Charro, 2021; González-García et al., 2021; Kloser, 2014; Krijtenburg-Lewerissa et al., 2019; Sachyani et al., 2024; Sakhnini & Blonder, 2015). Except for rare cases (e.g. Assaraf et al., 2025), seldom has any research targeted policymakers who have massive and far-reaching influences on the directions of science curriculum. Limiting stakeholder groups in this discussion will create a partial and incomplete picture of an effective reform process. This study intends to fill the gap in the literature by directly investigating policymakers' perspectives.

In this paper, we present an argument for the importance of taking into consideration policymakers' views on future-oriented science education. To this effect, we report an empirical study on policymakers from four European countries in order to reflect their views while also reaching a consensus about what should be the content of future-oriented science education. The countries were chosen to include various geographical locations representing a range of cultural and systemic differences across the continent: UK as a western, Finland as a northern; Italy as a southern and Lithuania as an eastern European country. Although the sample size is small, such diversity was meant to elicit some insights into the various factors that might come out of different parts of Europe that are deemed to be important for scientific literacy for the continent more broadly. However, we do not claim to have identified such potential factors with such a small sample size. Rather, we aim to explore some factors and to open up a discussion around them for subsequent consideration by other researchers.

The specific aim of the empirical study was to attempt a consensus among policymakers and to gain insights about some aspects of future-oriented science education on which further debates could base. Although the countries involved have a range of populations and hence are not equivalent in proportion relative to the policymakers recruited (e.g. Lithuania has a small population) what seems to unite the countries involved is the attention given to the European Union's GreenComp framework (Bianci et al., 2022) discussed later in the paper. Hence, there may be commonalities across the countries as well as differences given the common European sustainability framework. Among the stakeholders involved, UK is an outlier given the country has left the EU. The study was conducted at a time when the Brexit negotiations were taking place and the UK was still part of the EU.

We begin our discussion with a review of recent research on future-oriented science education and subsequently focus on research on policymakers. The four participant countries were by no means the limit of research endeavour but this paramount example was a significant step towards opening the black box of "what's behind the scene in policymaking". Characterised by its exploratory nature and utility, the study aims to encourage more engagement and conversations between research and policymaking in the future.

Given the scarcity of research on policymakers' views in science education, we draw on broader policy studies to inform the framing of this empirical study reported in subsequent sections. Much discussion on policy in science education relies on analysing science curricular and how other stakeholders like teachers interpreted such policy (e.g. Ryder et al., 2014). Except for two particular studies (Alake-Tuenter et al., 2013; Assaraf et al., 2025), hardly any related studies in the past two decades involved policymakers directly as the sample group and hence, the empirical study study reported in the paper may potentially fill this gap.

Future-Oriented Science Education

"Future" is becoming a burgeoning and recurrent theme across literature about education. Researchers are increasingly interested in, for example, how 21st century skills are translated into national policy (Hilt et al., 2019); what teachers understand about future-oriented pedagogy (Sachyani et al., 2024); or how science teaching develops students' future-scaffolding skills and agency (Levrini et al., 2021; Rasa et al., 2022). In the policymaking sector, ideas about the future dominate the global discourse (OECD, 2020, 2021). "Futures approaches" necessitate building consensus among stakeholders. Thus policymakers are encouraged to "conduct their own research" and "gather expert opinion" to "determine a vision for a new policy area" as pathways to "meet the common needs of policymakers" (Government Office for Science, 2021, p. 7). Considering these grand policy visions, initiating conversations with or building consensus between policymakers become a relevant part of the researcher's agenda, if the community is to make any impact on education policy (Morse et al., 2021).

Preparing students to be future-ready and implementing a 21st century curriculum has been the major goals of many education systems (Vincent-Lancrin et al., 2019). In STEM education, the Learning Compass 2030 (OECD, 2020) is often used to define future-oriented skills or future-oriented pedagogy (e.g. Aurava & Sormunen, 2023; Sachyani et al., 2024). This framework conceptualizes future-oriented skills as multimodal (e.g. disciplinary knowledge, creativity and collaboration) which equip young people to cope with new challenges and maintain a sustainable development of our future (Pellegrino, 2017). Although these core knowledge and skills in the OECD framework are nothing new in research and the framework has drawn critiques (Hughson & Wood, 2022), promoting future-oriented skills has gained increasing weight in policymaking at national and international levels (National Research Council, 2012; OECD, 2020).

The world is facing unprecedented challenges that demand innovative solutions (Laherto & Rasa, 2022; Levrini et al., 2019). Climate change, artificial intelligence, global pandemics, and the ethical implications of biotechnology are just a few examples. To address these issues effectively, we must cultivate a generation of thinkers, innovators and problem-solvers, equipped with the knowledge and skills to navigate an increasingly complex world. Future-oriented science education is key to this transformation in educational goals, emphasising not only the acquisition of scientific knowledge but also the development of critical thinking, creativity, ethical reasoning, and adaptability.

However, there is a legacy in science education where students' mastering of established knowledge and applying it in predictable contexts has been the norm (Hodson, 2003). Given the significant societal and technological developments of our time, such outcomes of students' learning of science is no longer fit for purpose (Lloyd & Wallace, 2004; Rasa et al., 2022). The knowledge students acquire today may quickly become outdated tomorrow (Kyle, 2020). The lines between scientific disciplines also become increasingly blurred (Nagele et al., 2025). This interconnectedness of scientific disciplines implies that using scientific knowledge to solve complex problems requires an interdisciplinary approach (Hodson, 2020; Leichenko & O'Brien, 2020). For example, addressing a problem requires knowledge of atmospheric science, ecology, economics and political science. This means teaching traditional science subjects such as biology, chemistry, physics and computer science should be integrated with social sciences, ethics and environmental studies to ensure that students can grasp and apply scientific knowledge taking cross-disciplinary perspectives (Clark & Button, 2011; Lang et al., 2012). Science education should thus shift the emphasis from a rigid understanding of current and established knowledge to developing interdisciplinary thinking (Bishop, 2010; Rasa et al., 2022).

One of the cornerstones of future-oriented science education is the promotion of critical thinking and problem-solving skills (Rasa et al., 2022; Thomas, 2009). In a digital world where information and misinformation flood our daily lives, the ability to analyze, evaluate and synthesize information is more important than ever. Questioning assumptions, recognizing biases and developing evidence-based arguments are key skills that students urgently need to develop. In this regard, inquiry-based learning through which students actively engage in the process of obtaining scientific knowledge is shown to be effective (Padeste et al., 2015). Future-oriented approaches encourage students to ask questions, conduct experiments, analyze data and draw conclusions based on findings. By engaging in real-world scientific investigations, students learn to navigate the uncertainties inherent in the scientific process and develop resilience in the face of challenges (Herman et al., 2019: Laherto & Rasa, 2022).

Understanding science and technology comes with a responsibility to use them for the greater good. Such responsibility can be fostered through an educative approach that encourages students to think about how their future work can contribute to solving global challenges and improving the lives of others (Chan & Erduran, 2025; Häggström & Schmidt, 2021). The problems of the future will not be solved by individuals working in isolation. They will require collaboration across disciplines and cultures. Future-oriented science education should therefore emphasize teamwork, communication, and interdisciplinary learning (Laherto & Rasa, 2022). Students must learn to work effectively in diverse teams, sharing ideas, negotiating differences, and building on each other's strengths (Paige & Lloyd, 2016).

Ethics is another important component to consider in relation to socio-scientific problems (Reiss, 1999). For example, animal testing in scientific experiments involves not just biology and chemistry but also ethics (Garrecht et al., 2023). By working on projects that require input from multiple disciplines, students can learn to integrate different perspectives and develop more holistic solutions to major problems in science and society (Levrini et al., 2019). The future is inherently uncertain but that is precisely the reason why future-oriented science education must prepare students to be adaptable, resilient, and open to new ideas (Zeidler et al., 2019). This involves cultivating a growth mindset, where students view challenges as opportunities to learn and are not afraid to take risks or make mistakes (Chan & Erduran, 2025). Science education can foster this mindset by creating a learning environment that encourages experimentation and values the process of learning as much as valuing the acquisition of scientific knowledge (Laherto & Rasa, 2022). Although various dimensions of future-oriented science education have been discussed in the literature, few documents bring together these dimensions into a comprehensive conceptual framework. *GreenComp* (Bianci et al., 2022) is one that provides a synthesis. GreenComp is the name given to the European Sustainability Competence Framework, developed by the Joint Research Centre of the European Commission. Given the focus on sustainability as a long-term agenda, the content of this framework is relevant to future-oriented science education. The framework specifies sustainability in elements as competencies for sustainability. The goal of these competences is to generate actions and new visions for the future based on sustainability related values. The competences are *'Embodying sustainability values'* (with sub-competencies of Valuing sustainability, Supporting fairness, Promoting nature); *'Embracing complexity in sustainability'* (with sub-competencies of Systems thinking, Critical thinking, Problem framing); *'Envisioning sustainable futures'* (with sub-competencies of Futures literacy, Adaptability, Exploratory thinking); and *'Acting for sustainability'* (with sub-competencies of Political agency, Collective action, Individual initiative).

In light of the recent arguments for the integration of future-oriented thinking in science education, how do policymakers' views align with such recommendations? Given the recent publication of *GreenComp* (Bianci et al., 2022) in the European context, it is worthwhile to explore such a question with related stakeholders across a range of countries in Europe. The broad context of this question is research on policymakers as stakeholders of educational reform. In the next section, we review research on policymakers' views on science education policy.

Policymakers' Views on Science Education Policy

Although there is a significant body of research on policy studies in education broadly speaking (e.g., Biesta, 2009; Maguire et al., 2019; Roberts et al., 2020), within the context of science education, there is paucity of research on policymakers themselves. There has been considerable discussion in the literature about national curriculum policies from around the world (e.g., Ioannidou & Erduran, 2022; Ioannidou et al., 2025; Nguyen et al., 2023). Yet, more specific aspects of policy in relation to science education remain limited in the literature (Zhang et al., 2022) and within this literature, the focus on policymakers is practically inexistent. Existing research focuses on engagement of policymakers in research and making research relevant to policymakers (e.g., Duiveman et al., 2018). In a report commissioned by the United Nations Education Scientific and Cultural Organisation (UNESCO), Fensham (2008) expressed that although policy is treated as a discrete area of research, it is often situated as an implication, rather than a central feature of research:

> *Science education researchers have all too often tended to treat Policy*, *Practice and Assessment as discrete areas for study. Although an Implications section commonly appears at the end of research reports*, *it is usually about further research. Implications for practice are sometimes discussed*, *but what the research means for science education policy is rarely mentioned* (p.13).

What can science education research gain from broad accounts of policy studies, particularly about what policymakers' views imply for educational practice? Research on policy has illustrated that educational reform has been a contentious and complex issue, with policymakers playing a crucial role in shaping the future of education systems (Bang et al., 2010; Saunders, 2007). Furthermore, understanding policymakers' views is essential for designing and implementing effective reforms that address the needs of students and teachers as well as the broader education eco-system (Jann & Wegrich, 2007). Fensham's point suggests that there has been a lack of interaction between research and policy, that policy is not a focal point or purpose of more research studies. Although Fensham made such argument over a decade ago, there has been limited focus on policy studies in science education research.

Research into policymakers' perspectives provides insights into factors that influence policy decisions as well as the challenges they face. Policymakers include government officials, legislators, administrators, and other influential figures, and they are key decision-makers in the education system (Niron, 2013). These stakeholders set the agenda, allocate resources, and craft policies that directly impact how education is delivered and experienced. Their views on educational reform are shaped by a variety of factors, including political ideologies, economic considerations, social priorities, and evidence from educational research (Sebba, 2007). Given their weight of influence, understanding policymakers' views is critical and can demystify how policy is formed and initiated. These views help determine which reforms are prioritized, how they are implemented, and how success is measured (Brooks & Perryman, 2023).

Research into policymakers' perspectives is essential for understanding the broader context of educational reform and identifying opportunities for meaningful change (West & Wolfe, 2019). Research into policymakers' views on educational reform reveals several recurring themes that reflect the complex and often competing priorities that shape education policy (Maguire et al., 2019). These themes provide a window into the challenges and opportunities associated with reform efforts.

One of the most prominent themes in policymakers' views on educational reform is the emphasis on accountability and performance measurement (Roberts et al., 2020; West & Wolfe, 2019). Policymakers generally view accountability as a means of ensuring that educational systems deliver on their promise to provide high-quality education to all students (Leckie & Goldstein, 2019), particularly in terms of student achievement and graduation rates (Robert et al., 2020). However, this focus can lead to a narrow emphasis on test scores, sometimes at the expense of other important aspects of education, such as creativity, critical thinking, and social-emotional development (Biesta, 2009). Critics argue that an overemphasis on accountability can create a high-stakes environment that pressures educators and students, leading to teaching to the test and other unintended consequences (Schwartz, 2000).

The quality of teaching is widely recognized as one of the most important factors influencing student outcomes, and as such, policymakers often focus on teacher quality in their educational reform efforts (Down et al., 2024). Research illustrates that policymakers are concerned with attracting and retaining high-quality teachers, improving teacher training and professional development, and ensuring that teachers have the support they need to succeed in the classroom (Armor et al., 2024). Policymakers' views on teacher quality are often shaped by broader debates about teacher evaluation and compensation. These differing views reflect broader ideological divides about the role of teachers and the best ways to improve educational outcomes (Barnes et al., 2023; Lowe et al., 2024).

While research on policymakers' views is invaluable (Eisenhauer & Nicholson, 2005), it also comes with significant challenges. Policymakers operate in a highly complex environment where decisions are influenced by a multitude of factors, including political pressures, public opinion, and the interests of various stakeholders (Aung, 2022). This makes it difficult to isolate and study policymakers' views in a straightforward way. One challenge is that policymakers' publicly stated views may not always align with their private opinions or the policies they ultimately support (Wright, 2022).

Public statements are often shaped by the need to appeal to voters or align with party platforms, which can obscure the underlying beliefs and priorities of individual policymakers. Another challenge is the dynamic nature of policy environments. Policymakers' views can change over time in response to new information, shifting political landscapes, and evolving public attitudes (Ogisu, 2017). Furthermore, access to policymakers can be a significant barrier for researchers. Gaining the trust and cooperation of policymakers is crucial for obtaining accurate and meaningful insights, but this can be difficult, particularly in highly politicized environments (Armor et al., 2024).

Understanding policymakers' views on educational reform has important implications for the design and implementation of effective policies. By gaining insights into what policymakers perceive as relevant to future-oriented science education, practitioners as well as researchers can more effectively engage with policymakers and advocate for reforms that are both evidence-based and responsive to the needs of students and communities (Oliver et al., 2022). If part of the researchers' role is to advocate evidence-based policymaking, research about policymakers and their perspectives is essential. Policymakers are more likely to support claims that are backed by evidence gathered from policymakers' point of views, particularly if that evidence is presented in a way that is accessible and relevant to their specific concerns. This underscores the need for more research into policymakers' views.

Given the scarcity of research on science education policymakers' views, and even less on future-oriented science education, we aimed to investigate what policy influencers in different European countries recommend as significant learning outcomes for science education. Hence, the empirical study that is reported in the rest of the paper addresses the main research questions as follow:

(1) What do policymakers from four European countries view as significant learning objectives for future-oriented science education?
(2) What aspects of future-oriented science education do policymakers agree on?

Methodology

The empirical study was taken from a larger supranational research project which aimed at reorienting the ecosystem of science education to be fit for the future (Ioannidou & Erduran, 2022). In order to converge policymakers' different opinions towards a consensus, we adopted the Delphi methodology, defined as "a method for the systematic solicitation and collection of judgements on a particular topic through a set of carefully designed sequential questionnaires interspersed with summarized information and feedback of opinions derived from earlier responses" (Delbecq et al., 1975, p. 10). These characteristics mean the Delphi method is particularly suitable for decision-making or social forecasting, thus has been widely chosen for social science and healthcare research (Humphrey-Murto & de Wit, 2019; Landeta, 2006; Mullen, 2003). In the recent decade this method is also gaining popularity in science education (e.g. Blanco-López et al., 2015; Charro, 2021; Ioannidou & Erduran, 2022; Sakhnini & Blonder, 2015). However, it is noteworthy that previous Delphi studies in science education have rarely solicited views from policymakers, leading to not just an incomplete state of knowledge but also a barrier for researchers to engage and collaborate with wider stakeholder groups (Powell, 2003).

Sampling

Sampling is key to the goal of consensus building (Hsu & Sandford, 2007; Mullen, 2003). Related literature suggests forming a panel group who not only has expertise in the area but also a willingness to contribute to the field so as to sustain participation at multiple stages of the opinion poll (Hung et al., 2008; Powell, 2003). Following the proposed criteria for selecting experts or Delphi participants (Keeney et al., 2006; Okoli & Pawlowski, 2004; Rowe & Wright, 1999; Skulmoski et al., 2007), the research team nominated a total of 73 potential participants from four countries whose professional engagements involved policymaking or system design for science education. The countries were chosen to represent a diversity of geographical locations and education systems across Europe: UK as a western, Finland as a northern; Italy as a southern and Lithuania as an eastern European country. Such diversity was meant to provide insights into a range of issues and the varying prominence that might concern different countries of the continent. As previously stated, although the countries involved have a range of populations and hence are not equivalent in proportion relative to the policymakers recruited (e.g. Lithuania has a small population) what seems to unite the countries involved is the attention given to the European Union's GreenComp framework (Bianci et al., 2022).

The participant list covered a variety of functions pertinent to the broad spectrum of policy development to ensure panel heterogeneity, for example, curriculum design, national or state assessment, policy advisory, school inspectorate, policy in research and teacher training (Winkler & Moser, 2016). Due to the political and high-stakes nature of their positions, the participants demanded that their background details could not be disclosed in any research materials or publications, neither verbal nor written, as a condition of them taking part in this study. To maintain research ethics, we are only referring to them in terms of the generic organisational affiliations they were associated with and not including any further information that may compromise anonymity.

Invitation and details of the study were sent to each nominee. Eventually 35 of them voluntarily responded to the first round of the questionnaire and the base sample for this study was formed. Only those who took part in the previous round of the Delphi questionnaire was invited to continue to the next round. All questionnaires were administered in English given the high proficiency amongst the policymakers and they did not want a translated version of the research instruments. As shown in Fig. 1, the 35 participants who answered the first questionnaire were invited to enter the second round; 22 of them (16 female, 6 male) filled in the second questionnaire. These 22 respondents were then asked to provide their final views in Round 3, and eventually 18 (13 female, 5 male) completed the final survey. In other words, 18 policymakers participated in all three rounds of this Delphi study whose final consensus opinions in the third questionnaire were analysed and reported in this article (see Fig. 2). More detailed data and results from Round 1 were published in another article (Ioannidou & Erduran, 2022).

The sample size in the final stage was small. The challenge about sample size is related to two issues. The first is that given that policymakers' roles are politically sensitive, it is often difficult to recruit participants for research. A second challenge is

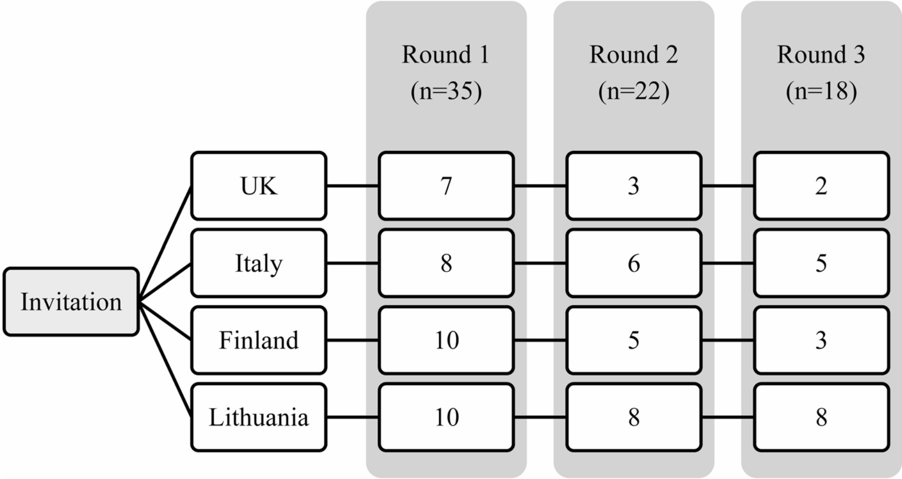

Fig. 1 Sample distribution across European countries

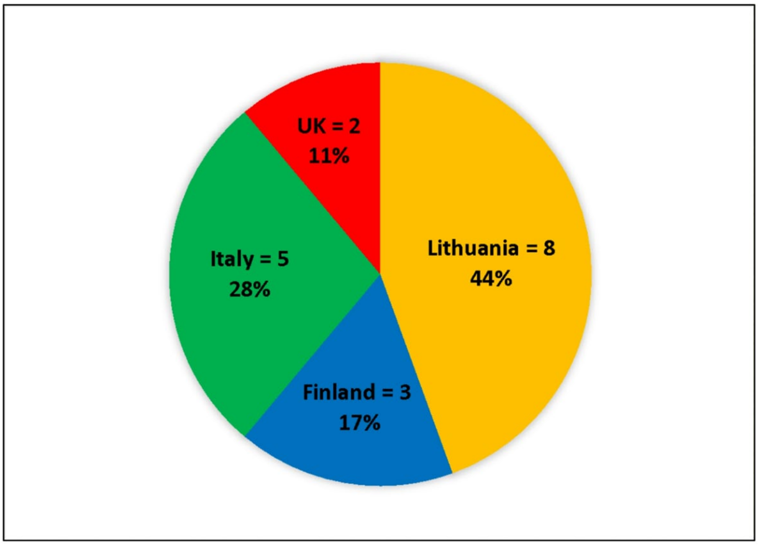

Fig. 2 Countries and participants in the final sample in Round 3 of the Delphi sutdy ($n = 18$)

the inherent decline in the number of participants across different stages of the Delphi study (Hsu & Sandford, 2007; Hung et al., 2008). Response rates in the first, second and third rounds are 48%, 63% and 82% respectively. The attrition rate declined as the study progressed is a limitation of this research which was a challenge to begin with due to the politically sensitive roles played by the participants and their general unwillingness to disclose viewpoints. Although the sample size is small, the study can still shed light on policymakers' views.

Furthermore, the timeframe coincided with the Covid and post-Covid interruptions. Taking part repeatedly in a Delphi study demanded strong and persistent interests from our participants whose work priorities during a disrupted period meant filling in multiple questionnaires voluntarily over the course of two years could be the last on their list. Another Delphi study in science education which unusually included policymakers also recorded the lowest retention rate from this group (alongside others such as teachers and researchers), with response rates from 50% in the first round to 16% in the second and 0% in the third round, i.e. high dropout (Alake-Tuenter et al., 2013).

Research in Delphi methodology recommends 10 to 18 experts on a panel (Delbecq et al., 1975; Ludwig, 1997) because the primary objective of this type of study is optimal group dynamics for arriving at consensus amongst respondents instead of statistical power (Okoli & Pawlowski, 2004; Powell, 2003). Our final sample met this recommendation by having 18 policymakers who shared their views throughout multiple iterations of the surveys. Education and demographic backgrounds of these 18 participants (13 female and 5 male) are presented in Figs. 3 and 4 respectively. The policymaker panel consisted of experts in STEM education since the majority have postgraduate degrees and almost all of them have teaching experiences at various levels of education.

We acknowledge that the sample would have been more representative had there been more respondents. However, readers should be reminded that the aim of Delphi studies is not generalisability of results but an attempt of consensus. Therefore the sample should not be evaluated based on representativeness for statistical purposes (Mullen, 2003; Powell, 2003). In fact, the unique functions of Delphi study mean that it has to recruit from purposefully sampled groups (Okoli & Pawlowski, 2004).

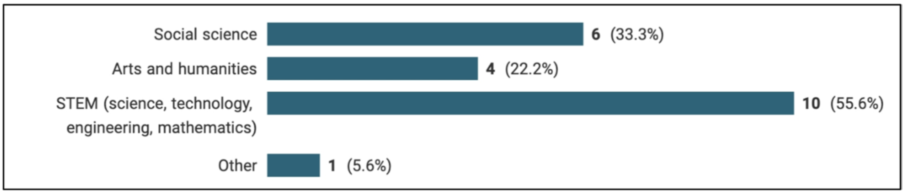

Fig. 3 Subjects studied in higher education by the policymakers. (Note that participants could choose more than one option if they had joint degrees, so the total number exceeds 18.)

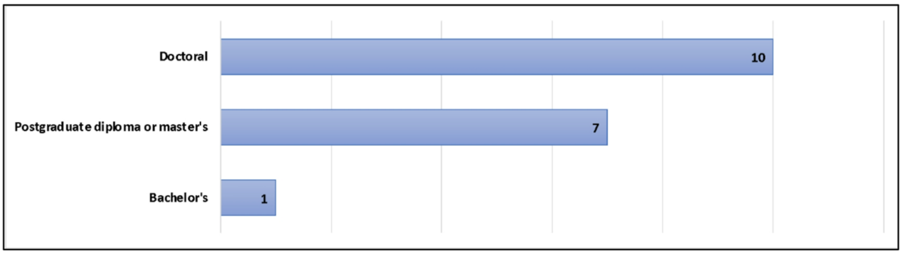

Fig. 4 Highest degree attained by the participants from Round 3 ($n=18$)

Considering the serious lack of previous work researching directly on policymakers, this study set out to be guiding research of this kind. This backdrop means the study objective was to unpack this stubborn challenge and unknown in research, and not about building a broad and representative sample (Rowe & Wright, 1999).

The use of survey in multiple rounds was intended to collect policymakers' judgements and eventually limit the divergence towards a broadly agreed trend (Powell, 2003). Following these objectives and the common protocols of Delphi methodology, especially "what constitutes an optimal number of subjects in a Delphi study never reaches a consensus in the literature" (Hsu & Sandford, 2007, p. 4), this study continued with the same sample despite its gradual shrink in size (Rowe & Wright, 1999). The advantage was that it avoided swaying the emergent consensus had new participants joined after the first round. Furthermore, given that we were dealing with a network of very busy individuals who are notoriously reluctant to share their views in any academic research due to the very sensitive and discreet nature of their jobs (Gollust et al., 2017), the current sample is still valuable in helping us understand how future-oriented science education is framed among a group of policymakers from different countries.

Data Collection

Data were collected through three rounds of questionnaires between 2021 and 2023, during which standard protocols for Delphi methodology such as anonymity among participants and controlled feedback by the researchers were followed (Hsu & Sandford, 2007; Humphrey-Murto & de Wit, 2019; Murry & Hammons, 1995). In other words, in the study the participants were anonymous to each other but clearly not to the researchers conducting the investigation. They were not anonymous to the researchers because of the nature of the Delphi study where subsequent iteration of the survey had to be circulated to the same participants.

Round 1

In the first round, based on a review of related literature, a questionnaire was drafted encapsulating prominent issues in education policy and science education. To increase its content validity, the questionnaire was sent to 10 experts outside of the sample for comments. It was then revised until the experts agreed with the final version. Round 1 (Appendix 1) included both closed and open-ended questions about futurizing science education (Delbecq et al., 1975; Keeney et al., 2006). With respect to the closed-ended questions, descriptive statistics were performed to summarise participants' demographic information, as well as their agreement with the set of statements (e.g. Likert scale items).

The open-ended questions were analysed thematically using MAXQDA. In the first coding phase, the participants' answers were clustered deductively according to the broad topics in the survey items (e.g. future challenges). In the second coding phase, participants' answers were coded openly for generating initial codes. In the third coding phase, the open codes were clustered into larger categories, and all the codes and sub-codes were organised hierarchically to reflect the initial themes. The results of Round 1 were reported in Ioannidou and Erduran (2022).

Round 2

According to the Delphi methodology, the results of Round 1 are used to produce a new set of questions that would be sent back to the experts in the form of a "reworked questionnaire" (Klenk & Hickey, 2011). The purpose of the Round 2 (Appendix 2) was twofold. The first goal was to validate the themes that emerged during the qualitative analysis of the first round. In order to achieve this goal, all the themes that emerged from the analysis of the responses to the open-ended questions were presented to the participants in order of frequency.

The second goal was to investigate if the individual policymakers' views would change given the views expressed by the rest of the sample. To address the second goal, the revised survey included all the statements from the previous survey as well as those that emerged through the policymakers' responses. In addition, the median values for all the statements that were agreed upon were presented next to each statement. This allowed respondents to acquire a sense of the trends and views of other experts participating in the Delphi study. They would have the option to revise their answers given this information while, in addition, they would be able to add new responses and comments in the blank spaces provided (Humphrey-Murto & de Wit, 2019; Landeta, 2006). To calculate the degree of agreement between participants' views in Round 2 descriptive statistics were performed for all the items included in the survey in Round 1.

Although in Round 1 the median score for each of the presented statements were calculated and included in the survey, it was decided that the mean scores would be a more adequate metric that could be included in Round 2. This decision was based on the study's need to take into account discrepancy measures, such as the standard deviation, to calculate the degree of agreements among participants. In addition, the inclusion of mean scores was useful in the cases of equal scores, as items with a lower standard deviation were positioned in a higher rank due to the higher level of agreement that they demonstrated. All the items that were in a rank order were repositioned based on the calculation of the mean score and standard deviation. In summary, in Rounds 1 and 2, we calculated the median and mean scores, as well as the standard deviation of each rated statement, then ranked all of them in order of importance under each question item. These preliminary results were communicated to the respondents in the next questionnaire so that they were informed about the emerging group trend before expressing their adjusted views.

The questions that presented a high degree of consensus (high agreement with Round 1 responses and $SD < 1$) were removed (Appendix 4) as the goal was to establish further consensus among those that did not have consensus. It has been argued that attainment of consensus can be used as a criterion for progressing or terminating rounds in Delphi studies (Diamond at al., 2014; Okoli & Pawlowski, 2004). In line with this principle, we adopted a nested approach to the Delphi method in which items that achieved a desirable consensus threshold were removed from subsequent rounds. This approach allowed later rounds to focus on items for which consensus had not yet been reached.

Two considerations informed this decision. First, limiting subsequent rounds to unresolved items reduces respondent burden and would help minimise response fatigue, which is a recognised challenge in multi-round Delphi studies. Second, given that attrition is common in Delphi panels, we anticipated that earlier rounds would capture the widest range of perspectives from the expert panel. This would allow us to refine areas of disagreement while preserving the results of items for which consensus had already been achieved.

Round 3

Similar to Round 2, the questionnaire in Round 3 consisted of ranking questions only, with space for qualitative feedback under each question in case respondents wanted to provide any. In this final round, answers to the questionnaire from the previous round were summarised and fed back to the respondents in the questionnaire (Hsu & Sandford, 2007). In this way participants were informed about how the group assessed each option that produced the overall ranking, and as such they could contemplate the collective judgements before reassessing and posing their individual views again (Humphrey-Murto & de Wit, 2019; Landeta, 2006).

Halfway through the Delphi timeframe that stretched over two years, interim analyses of the two earlier surveys were disseminated to the participants in a virtual event, in which they had the chance to comment on the preliminary results, seek clarifications or raise questions (Landeta, 2006; López-Zerón et al., 2021). These interactions contributed positively to the controlled feedback element inherent to any Delphi studies; at the same time sustained participation, facilitated group discussions and subsequently prompted individuals to reconsider own judgements before progressing to the final round of the survey. This extra step also helped evaluate the study design and therefore enhanced methodological rigour. For the sake of protecting anonymity, it was emphasised at the meeting that the identity of the participants was to remain private and not disclosed in any circumstances outside the meeting.

Data analysis

As a feature of the Delphi method, the data for this study were analysed at different timepoints throughout the study lifespan, at the same time the design was also evaluated. This repeated process boosted the test-retest reliability and internal consistency of the instruments. Although there are no agreed guidelines for data analysis for Delphi studies (Grant et al., 2018; Humphrey-Murto & de Wit, 2019), descriptive statistics and interrater agreement are generally the recommended in respect to the scaled items in the questionnaire and our research questions. The questionnaires used in the three rounds are included in Appendices 1, 2 and 3. The three rounds of the Delphi study and the content of each survey is explained in Fig. 5. Elements of the European Sustainability Framework were included in Rounds 2 and 3 in order to explore the policymakers' views of this European initiative.

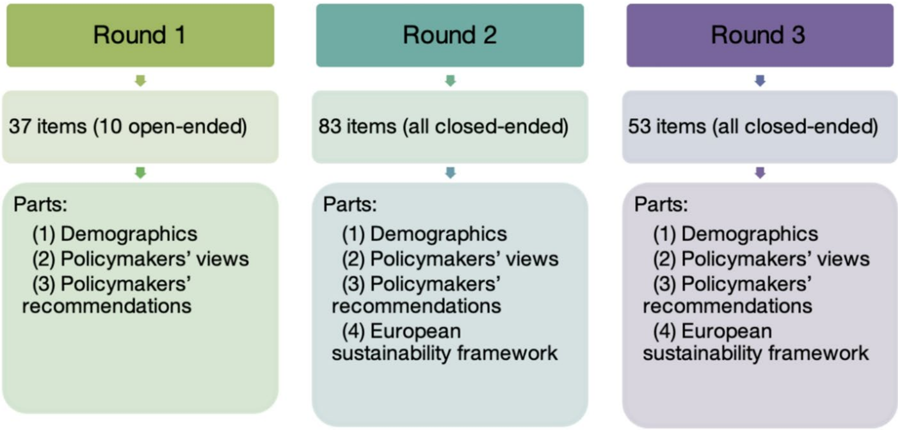

Fig. 5 Three rounds of the Delphi study

In the analysis of the responses in the third round of the survey (Appendix 3), policymakers' consensus on each of the sub-questions was determined by comparing the mean ranks (nonparametric) of different categories ranked by the respondents (Hung et al., 2008; Tastle & Wierman, 2007). Kendall coefficient of concordance (*W*) was calculated to indicate the magnitude of the consensus by different judges on those issues (Gisev et al., 2013; Powell, 2003). Kendall's is a more robust measure than Kappa or Friedman's in this case because the variables are ordinal (Field, 2005; Gisev et al., 2013) and the Kendall index gives a stronger power for correcting Type I error when claiming concordance (Legendre, 2005); and statistically significance can still be achieved in case of low *W* score (Gisev et al., 2013). Hence this measurement is especially suitable for our Delphi study on an innovative topic in the field (Okoli & Pawlowski, 2004; Schmidt, 1997). This paper presents results that concluded all the three rounds of the survey, i.e., the consensus of the policymakers on issues imperative to reform in science education.

Results

We asked the respondents a range of sub-questions pertinent to future-oriented science education and ways to foster it. The degree of importance of the specific answers voted by the panel in each sub-question is determined by calculating the mean rank of each category (Tables 1, 2, 3, 4, 5, 6, 7, 8 and 9). Table 1 addresses the central challenges perceived by the participants about science and future of society. Table 2 identifies the key related student competencies while Table 3 focuses more specifically on competences about envisioning the future. Table 4 highlights the issue of integration of student competencies in science education while Table 5 illustrates the views on obstacles to reform in science education. What is required of students to think about the future (Table 6) and more specifically about a global future (Table 7) are reported. Subsequent data switch to the dynamics of policymaking and research with Table 8 illustrating results about the obstacles while Table 9 outlines components of effective

Table 1 What are the central challenges for science and the future society?

	Mean rank
Environmental issues	1.67
Societal tensions	2.72
Lack of trust in science	3.83
Economic issues	4.00
New diseases or viruses	4.06
Automatisation	4.78

$W = 0.585$; $p < .001$

Table 2 What key competencies will students need to address future challenges in science and the society?

	Mean rank
Critical thinking	1.67
Problem-solving skills	2.67
Creativity	3.94
Social intelligence	4.28
Metacognitive skills	4.72
Digital skills	5.06
Communication skills	5.89

$W = 0.590$; $p < .001$

Table 3 What competencies do students need for envisioning the future?

	Mean rank
Critical thinking	2.39
Interdisciplinarity	2.50
Imagination	3.06
Creativity	3.33
Problem-solving skills	3.83

$W = 0.473$; $p < .001$

Table 4 In what ways can competencies for imagining the future be integrated in science education?

	Mean rank
Inclusion of interdisciplinary approaches	2.17
Promoting imagination or creativity	3.06
Inclusion of socioscientific issues	3.28
Promoting collaborative skills	3.39
Project-based learning	4.56
Inclusion of various stakeholders in curriculum design	4.83
Reducing focus on content	6.83

$W = 0.650$; $p < .001$

Table 5 What are the obstacles to reform in science education?

	Mean rank
Rigid organisation of curricular	2.65
Teachers' perceptions	2.82
Lack of shared understanding between stakeholders	3.06
Teachers' skills	3.29
Lack of available resources	3.88

$W = 0.274$; $p < .001$

Table 6 What is required for students to think about their own future?

	Mean rank
A sense of agency	
A growth mindset	2.17
A sense of hope	2.78
A vision for their future career	3.39
$W = 0.438$; $p < .001$	

Table 7 What is required for students to think about the global future?

	Mean rank
A sense of agency	2.00
Informed about global issues	2.71
Aware of the impact of their actions on the environment	2.71
Developing perspective-taking	2.82
$W = 0.432$; $p < .001$	

Table 8 What are the major obstacles to research in the policymaking process?

	Mean rank
Policymakers' insufficient understanding of research evidence	1.59
Limited openness by politicians	2.65
Traditional decision-making process	2.94
Lack of political will	3.29
Jargons not correspond to policy environment	4.53
$W = 0.455$; $p < .001$	

Table 9 What are the key components of effective policy to foster future-oriented skills?

	Mean rank
Collaboration between stakeholders	2.06
Greater consistency in educational goals and the designed resources	2.67
Provision of teacher training opportunities	2.72
Greater emphasis on addressing fundamental educational needs	3.17
$W = 0.304$; $p < .001$	

policies for fostering future-oriented skills. Results about the most and least consensus are reported in Table 10.

In terms of the data in the tables, the smaller the value of the mean rank, the higher the importance of the category placed by the respondents ("1" being the most important; "2" being less important and so forth). The strength of the panel's agreement is indicated by Kendall's W score ($0 < W < 1$) and the asymptotic significance (p-value) is also given. The closer the W value is to 1, the stronger the consensus is (and vice versa). It is worth mentioning that regardless of the magnitude of concordance (W), every question of the opinion-based results produced statistical significance ($p < .05$) so the null hypothesis can be rejected. That means these policymakers are not entirely independent from one another and their views do align with each other to some extent

Table 10 Survey questions from the highest to lowest consensus among the policymakers

Question item	Strength of consensus (W)
How can the competencies for imagining the future and addressing future challenges be integrated into science education?	0.650
What key competencies will students need to address future challenges in science and the society?	0.590
What are the central challenges for science and the future society?	0.585
What are the competencies students need for envisioning the future?	0.473
What are the major obstacles to uptake of research in policymaking process?	0.455
What does it require for students to think about their own future?	0.438
What does it require for students to think about the global future?	0.432
What are the key components of effective policy to foster future-oriented skills?	0.304
What are the obstacles to reform of science education?	0.274
How significant are the statements from the sustainability competence framework?	0.208

(Legendre, 2005). The policymakers in our sample viewed environmental issues as the most important and automatisation as the least important challenges. They thought what students need the most for future challenges is critical thinking skills and communication skills as the least needed skills.

Similarly, for students to envision the future, the participants thought critical thinking is the most important competence and the ability to engage in interdisciplinarity is considered as the second important competence (Table 3). Consistent with the high value that they attributed to interdisciplinarity, the policymakers considered an interdisciplinary approach to be the best for infusing future-oriented skills into science education (Table 4). Despite having influences on curriculum design in different ways themselves, these respondents thought of the rigid organisation of the curriculum as the chief obstacle to reforming science education (Table 5). Policymakers believed students need a sense of agency in order to care about their future (Table 6). The same applies to collective future, that students need agency more than other skills to think about the shared future (Table 7). The policymakers ranked inadequate understanding of research evidence by policymakers as the biggest obstacle to the policymaking process (Table 8). The respondents viewed collaboration between stakeholders as the most effective means for policy to foster future-oriented skills (Table 9).

Another dimension highlighted by the results is the consensual level of various issues within the panel. Comparing the strength of consensus across all the questions, stronger consensus was recorded on issues related to what the future challenges are, the competencies students need in order to deal with the challenges and specific ways to integrate those competencies to science learning. Table 10 lists all the ten survey questions from the highest consensus to the lowest.

Overall, our main objective in the Delphi consensus building was to systematically collate and indicate some directions that might spark further debate in the European policy contexts. In line with the generic purposes of Delphi study, results reported in this article should not be interpreted as conclusive or generalisable to wider populations outside of our sample (Powell, 2003). The results presented are not to make bold claims about what policymakers necessarily would recommend for decision-making in policy. We recognise the sensitivities around policymaking which may have hindered full disclosure of policymakers' views and recommendations. Furthermore, nuances across the national priorities may potentially hinder adoption of those views.

We have considered that even if significance values between the items were presented, they might not help interpret the results meaningfully. For example, what implication would it have if we added *"policymakers regarded economic issues" (ranked 4th) as more important than "new diseases or viruses (ranked 5th)"* as the central challenges for science education, but the difference in the ranking of these two items was not significant"? The research questions and analytical methods aimed at gathering participants from vastly different regions in Europe to converge collectively on prioritised learning outcomes for science education. In relation to these questions and methods, the study initiated a conversation for a future orientation in science education in Europe. Future studies can begin to unpack the nuances across potential regional variations.

Discussion and Implications

The contextual and theoretical framing of research reported in the paper exposed the an underemphasis on understanding about policymakers' views of science education in fostering higher-order skills. Previous research built some consensual understandings on certain issues in science education. However, existing Delphi studies are predominantly interested in subject-specific content within particular science curriculum (e.g. Charro, 2021; González-García et al., 2021; Krijtenburg- Lewerissa et al., 2019; Sakhnini & Blonder, 2015). Scarce research is available on the policymaking domain in science education or its relevance to future-oriented thinking which has overarching impacts on instructional design. The empirical study reported in the paper has taken the initiative to fill an uncharted terrain of policymakers' views on futurizing science education and its pathways.

Sampling in previous Delphi studies has relied almost exclusively on science teachers, students and researchers (e.g. Charro, 2021; Kloser, 2014; Sachyani et al., 2024; Sakhnini & Blonder, 2015). Although the composition of participants in those studies reflected a mix of stakeholder groups, seldom does research in science education target policymakers who may have massive and far-reaching influences. In fact, no Delphi studies involving policymakers could be identified in the last two decades of research in science education although a Delphi study on teacher competence is available (Alake-Tuenter et al., 2013). Hence, despite the small sample size and an unequal representation of the countries in our sample, this study offers a significant but often neglected glimpse into policymakers' views. Most importantly, the results reported here can inform researchers on how to respond to those views going forward.

The call for linking research to understanding policymakers or policy formation in science education prevails (Fensham, 2009; Huang & Asghar, 2016). Despite their far-reaching influences, policymakers have constantly been excluded in past research in STEM education so our study has widened the much-needed perspective on this debate. In summary, these results have generated multi-faceted answers to the overarching question of "What and to what extent do policymakers agree on future-oriented science education and ways to promote it?".

At conceptual level, the top-ranking categories in each of the sub-questions intrinsically reflected what policymakers voted as the most critical or urgent to the specific issue in question. For instance, their advocacy of an interdisciplinary approach to integrating future-oriented competencies into science education is consistent with previous research (Huang & Asghar, 2016). Evidence has shown that infusing interdisciplinarity can benefit students' higher-order learning in science (Erduran et al., 2022; Ioannidou et al., 2025; Melton et al., 2022; Nagele et al., 2025; Tytler et al., 2021). In terms of the skills and attributes that students need to navigate the future, by and large the policymakers prioritized critical thinking and sense of agency. Both of which are, on average, voted as the most important for twice in different questions.

Student agency has not attracted wide interest in science education but is recently more emphasised in international policy documents (OECD, 2020, 2022, 2023; UNESCO, 2023, 2024) as well as latest research (Barelli, 2022; Cuzzolino et al., 2024; Rap et al., 2022). Future studies can contribute to the discourses in policymaking and scientific knowledge by testifying its relationship with students' academic and future-oriented skills. In short, policymakers putting critical thinking, student agency and interdisciplinarity as foremost to futurising science education is in line with research recommendations and international policy documents (Assaraf et al., 2025; Aurava & Sormunen, 2023; OECD, 2022, 2023). These results also imply that this field of knowledge is widely recognised by policymakers.

Interestingly, the policymakers were less agreeable with each other about topics related to policymaking. The two issues that the Delphi panel held the most divergent views, which means the lowest consensus, are "obstacles to reform of science education" and "key components of effective policy to foster future-oriented skills". This outcome is in fact unsurprising, considering that policymaking is a contentious subject that by nature divides opinions and views. Research studies argued that policymaking in education is a hotbed of ideological, economical and power struggles, thus not entirely driven by education ideals (Furlong et al., 2011; Whitty et al., 2016). Decision-making is opaque and related views are often reflections of shifting political ideologies, cultural beliefs or vested interests instead of evidence (Gomendio & Wert, 2023; Huang & Asghar, 2016). The meaning of policy is also multi-faceted and can be conceived vastly differently (Ball, 2015). The increasing influences by international agencies on national policymaking further complicates the arena which has already filled with contradictions and dilemmas (Edwards et al., 2024; Francis et al., 2017). These complications may explain why it was harder for our panel of policymakers to agree with each other on issues about reforming science education.

It is worthwhile to note that the "lower" consensus on policy and reform should be interpreted in comparison with other questions such as future-oriented competencies investigated by this study. There is no definitive yardstick to determine if policymaking recorded a genuinely "low" or "not high" consensus. Unlike other Delphi studies, consensus cannot be defined a priori for this study because far little work in science education has been conducted involving policymakers, or precisely on anything related to future-oriented skills so it was not possible for researchers to determine the optimal level of consensus, or to argue any consensus level as "high" or "low". In this regard, the current study serves as an initial benchmark or case in point to gauge the definition of or expected consensus for forthcoming work on related topics (Grant et al., 2018; Humphrey-Murto & de Wit, 2019).

Similar to other Delphi studies, judgements made by the policymaker sample might be subjective and their consensus, despite having statistical significance, do not represent truth or fixed views (Landeta, 2006; Powell, 2003). While this study has tapped into the perspectives of an under-researched stakeholder group on a relatively new topic, critical variations in opinions between individuals might be concealed (Mullen, 2003). Future studies can aim to unpack the implicit ideas about future-oriented science education held by different policymakers, including those from other countries.

Overall, the results have shed light on the agreed priorities or directions for futurizing science education by aggregating the views of policymakers from four countries. Similar to the GreenComp initaive's recommendations, the policymakers identified competences that are needed to generate actions and new visions for the future based on sustainability related values. In particular, the competences related to *'Embracing complexity in sustainability'* (with sub-competencies of Systems thinking, Critical thinking, Problem framing) were particularly pronounced in policymakers' views. Useful pointers and possibilities for research and practice can be drawn. Other stakeholders in the wider community can review or evaluate their policies in curriculum design or high-stakes assessment in science education, for example, by examining to what extent the objectives of existing designs are in line with or diverge from the common understandings reported in this study.

Practitioners such as school managers, teachers and teacher educators should enrich the discourse by expressing their opinions on the policymakers' consensus. Teachers' voices being excluded in policy formation is a common criticism (Giudici 2021; Harris & Jones 2019; Shieh 2023a). Policy documents also potentially create confusing, incoherent or unclear messages to science teachers (Tanas & Fulmer, 2023). Teachers may feel helpless or neglected and use strategies such as rejection to reconciliate their dilemmas (Bateman & McDonald 2023; Beck 2024; Shieh 2023b). Communicating what is understood across stakeholder groups including teachers and policymakers is essential to inclusion and effective education reform (OECD, 2020; Zitzmann et al., 2023). The consensus built by this study is intended to be a useful and pragmatic move towards meaningful stakeholder engagement (Gerrard et al., 2024). It provides a basis on which policymakers, schools, practitioners, researchers and other stakeholders can contribute to the debate in a responsive and constructive manner.

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Data Availability The data are available from University of Oxford, UK.

Declarations

Ethical Approval The authors declare that they have read and understood the ethical guidelines provided to the authors at the following link, and confirm that there are no ethical violations in relation to the submitted manuscript. (https://www.springer.com/journal/10763/submission-guidelines?IFA#Instructions%20for%20Authors_Ethical%20Responsibilities%20of%20Authors). Ethcis approval was granted by the Departmental Research Ethics Committee at University of Oxford (reference ED-CIA-21-046).

Competing interest The authors declare that they do not have any conflict of interest in relation to the manuscript.

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